CHAPTER 5
RESULTS AND ANALYSIS

5.1 ESTIMATION OF VARIOUS METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

Meteorological drought refers to a prolonged period of below-average precipitation or reduced rainfall in a region. Meteorological drought is primarily concerned with deviations from the normal patterns of precipitation and can have significant impacts on water availability, agriculture, ecosystems, and various other sectors.

In the current assessment study, different meteorological drought indices i.e., percent normal (PN), Percentage of departure from mean (PD), deciles index (DI), Standardized Precipitation Index (SPI), Reconnaissance Drought index (RDI), Standardised Potential Evapotranspiration Index (SPEI), China Z Index(CZI), Modified China Z Index (MCZI) and the Z-Score were used for estimating drought severity and drought years in North Gujarat districts. All the aforesaid indices calculated using precipitation data, temperature data and potential evapotranspiration data.

5.1.1 Estimation of various Meteorological Drought Indices in Banaskantha district

The statistical parameters of the rainfall data for Banaskantha for 102 years i.e., from 1901 to 2002 were analyzed and results shown in below Table 5.1, which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1072.68 mm in 1917 and minimum rainfall 115.23 mm in 1974 in the study area.

Table 5.1: Seasonal Rainfall in mm for Banaskantha district

Rainfall parameters	June	July	August	Sept	Winter (Jan-Feb)	Pre-monsoon (March to May)	SW monsoon (June to Sept)
Mean Rainfall	60.70	196.75	152.91	82.61	1.5	2.90	123.24
Standard Deviation	55.73	124.49	109.36	94.00	3.23	6.89	95.90

The monthly analysis of rainfall for Banaskantha district is given in Table 5.2. The same is based on assumption that a month is with drought when the rainfall for the month is less than half of the average rainfall for this month. The percentage of drought in a month was calculated as (number of drought months for a particular month/ total number of drought months) multiplied by 100 viz., for January, the

percentage of drought month is equal to 9.42%. Also, the highest average rainfall was observed as 196.75 mm in the month of July in the span of 102 years. The months of March, November and December have 81, 81, 79 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 23, 25 respectively.

Table 5.2: Drought Analysis based on Monthly Rainfall for Banaskantha district

Month	Mean, mm	Half of Average Rainfall, mm	No. of Drought Months	Percentage of Drought Months
Jan	1.55	0.78	67	9.42
Feb	1.47	0.74	73	10.26
Mar	2.53	1.26	81	11.39
Apr	0.64	0.32	55	7.73
May	5.53	2.77	68	9.56
Jun	60.70	30.35	43	6.04
Jul	196.75	98.37	23	3.23
Aug	152.91	76.45	25	3.51
Sep	82.61	41.30	51	7.17
Oct	8.80	4.40	65	9.14
Nov	5.09	2.54	81	11.39
Dec	1.11	0.56	79	11.11
			711	100

1.1.1 Percent of Normal

The classification of drought years obtain using percentage of normal index is shown below Table 5.3.

Table 5.3: Drought years obtained using percentage of normal method

Classification	**Range**	**Year**
Extremely Drought	≤ 40	1901, 1904, 1911, 1915, 1923, 1974, 1987
Severe Drought	40 to 55	1936, 1939, 1948, 1951, 1960, 1968, 1969, 2002
Moderate Drought	55 to 80	1902, 1905, 1918, 1920, 1925, 1930, 1932, 1935, 1940, 1949, 1957, 1962, 1972, 1985, 1986, 1991, 1995, 1999
Near Normal	80 to 110	1903, 1906, 1912, 1914, 1922, 1928, 1929, 1931, 1938, 1941, 1942, 1943, 1947, 1952, 1953, 1955, 1958, 1963, 1965, 1966, 1971, 1979, 1980, 1982, 1983, 1989, 1992, 1993, 2000, 2001
Moderate Wet	≥ 110	1907, 1908, 1909, 1910, 1913, 1916, 1917, 1919, 1921, 1924, 1926, 1927, 1933, 1934, 1937, 1944, 1945, 1946, 1950, 1954, 1956, 1959, 1961, 1964,

		1967, 1970, 1973, 1975, 1976, 1977, 1978, 1981, 1984, 1988, 1990, 1994, 1996, 1997, 1998

From the above Table 5.3 of Percent of Normal Index it was observed that extreme drought condition occurs in the year 1901, 1904, 1911, 1915, 1923, 1974, 1987, severe drought condition occurred during 1936, 1939, 1948, 1951, 1960, 1968, 1969, 2002, moderate drought condition occurred during 1902, 1905, 1918, 1920, 1925, 1930, 1932, 1935, 1940, 1949, 1957, 1962, 1972, 1985, 1986, 1991, 1995, 1999.

During the period of (1901-1930) there were total nine (11 nos) drought events, for (1930-1960) there were five (10 drought events) and (1960-1990) total 12 drought events were observed. Also, from above Table 5.3 it was observed that every 3 to 4 years drought condition was occurred in Banaskantha district. Below Figure 5.1 shows percentage of normal index plot for Banaskantha District.

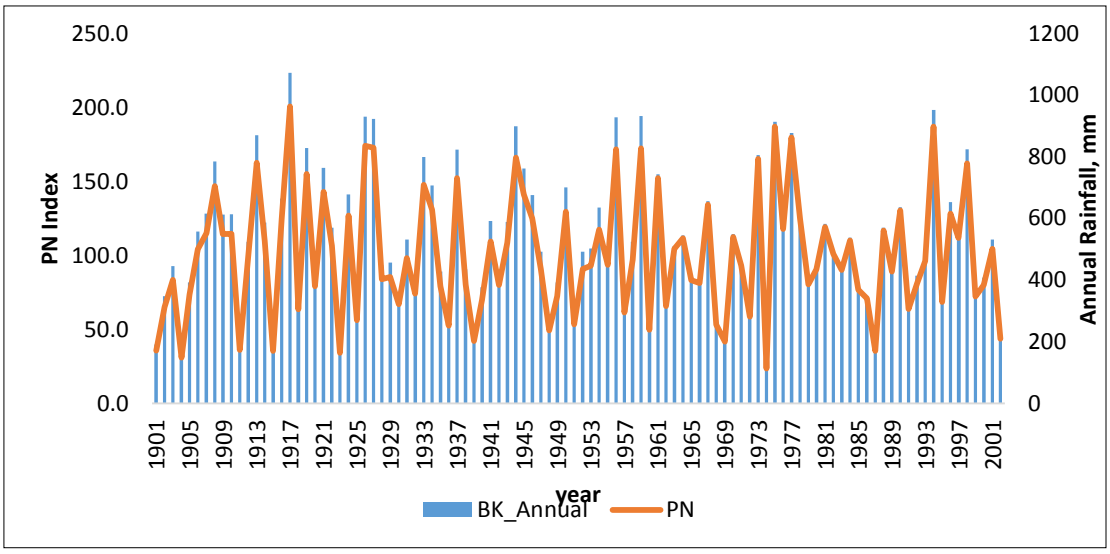


Figure 5.1: Percentage of Normal Plot for Banaskantha District

1.1.2 Percentage of Departure from Mean for Annual Rainfall

Annual Rainfall Departure from mean for identification of drought years has been carried out. A year is considered as drought year if the total amount of annual rainfall over an area is deficient by more than 25% of its normal value. The classification of drought years obtain using percentage of departure from mean for annual rainfall & for seasonal rainfall is shown in below Table 5.4 and 5.5.

Table 5.4: Drought years obtained using percentage of departure method for annual rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, 2002
Moderate Drought	-25 to -50	1902, 1918, 1925, 1930, 1936, 1940, 1948, 1951, 1957, 1960, 1962, 1968, 1972, 1985, 1986, 1991, 1995, 1999
Mild Drought	0.0 to -25	1903, 1905, 1920, 1928, 1929, 1932, 1935, 1938, 1942, 1947, 1949, 1952, 1953, 1955, 1963, 1965, 1966, 1971, 1979, 1980, 1982, 1983, 1989, 1992, 1993, 2000
No Drought	0.0 or Above	1906, 1907, 1908, 1909, 1910, 1912, 1913, 1914, 1916, 1917, 1919, 1921, 1922, 1924, 1926, 1927, 1931, 1933, 1934, 1937, 1941, 1943, 1944, 1945, 1946, 1950, 1954, 1956, 1958, 1959, 1961, 1964, 1967, 1970, 1973, 1975, 1976, 1977, 1978, 1981, 1984, 1988, 1990, 1994, 1996, 1997, 1998, 2001

Below Figure 5.2 and 5.3 shows Percentage of Departure from Mean for Annual Rainfall and for seasonal rainfall for Banaskantha District.

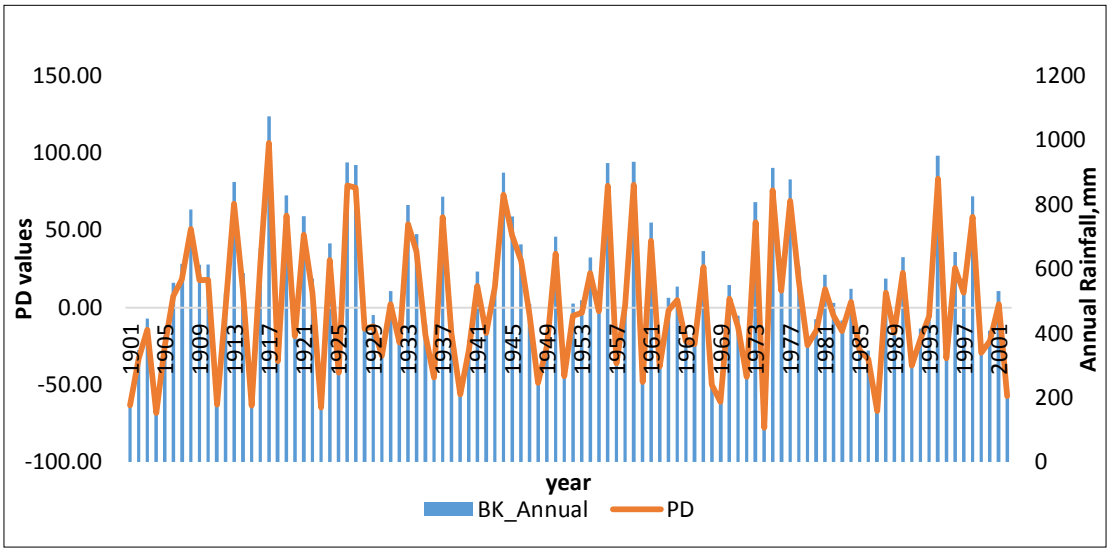


Figure 5.2: Percentage of Departure from Mean and Annual Rainfall for Banaskantha district

Percentage of Departure from Mean for Seasonal Rainfall

For seasonal rainfall departure analysis monsoon season rainfall months i.e., June to September is considered.

Table 5.5: Drought years obtained using percentage of departure method for seasonal rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1901, 1904, 1911, 1915, 1923, 1939, 1948, 1969, 1974, 1987, 2002
Moderate Drought	-25 to -50	1902, 1918, 1925, 1930, 1936, 1940, 1951, 1957, 1960, 1962, 1968, 1972, 1979, 1982, 1985, 1986, 1991, 1995, 1999
Mild Drought	0.0 to -25	1903, 1905, 1912, 1920, 1928, 1929, 1932, 1935, 1938, 1942, 1947, 1949, 1952, 1958, 1963, 1965, 1966, 1970, 1971, 1980, 1983, 1989, 1992, 1993, 2000, 2001
No Drought	0.0 or Above	1906, 1907, 1908, 1909, 1910, 1913, 1914, 1916, 1917, 1919, 1921, 1922, 1924, 1926, 1927, 1931, 1933, 1934, 1937, 1941, 1943, 1944, 1945, 1946, 1950, 1953, 1954, 1955, 1956, 1959, 1961, 1964, 1967, 1973, 1975, 1976, 1977, 1978, 1981, 1984, 1988, 1990, 1994, 1996,1997, 1998

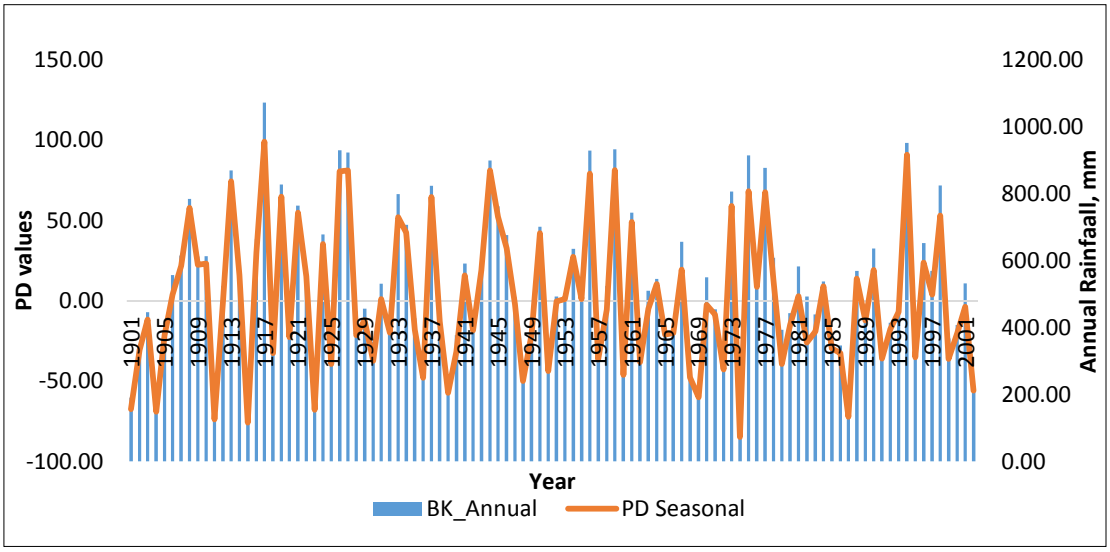


Figure 5.3: Percentage of Departure from Mean and Seasonal Rainfall for Banaskantha District

From the above Table 5.4 and 5.5 it was observed that severe drought condition occurred during 1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, 2002 and moderate drought condition occurred during 1902, 1918, 1925, 1930, 1936, 1940, 1948, 1951, 1957, 1960, 1962, 1968, 1972, 1985, 1986, 1991, 1995, 1999. From this indices it was observed that there were 28 number year's identified as dry years during 102 years.

1.1.3 Rainfall Anomaly Index

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The results for RAI is presented below Table 5.6.

Table 5.6: Drought years obtained using rainfall anomaly index

Classification	Range	Year
Extremely dry	≤ -3.0	1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, 2002
Very dry	-2.0 to -2.99	1903, 1905, 1920, 1928, 1932, 1935, 1938, 1942, 1949, 1965, 1966, 1979, 1980, 1983, 1989, 1992, 2000
Moderate dry	-1.0 to -1.99	1902, 1918, 1925, 1930, 1936, 1940, 1948, 1951, 1957, 1960, 1962, 1968, 1972, 1985, 1986, 1991, 1995, 1999
Normal	0.5 to -0.99	1906, 1912, 1914, 1922, 1929, 1931, 1947, 1952, 1953, 1955, 1958, 1963, 1964, 1970, 1971, 1976, 1981, 1982, 1984, 1988, 1993, 1997, 2001
Moderate wet	1 to 1.99	1908, 1916, 1921, 1924, 1934, 1945, 1946, 1950, 1961, 1967
Very wet	2 to 2.99	1907, 1909, 1910, 1913, 1919, 1927, 1933, 1937, 1941, 1943, 1944, 1954, 1956, 1973, 1975, 1977, 1978, 1990, 1996, 1998
Extremely wet	≥ 3.0	1917, 1926, 1959, 1994

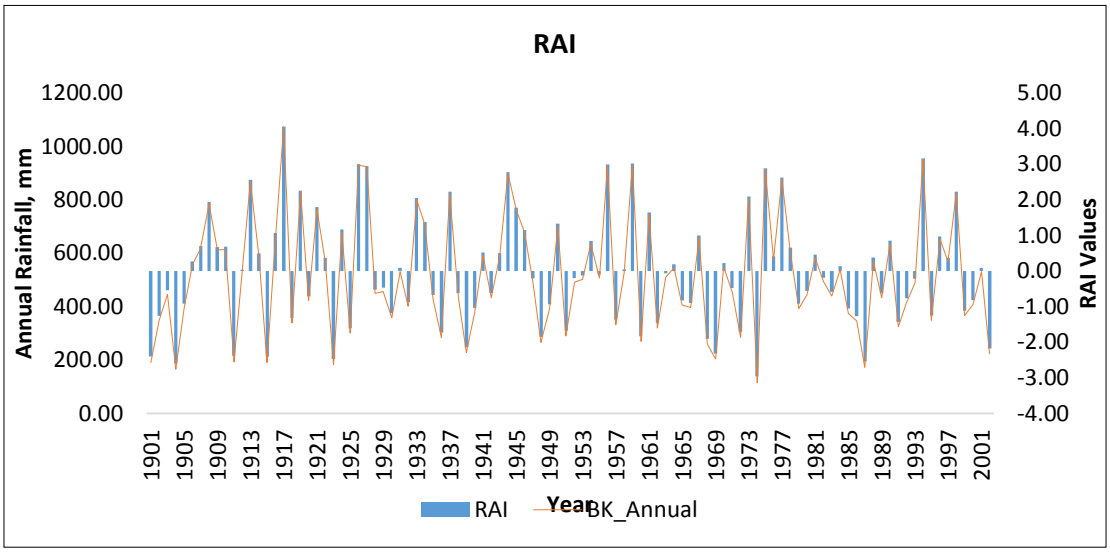


Figure 5.4: Rainfall Anomaly Index and Annual Rainfall for Banaskantha District

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall which is shown in above Figure 5.4. The mean value of the 10 highest and 10 lowest rainfall values is calculated. From the results it is observed that extreme dry condition occurs in the year of 1901, 1904, 1911, 1915,

1923, 1939, 1969, 1974, 1987, and 2002 during this year the average rainfall is about 186.40 mm. Also, very dry condition occurred during 1903, 1905, 1920, 1928, 1932, 1935, 1938, 1942, 1949, 1965, 1966, 1979, 1980, 1983, 1989, 1992 and 2000 years and during very dry years the average rainfall is around 419.64 mm during study period.

1.1.4 Deciles

The deciles were estimated for the study area having 102 years (i.e., 1901 to 2002) of monthly rainfall data. Below Table 5.7 shows the detail classification of drought years under different class for Banaskantha district.

Table 5.7: Drought years obtained using Deciles

Classification	Range	Year
Much Below Normal	1-2	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1957, 1960, 1962, 1968, 1969, 1972, 1974, 1987, 1991, 2002
Below Normal	3-4	1902, 1905, 1920, 1930, 1932, 1935, 1938, 1940, 1942, 1949, 1965, 1966, 1979, 1985, 1986, 1989, 1992, 1995, 1999, 2000
Near Normal	5-6	1903, 1912, 1928, 1929, 1931, 1947, 1952, 1953, 1955, 1958, 1963, 1964, 1970, 1971, 1980, 1982, 1983, 1984, 1993, 2001
Above Normal	7-8	1906, 1907, 1909, 1910, 1914, 1916, 1922, 1924, 1941, 1943, 1946, 1954, 1967, 1976, 1978, 1981, 1988, 1990, 1996, 1997.
Much Above Normal	9-10	1908, 1913, 1917, 1919, 1921, 1926, 1927, 1933, 1934, 1937, 1944, 1945, 1950, 1956, 1959, 1961, 1973, 1975, 1977, 1994, 1998.

The class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. From the analysis, the much below normal DI is concerned with value of 10 percent in 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1957, 1960, 1962, 1968, 1969, 1972, 1974, 1987, 1991, and 2002 years respectively which is 21 number of years. Graphical representation of deciles index is shown in below Figure 5.5

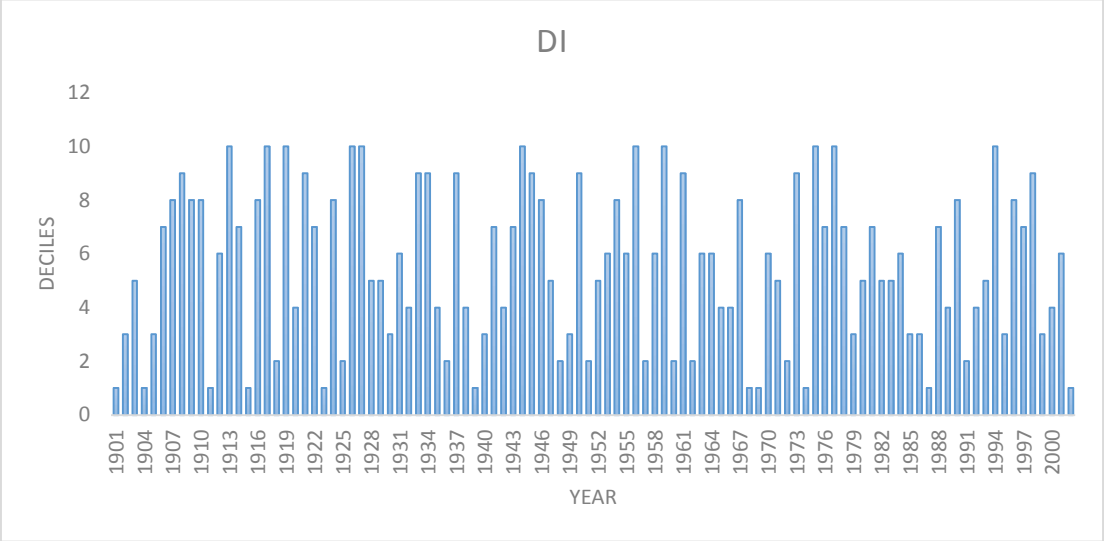


Figure 5.5: Decile index for Banaskantha district

1.1.5 Standardized Precipitation Index

The results of SPI were estimated for the study area with 102 years (i.e., 1901 to 2002) of rainfall data. Below Table 5.8 shows the classification of drought years obtain using SPI 12 time steps for Banaskantha district.

Table 5.8: Drought years obtained using SPI 12 month time steps

Classification	Range	Year
Extremely Dry	-2 to less	1904 – 1905, 1974 – 1975, 1987 – 1988
Severe Dry	-1.5 to -1.99	1901 – 1902, 1911 – 1912, 1915 – 1916, 1923 – 1924, 1939 – 1940, 1969 – 1970, 2002 – 2003
Moderate Dry	-1.0 to -1.49	1925 – 1926, 1936 – 1937, 1948 – 1949, 1951 – 1952, 1960 – 1961, 1968 – 1969, 1972 – 1973
Near Normal	-0.99 to 0.99	1902 – 1903, 1903 – 1904, 1905 – 1906, 1906 – 1907, 1907 – 1908, 1909 – 1910, 1910 – 1911, 1912 – 1913, 1914 – 1915, 1916 – 1917, 1918 – 1919, 1920 – 1921, 1922 – 1923, 1924 – 1925, 1928 – 1929, 1929 – 1930, 1930 – 1931, 1931 – 1932, 1932 – 1933, 1934 – 1935, 1935 – 1936, 1938 – 1939, 1940 – 1941, 1941 – 1942, 1942 – 1943, 1943 – 1944, 1946 – 1947, 1947 – 1948, 1949 – 1950, 1950 – 1951, 1952 – 1953, 1953 – 1954, 1954 – 1955, 1955 – 1956, 1957 – 1958, 1958 – 1959, 1962 – 1963, 1963 – 1964, 1964 – 1965, 1965 – 1966, 1966 – 1967, 1967 – 1968, 1970 – 1971, 1971 – 1972, 1976 – 1977, 1978 – 1979, 1979 – 1980, 1980 – 1981, 1981 – 1982, 1982 – 1983, 1983 – 1984, 1984 – 1985, 1985 – 1986, 1986 – 1987, 1988 – 1989, 1989 – 1990,

		1990 – 1991, 1991 – 1992, 1992 – 1993, 1993 – 1994, 1995 – 1996, 1996 – 1997, 1997 – 1998, 1999 – 2000, 2000 – 2001, 2001 – 2002,
Moderate Wet	1.0 to 1.49	1908 – 1909, 1913 – 1914, 1919 – 1920, 1921 – 1922, 1933 – 1934, 1937 – 1938, 1945 – 1946, 1961 – 1962, 1973 – 1974, 1977 – 1978, 1998 – 1999
Very Wet	1.5 to 1.49	1926 – 1927, 1927 – 1928, 1944 – 1945, 1956 – 1957, 1959 – 1960, 1975 – 1976, 1994 – 1995,
Extremely Wet	2.0 +	1917 – 1918

The total number of dry years obtain for different category using Standardized Precipitation Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per SPI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 9 times and moderate drought has occurred 12 times in 102 years.
- As per SPI 6, it is observed that extreme drought has occurred 3 times, severe drought has occurred 4 time and moderate drought has occurred 11 times in 102 years.
- As per SPI 9, it is observed that extreme drought has occurred 2 times, severe drought has occurred 7 times and moderate drought has occurred 5 times in 102 years.
- As per SPI 12, it is observed that extreme drought has occurred 3 times in 102, severe drought has occurred 7 times in 102 years and Moderate drought has occurred 8 times in 102 years.

For Banaskantha district, the SPI 12 values of extreme drought ranges from -2.01 in 1987 to -2.09 in 1904. The value of maximum severe drought occurred with the values of -1.57 in 2002 and minimum value was -1.84 in 1901. From the results it was observed that 1904 – 1905, 1974 – 1975, 1987 – 1988, 1901 – 1902, 1911 – 1912, 1915 – 1916, 1923 – 1924, 1939 – 1940, 1969 – 1970, and 2002 – 2003 were the most intense drought affected years in the Banaskantha district. The Graphical representation of SPI 12 and annual rainfall for Banaskantha district is shown in below Figure 5.6

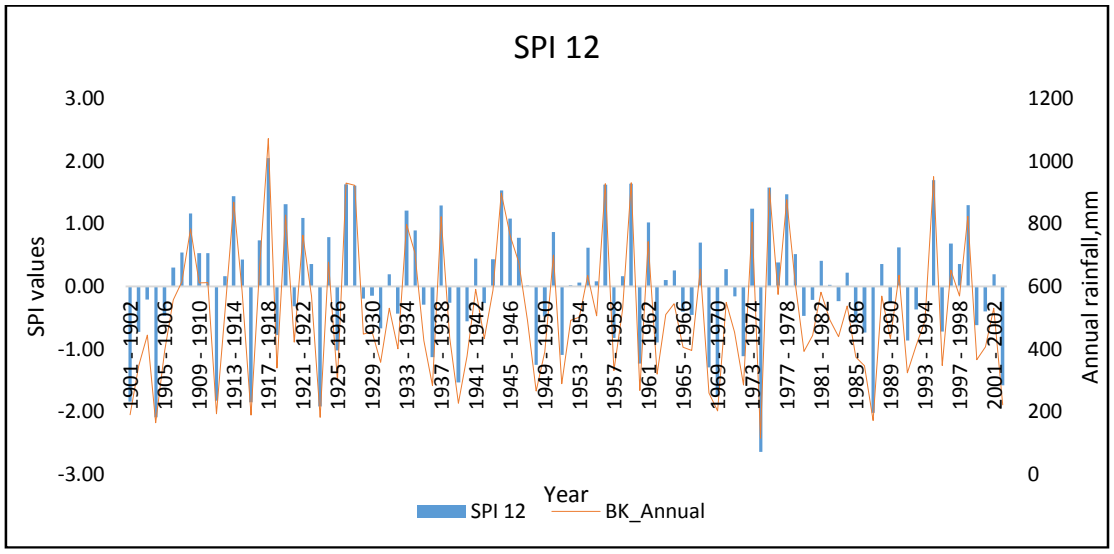


Figure 5.6: SPI 12 plot for Banaskantha District and Annual Rainfall

1.1.6 Reconnaissance Drought Index

The results of RDI were estimated for the study area with 102 years (i.e., 1901 to 2002) of rainfall and PET data. Below Table 5.9 shows the classification of drought years obtain using RDI 12 time steps for Banaskantha district.

Table 5.9: Drought years obtained using RDI 12 month time steps

Classification	Range	Year
Extreme Drought	-2 or less	1904 – 1905, 1923 – 1924, 1974 – 1975, 1987 – 1988
Severe Drought	-1.5 to -1.99	1901 – 1902, 1911 – 1912, 1915 – 1916, 1939 – 1940, 1969 – 1970, 2002 – 2003
Moderate Drought	-1 to -1.49	1936 – 1937, 1948 – 1949, 1951 – 1952, 1960 – 1961, 1968 – 1969, 1972 – 1973
Normal Conditions- Wet	0 to 0.99	1906 – 1907, 1907 – 1908, 1909 – 1910, 1910 – 1911, 1912 – 1913, 1914 – 1915, 1916 – 1917, 1922 – 1923, 1924 – 1925, 1931 – 1932, 1934 – 1935, 1941 – 1942, 1943 – 1944, 1946 – 1947, 1947 – 1948, 1950 – 1951, 1952 – 1953, 1953 – 1954, 1954 – 1955, 1955 – 1956, 1958 – 1959, 1963 – 1964, 1964 – 1965, 1967 – 1968, 1970 – 1971, 1976 – 1977, 1978 – 1979, 1981 – 1982, 1982 – 1983, 1984 – 1985, 1988 – 1989, 1990 – 1991, 1993 – 1994, 1996 – 1997, 1997 – 1998, 2001 – 2002
Normal Conditions-Dry	0 to -0.99	1902 – 1903, 1903 – 1904, 1905 – 1906, 1918 – 1919, 1920 – 1921, 1925 – 1926, 1928 – 1929, 1929 – 1930, 1930 – 1931, 1932 – 1933, 1935 – 1936, 1938 – 1939, 1940 – 1941, 1942 – 1943, 1949 – 1950, 1957 – 1958, 1962 – 1963, 1965 – 1966, 1966 – 1967, 1971 – 1972,

		1979 – 1980, 1980 – 1981, 1983 – 1984, 1985 – 1986, 1986 – 1987, 1989 – 1990, 1991 – 1992, 1992 – 1993, 1995 – 1996, 1999 – 2000, 2000 – 2001,
Moderately Wet	1.00 to 1.49	1908 – 1909, 1913 – 1914, 1919 – 1920, 1921 – 1922, 1926 – 1927, 1927 – 1928, 1933 – 1934, 1937 – 1938, 1944 – 1945, 1945 – 1946, 1956 – 1957, 1959 – 1960, 1961 – 1962, 1973 – 1974, 1975 – 1976, 1977 – 1978, 1998 – 1999
Severely Wet	1.5 to 1.99	1917 – 1918, 1994 – 1995

The total number of dry years obtain for different category using Reconnaissance drought Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per RDI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 14 times and moderate drought has occurred 06 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 5 times, severe drought has occurred 3 time and moderate drought has occurred 7 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 5 times, severe drought has occurred 4 times and moderate drought has occurred 4 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 4 times in 102, severe drought has occurred 6 times in 102 years and moderate drought has occurred 6 times in 102 years.

From the results it was observed that 1904 – 1905, 1923 – 1924, 1974 – 1975, 1987 – 1988, 1901 – 1902, 1911 – 1912, 1915 – 1916, 1939 – 1940, 1969 – 1970, and 2002 – 2003 were the most intense drought affected years. Also, moderate drought years as 1936 – 1937, 1948 – 1949, 1951 – 1952, 1960 – 1961, 1968 – 1969, 1972 – 1973 in the Banaskantha district. The results of RDI 12 and annual rainfall for Banaskantha district is shown in below Figure 5.7.

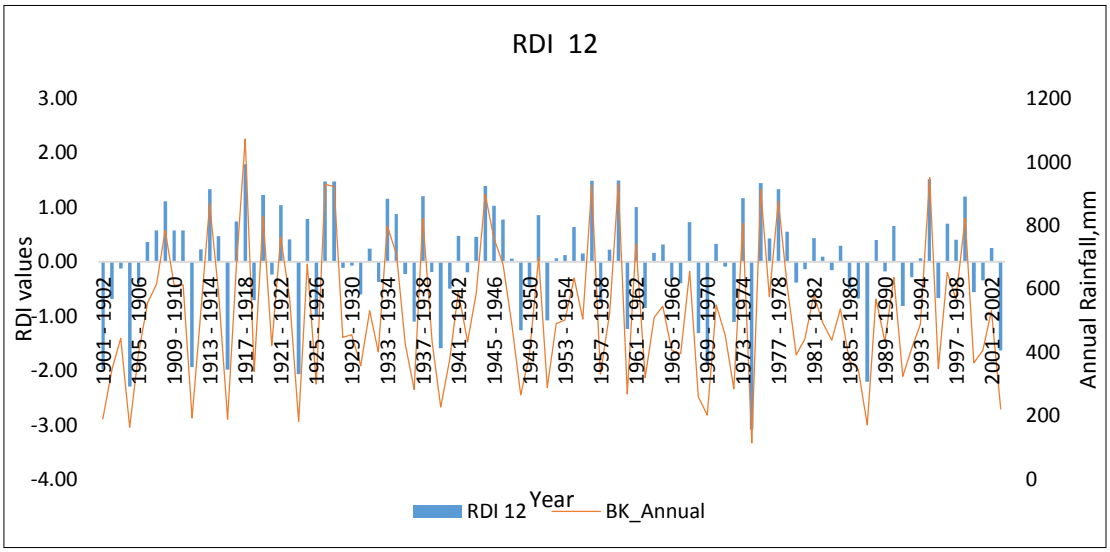


Figure 5.7: RDI 12 plot for Banaskantha District and Annual Rainfall

1.1.7 Standardised Precipitation Evapotranspiration Index

The classification of drought years obtain using SPEI 12 time steps under different class for Banaskantha district is shown in below Table 5.10.

Table 5.10: Drought years obtained using SPEI 12 month time steps

Classification	Range	Year
Extreme dry	≤ -2.0	1973
Severe dry	-1.5 to -1.99	1901, 1904, 1911, 1915, 1923, 1968, 1986
Moderate dry	-1.0 to -1.49	1925, 1936, 1939, 1948, 1951, 1960, 1967, 1971, 2002
Near normal	0.99 to -0.99	1902, 1903, 1905, 1906, 1907, 1909, 1910, 1912, 1914, 1916, 1918, 1920, 1922, 1924, 1928, 1929, 1930, 1931, 1932, 1934, 1935, 1938, 1940, 1941, 1942, 1943, 1946, 1947, 1949, 1950, 1952, 1953, 1954, 1955, 1957, 1958, 1962, 1963, 1964, 1965, 1966, 1969, 1970, 1975, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1994, 1995, 1996, 1998, 1999, 2000, 2001
Moderate wet	1.0 to 1.49	1908, 1919, 1921, 1933, 1937, 1945, 1961, 1972, 1997
Very wet	1.5 to 1.99	1913, 1926, 1927, 1944, 1956, 1959, 1974, 1976, 1993
Extreme wet	≥ 2.0	1917

From the above Table 5.10 of SPEI Index it was observed that extreme drought condition occurred in 1973 year, severe drought condition occurred during 1901,

1904, 1911, 1915, 1923, 1968, 1986 moderate drought condition occurred during 1925, 1936, 1939, 1948, 1951, 1960, 1967, 1971, 2002. Also, from above Table it was observed total 17 years as drought years that every 3 to 4 years drought condition was occurred in Banaskantha district. Graphical representation of SPEI index is shown in below Figure 5.8

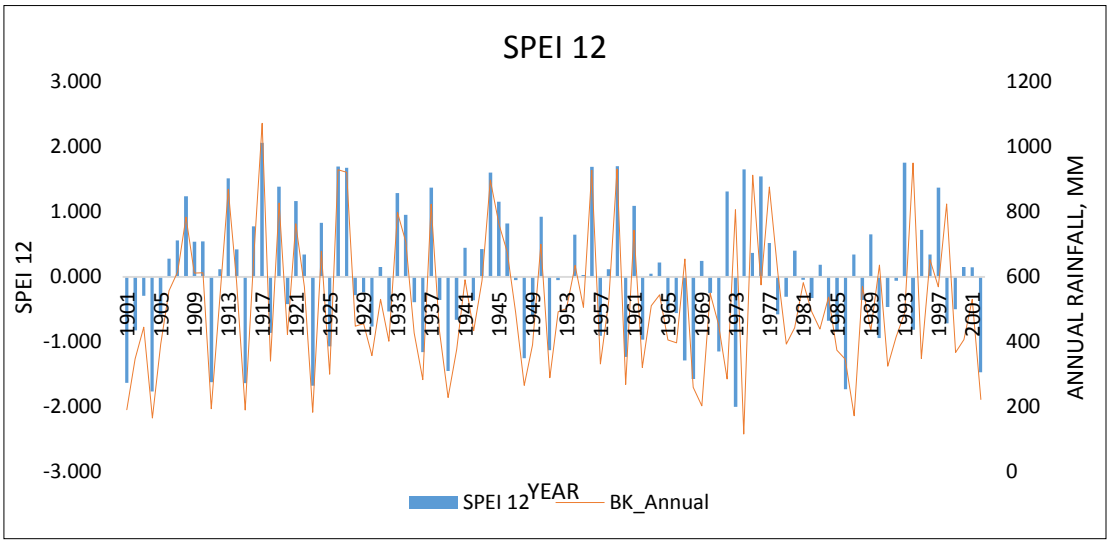


Figure 5.8: SPEI 12 plot for Banaskantha District and Annual Rainfall

1.1.8 China Z Index & Modified China Z Index

The classification of drought years obtain using China- Z-index and Modified China Z-index and the number of years in each category are shown in below Table 5.11 and 5.12. The Graphical representation of CZI and MCZI is shown in below Figure 5.9 and 5.10 respectively.

Table 5.11: Drought years obtained using China Z Index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	NIL
Moderate dry	-1.0 to -1.49	1905, 1930, 1957, 1962
Near normal	0.99 to -0.99	1902, 1903, 1906, 1907, 1909, 1910, 1912, 1914, 1920, 1922, 1924, 1928, 1929, 1931, 1932, 1934, 1935, 1938, 1940, 1941, 1942, 1943, 1946, 1947, 1949, 1952, 1953, 1954, 1955, 1958, 1963, 1964, 1965, 1966, 1967, 1970, 1971, 1976, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990, 1992, 1993, 1996, 1997,

		1999, 2000, 2001,
Moderate wet	1.0 to 1.49	1908, 1913, 1916, 1919, 1921, 1933, 1937, 1945, 1950, 1961, 1973, 1998
Very wet	1.5 to 1.99	1917, 1926, 1927, 1944, 1956, 1959, 1975, 1977, 1994
Extreme wet	≥ 2.0	

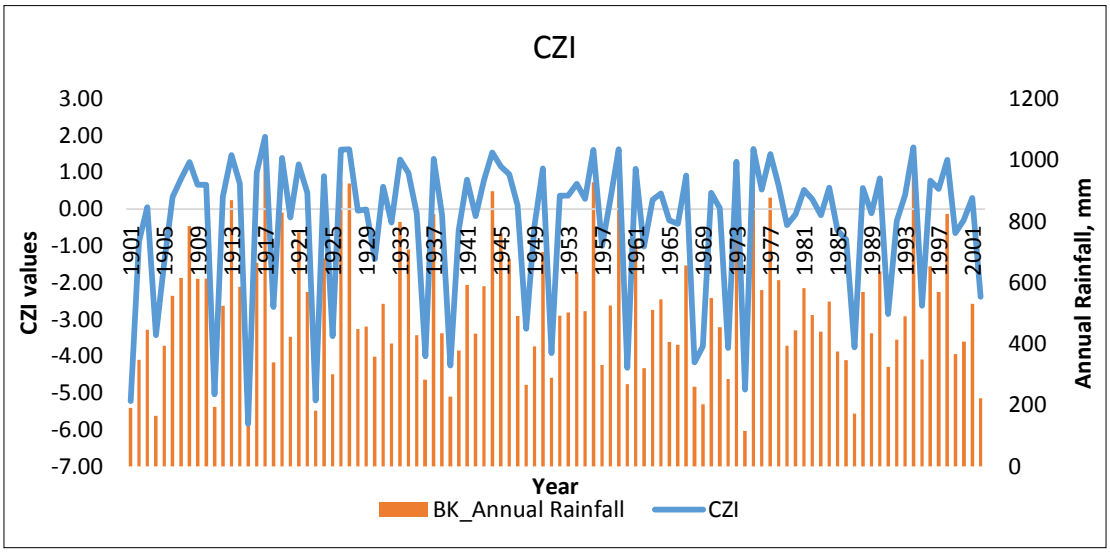


Figure 5.9: CZI index for Banaskantha District and Annual Rainfall

Modified China Z Index

Table 5.12: Drought years obtained using Modified China Z Index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1974, 1987, 1991, 1995
Severe dry	-1.5 to -1.99	1972, 2002
Moderate dry	-1.0 to -1.49	NIL
Near normal	0.99 to -0.99	1902, 1903, 1905, 1906, 1907, 1909, 1910, 1912, 1914, 1920, 1922, 1924, 1928, 1929, 1930, 1931, 1932, 1935, 1938, 1940, 1941, 1942, 1943, 1947, 1949, 1952, 1953, 1954, 1955, 1957, 1958, 1962, 1963, 1964, 1965, 1966, 1967, 1970, 1971, 1976, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988, 1989, 1990, 1992, 1993, 1996, 1997, 1999, 2000, 2001
Moderate wet	1.0 to 1.49	1908, 1916, 1919, 1921, 1933, 1934, 1937, 1945, 1946, 1950, 1961, 1973, 1998
Very wet	1.5 to	1913, 1926, 1927, 1944, 1956, 1959, 1975, 1977, 1994

	1.99	
Extreme wet	≥ 2.0	1917

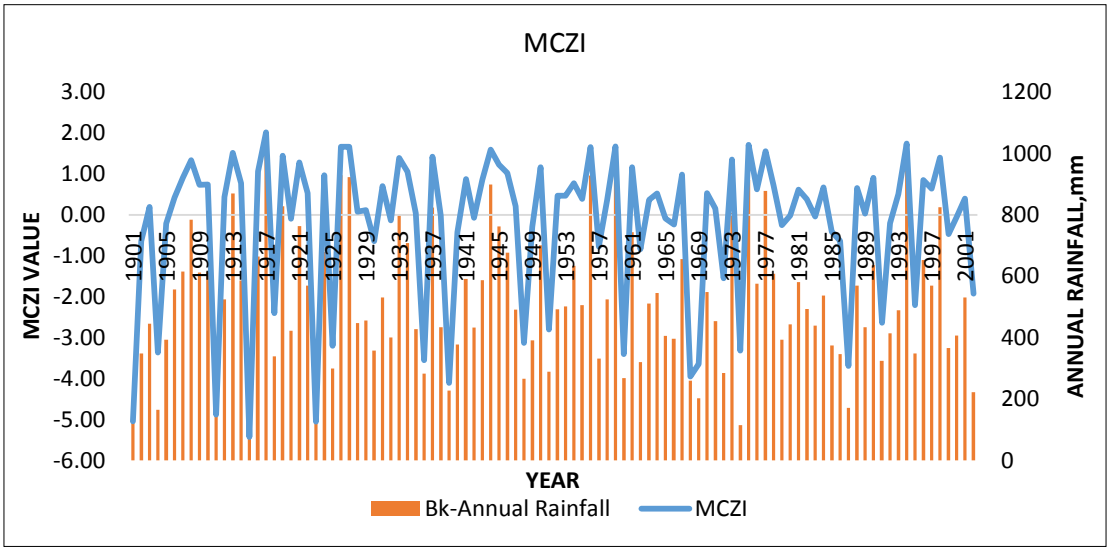


Figure 5.10: MCZI index for Banaskantha District and Annual Rainfall

The (1901-2002) viz., 102 historical years assessed using China Z index and Modified China Z index from the analysis, Dry years are observed as total 24 number of years. The extreme dry years as 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002. Also, moderate drought years as 1905, 1930, 1957, and 1962 in Banaskantha district.

1.1.9 Z- Score Index

The meteorological drought indices of Z score index for drought detection and monitoring in Banaskantha district is carried out and the results is shown in below Table 5.13.

Table 5.13: Drought years obtained using Z score Index

Classification	Range	Year
Extreme dry	≤ -2.0	NIL
Severe dry	-1.5 to -1.99	1901, 1904, 1911, 1915, 1923, 1974, 1987
Moderate dry	-1.0 to -1.49	1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 2002

From this method, Out of the 102 study period dry years are observed in 17 years. The results shows that severe drought conditions occurred during 1901, 1904, 1911, 1915, 1923, 1974, 1987 and moderate dry years as 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 2002 in Banaskantha district.

Both Z-Score and SPI can be used in drought analysis, the Z-Score is a general statistical measure that can be applied to various data types, whereas SPI is specifically designed for characterizing drought conditions based on precipitation data. SPI is widely used in meteorology and hydrology for drought monitoring and early warning systems.

5.2.2 Estimation of various Meteorological Drought Indices in Gandhinagar district

The statistical parameters of the rainfall data for Gandhinagar for 102 years i.e., 1901 to 2002 were analyzed and are given in below Table 5.14, which indicates that there are high fluctuations in occurrence of rainfall ranging from maximum rainfall 1261.90 mm in 1959 and minimum rainfall 237.90 mm in 1911 in the study area.

Table 5.14: Seasonal Rainfall in mm for Gandhinagar district

Rainfall parameters	June	July	August	Sept	Winter	Pre-monsoon	SW monsoon
Mean Rainfall	85.09	272.66	170.54	112.90	1.26	3.76	160.29
Standard Deviation	64.45	135.50	104.93	114.12	2.81	7.02	104.75

Table 5.15: Drought Analysis based on Monthly Rainfall for Gandhinagar district

Month	Mean, mm	Half of Average Rainfall, mm	No. of Drought Months	Percentage of Drought Months
Jan	1.35	0.68	72	10.22
Feb	1.18	0.59	76	10.79
Mar	1.22	0.61	82	11.64
Apr	0.72	0.36	70	9.94
May	9.37	4.69	63	8.94
Jun	85.09	42.55	31	4.40
Jul	272.66	136.33	20	2.84
Aug	170.54	85.27	23	3.26
Sep	112.90	56.45	41	5.82
Oct	13.89	6.94	65	9.23
Nov	6.35	3.18	80	11.36
Dec	1.80	0.90	81	11.50
			704	100

The monthly analysis of rainfall for Gandhinagar district is given in Table 5.15. The percentage of drought in a month for January, the percentage of drought month is equal to 10.22 %. Also, the highest average rainfall was observed as 272.66 mm in the month of July in the span of 102 years. The months of March, November and

December have 81, 80, 81 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 20, 23 respectively.

1.2.1 Percent of Normal

Table 5.16: Drought years obtained using percentage of normal method

Classification	Range	Year
Extremely Drought	≤ 40	1911, 1918, 1987
Severe Drought	40 to 55	1904, 1915, 1923, 1948, 1951, 1968, 1972
Moderate Drought	55 to 80	1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002

From the above Table 5.16 of Percent of normal index it was observed that extreme drought condition occurs in the year 1911, 1918, 1987severe drought condition occurred during 1904, 1915, 1923, 1948, 1951, 1968, 1972 moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002.

During the period of (1901-1930) there were total nine (06 nos) drought events, for (1930-1960) there were five (08 drought events) and (1960-1990) total 12 drought events were observed. Also, from above Table 5.16 it was observed that every 3 to 4 years drought condition was occurred in Gandhinagar district.

1.2.2 Percentage of Departure from Mean for Annual Rainfall

The classification of drought years obtain using percentage of departure from mean for annual rainfall & for seasonal rainfall is shown in below Table 5.17 and 5.18.

Table 5.17: Drought years obtained using percentage of departure method for annual rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1987
Moderate Drought	-25 to -50	1901, 1939, 1940, 1957, 1960, 1965, 1969, 1974, 1985, 1986, 1991, 1995, 2002

Percentage of Departure from Mean for Seasonal Rainfall

For seasonal rainfall departure analysis monsoon season rainfall months i.e., June to September is considered.

Table 5.18: Drought years obtained using percentage of departure method for seasonal rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1974, 1987
Moderate Drought	-25 to -50	1901, 1939, 1940, 1951, 1957, 1960, 1965, 1979, 1982, 1985, 1986, 1995, 2002

From the above Table 5.17 and 5.18 it was observed that severe drought condition occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1987 and moderate drought condition occurred during 1901, 1939, 1940, 1957, 1960, 1965, 1969, 1974, 1985, 1986, 1991, 1995, 2002. From this indices it was observed that there were 23 number year's identified as dry years during 102 years.

1.2.3 Rainfall Anomaly Index

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The results for RAI is presented below Table 5.19.

Table 5.19: Drought years obtained using Rainfall Anomaly Index

Classification	Range	Year
Extremely dry	≤ -3.0	1911, 1918, 1987
Very dry	-2.0 to -2.99	1904, 1915, 1923, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1995, 2002
Moderate dry	-1.0 to -1.99	1901, 1925, 1929, 1936, 1939, 1940, 1947, 1957, 1966, 1969, 1971, 1985, 1986, 1991, 1992, 1999
Slight dry	-0.50 to -0.99	1905, 1916, 1920, 1924, 1935, 1938, 1949, 1952, 1978, 1979, 1980, 1982, 1989, 2000, 2001

From this results it is observed that extreme dry condition occurs in the year of 1911, 1918, 1987 during this year the average rainfall is about 232.15 mm. Also, very dry condition occurred during 1904, 1915, 1923, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1995, 2002years and during moderate dry years 1901, 1925, 1929, 1936, 1939, 1940, 1947, 1957, 1966, 1969, 1971, 1985, 1986, 1991, 1992, 1999 the average rainfall is around 325.15 mm during study period.

1.2.4 Deciles

The deciles were estimated for the study area having 102 years (i.e., 1901 to 2002) of monthly rainfall data. Below Table 5.20 shows the detail classification of drought years under different class in Gandhinagar district.

Table 5.20: Drought years obtained using Deciles

Classification	Range	Year
Much Below Normal	1-2	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1972, 1974, 1985, 1986, 1987, 1995, 2002
Below Normal	3-4	1905, 1916, 1925, 1929, 1935, 1936, 1938, 1947, 1949, 1966, 1969, 1971, 1979, 1980, 1982, 1989, 1991, 1992, 1999, 2000

The class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. From the analysis, the much below normal DI is concerned with value of 10 percent in 1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1972, 1974, 1985, 1986, 1987, 1995, and 2002 respectively which is 21 number of years.

1.2.5 Standardized Precipitation Index

The results of SPI 12 were estimated for the study area having 102 years (i.e., 1901 to 2002) using rainfall data. Below Table 5.21 shows the classification of drought years under different class for Gandhinagar district.

Table 5.21: Drought years obtained using SPI 12 month time steps

Classification	Range	Year
Extremely Dry	-2 to less	1911 – 1912, 1918 – 1919, 1987 – 1988
Severe Dry	-1.5 to -1.99	1904 – 1905, 1915 – 1916, 1923 – 1924, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1972 – 1973, 2002 – 2003
Moderate Dry	-1.0 to -1.49	1901 – 1902, 1940 – 1941, 1960 – 1961, 1965 – 1966, 1974 – 1975, 1986 – 1987, 1995 – 1996

For Gandhinagar district, the SPI 12 values of extreme drought ranges from -2.17 in 1987 to -2.37 in 1911. The value of maximum severe drought occurred with the values of -1.52 in 2002 and minimum value was -1.77 in 1904. From the results it was observed that 1911 – 1912, 1918 – 1919, 1987 – 1988, 1904 – 1905, 1915 – 1916, 1923 – 1924, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1972 – 1973, and 2002 – 2003 were the most intense drought affected years in the Gandhinagar district.

1.2.6 Reconnaissance Drought Index

The results of RDI 12 were estimated for the study area having 102 years (i.e., 1901 to 2002) of rainfall and PET data. Below Table 5.22 shows the classification of drought years under different class for Gandhinagar district.

Table 5.22: Drought years obtained using RDI 12 month time steps

Classification	Range	Year
Extreme Drought	-2 or less	1911 – 1912, 1918 – 1919, 1972 – 1973, 1987 – 1988
Severe Drought	-1.5 to -1.99	1904 – 1905, 1915 – 1916, 1923 – 1924, 1948 – 1949, 1951 – 1952, 1968 – 1969, 2002 – 2003
Moderate Drought	-1 to -1.49	1901 – 1902, 1940 – 1941, 1960 – 1961, 1965 – 1966, 1974 – 1975, 1986 – 1987, 1995 – 1996

The total number of dry years obtain for different category using Reconnaissance drought Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per RDI 3, it is observed that extreme drought has occurred 5 times, severe drought has occurred 7 times and moderate drought has occurred 9 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 6 times, severe drought has occurred 4 time and moderate drought has occurred 7 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 4 times, severe drought has occurred 3 times and moderate drought has occurred 7 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 4 times in 102, severe drought has occurred 6 times in 102 years and Moderate drought has occurred 6 times in 102 years.

From the results it was observed that 1911 – 1912, 1918 – 1919, 1972 – 1973, 1987 – 1988, 1904 – 1905, 1915 – 1916, 1923 – 1924, 1948 – 1949, 1951 – 1952, 1968 – 1969, 2002 – 2003 were the most intense drought affected years. Also, moderate drought years as 1901 – 1902, 1940 – 1941, 1960 – 1961, 1965 – 1966, 1974 – 1975, 1986 – 1987, 1995 – 1996 in the Gandhinagar district.

1.2.7 Standardised Precipitation Evapotranspiration Index

The classification of drought years obtain using standardized precipitation Evapotranspiration index (SPEI 12) is shown in below Table 5.23.

Table 5.23: Drought years obtained using SPEI 12 month time steps

Classification	Range	Year
Extreme dry	≤ -2.0	
Severe dry	-1.5 to -1.99	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987
Moderate dry	-1.0 to -1.49	1901, 1939, 1940, 1951, 1957, 1960, 1965, 1974, 1986, 1995, 2002

From the above Table 5.23 of SPEI Index it was observed that severe drought condition occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987 moderate drought condition occurred during 1901, 1939, 1940, 1951, 1957, 1960, 1965, 1974, 1986, 1995, 2002. Also, from above Table it was observed total 20 years as drought years that every 4 to 5 years drought condition was occurred in Gandhinagar district.

1.2.8 China Z Index and Modified China Z Index

The classification of drought years obtain using China- Z-index and Modified China Z-index and the number of years in each category are shown in below Table 5.24 and 5.25 respectively.

Table 5.24: Drought years obtained using China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1957, 1965, 1968, 1972, 1986, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	1939, 1960, 1974
Moderate dry	-1.0 to -1.49	1940, 1985

Modified China Z Index

Table 5.25: Drought years obtained using Modified China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1918, 1923, 1948, 1951, 1965 1968, 1972, 1986, 1987, 1995, 2002
Severe dry	-1.5 to -1.99	1915, 1991
Moderate dry	-1.0 to -1.49	1939, 1940, 1957, 1960, 1974

The (1901-2002) viz., 102 historical years assessed using China Z index and Modified China Z index from the analysis, dry years are observed as total 22 number of years which include extreme dry years as 1901, 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1957, 1965, 1968, 1972, 1986, 1987, 1991, 1995, 2002 and moderate drought years as 1939, 1940, 1957, 1960, 1974 in Gandhinagar district.

1.2.9 Z- Score Index

The meteorological drought indices of Z score index for drought detection and monitoring in Gandhinagar district is carried out and the results shown in below Table 5.26.

Table 5.26: Drought years obtained using Z score index

Classification	Range	Year
Extreme dry	≤ -2.0	
Severe dry	-1.5 to -1.99	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987
Moderate dry	-1.0 to -1.49	1901, 1939, 1940, 1951, 1960, 1965, 1974, 1986, 1995, 2002

From this method, Out of the 102 study period dry years are observed in 19 years. The results shows that Severe drought conditions occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987 and Moderate dry years as 1901, 1939, 1940, 1951, 1960, 1965, 1974, 1986, 1995, 2002 in Gandhinagar district.

5.1.3 Estimation of various Meteorological Drought Indices in Mehsana district

The statistical parameters of the rainfall data for Mehsana for 102 (i.e., 1901 to 2002) years were analyzed and are given in Table 5.27, which indicates that there are high fluctuations in occurrence of rainfall ranging from maximum rainfall 1195.33 mm in 1959 and minimum rainfall 214.01 mm in 1987 in the study area.

Table 5.27: Seasonal Rainfall in mm for Mehsana district

Rainfall parameters	June	July	August	Sept	Winter	Pre-monsoon	SW monsoon
Mean Rainfall	75.61	241.94	172.90	105.91	1.23	3.84	149.09
Standard Deviation	57.85	126.12	108.53	109.62	2.48	7.53	100.53

The monthly analysis of rainfall for Mehsana district is given in Table 5.28. The percentage of drought in a month for January, the percentage of drought month is equal to 10.34 %. Also, the highest average rainfall was observed as 241.94 mm in the month of July in the span of 102 years. The months of March, November and December have 85, 78, 81 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 17, 20 respectively.

Table 5.28: Drought Analysis based on Monthly Rainfall for Mehsana district

Month	Mean, mm	Half of average rainfall	No. of Drought Months	Percentage of Drought Months
Jan	1.78	0.89	72	10.34
Feb	0.69	0.35	75	10.78
Mar	2.39	1.19	85	12.21

Apr	0.52	0.26	70	10.06
May	8.64	4.32	64	9.2
Jun	75.61	37.8	29	4.17
Jul	241.94	120.97	17	2.44
Aug	172.9	86.45	20	2.87
Sep	105.91	52.96	42	6.03
Oct	14.39	7.19	63	9.05
Nov	6.75	3.38	78	11.21
Dec	1.11	0.56	81	11.64
Total			696	100

1.3.1 Percent of Normal

Table 5.29: Drought years obtained using percentage of normal method

Classification	Range	Year
Extremely Drought	≤ 40	1904, 1911, 1987
Severe Drought	40 to 55	1915, 1918, 1923, 1948, 1951, 1968, 1972, 1974, 2002
Moderate Drought	55 to 80	1901, 1925, 1929, 1935, 1936 1938, 1939, 1940, 1949, 1957, 1960, 1965, 1969, 1985, 1986, 1991, 1995

From the above Table 5.29 of Percent of normal index it was observed that extreme drought condition occurs in the year 1904, 1911, 1987 severe drought condition occurred during 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1974, 2002 and moderate drought condition occurred during 1901, 1925, 1929, 1935, 1936 1938, 1939, 1940, 1949, 1957, 1960, 1965, 1969, 1985, 1986, 1991, 1995 years.

During the period of (1901-1930) there were total nine (08 nos) drought events, for (1930-1960) there were five (10 drought events) and (1960-1990) total 11 drought events were observed. Also, from above Table it was observed that every 3 to 4 years drought condition was occurred in Mehsana district.

1.3.2 Percentage of Departure from Mean for Annual Rainfall

The classification of drought years obtain using percentage of departure from mean for annual rainfall & for seasonal rainfall is shown in below Table 5.30 and 5.31 respectively.

Table 5.30: Drought years obtained using percentage of departure method for annual rainfall

Classification	Range	Year
Severe	-50 to -75	1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987,

Drought		2002
Moderate Drought	-25 to -50	1901, 1925, 1936, 1939, 1940, 1951, 1957, 1960, 1965, 1968, 1969, 1985, 1986, 1991, 1995
Mild Drought	0.0 to -25	1902, 1903, 1905, 1916, 1920, 1929, 1930, 1932, 1935, 1938, 1947, 1949, 1952, 1962, 1964, 1966, 1971, 1978, 1979, 1980, 1982, 1984, 1988, 1989, 1992, 1993, 1999, 2000, 2001

Percentage of Departure from Mean for Seasonal Rainfall

For seasonal rainfall departure analysis monsoon season rainfall months i.e., June to September is considered.

Table 5.31: Drought years obtained using percentage of departure method for seasonal rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1904, 1911, 1915, 1918, 1923, 1948, 1974, 1987
Moderate Drought	-25 to -50	1901, 1925, 1936, 1939, 1940, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1979, 1982, 1985, 1986, 1991, 1995, 1999, 2002
Mild Drought	0.0 to -25	1902, 1903, 1905, 1916, 1920, 1929, 1930, 1935, 1938, 1947, 1949, 1952, 1962, 1966, 1971, 1978, 1980, 1989, 1992, 1993, 1997, 2000, 2001

From the above Table 5.30 and 5.31 it was observed that severe drought condition occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987, 2002 and moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1951, 1957, 1960, 1965, 1968, 1969, 1985, 1986, 1991, 1995. From this indices it was observed that there were 25 number year's identified as dry years during 102 years. Also, 29 number year's identified as mild dry years during 102 years.

1.3.3 Rainfall Anomaly Index

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The results for RAI is presented below Table 5.32 for Mehsana district.

Table 5.32: Drought years obtained using rainfall anomaly index

Classification	Range	Year
Extremely dry	≤ -3.0	1904, 1987
Very dry	-2.0	1901, 1911, 1915, 1918, 1923, 1948, 1951, 1968,

	to -2.99	1972, 1974, 1995, 2002
Moderate dry	-1.0 to -1.99	1925, 1929, 1936, 1939, 1940, 1957, 1960, 1965, 1966, 1969, 1985, 1986, 1991, 1999
Slight dry	-0.50 to -0.99	1902, 1903, 1905, 1920, 1935, 1938, 1947, 1949, 1962, 1971, 1979, 1989, 1992, 2000

From this results it is observed that extreme dry condition occurs in the year of 1904, 1987 during this year the average rainfall is about 248.49 mm. Also, very dry condition occurred during 1901, 1911, 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1974, 1995, 2002 years and during moderate dry years 1925, 1929, 1936, 1939, 1940, 1957, 1960, 1965, 1966, 1969, 1985, 1986, 1991, 1999 the average rainfall is around 342.08 mm during study period.

1.3.4 Deciles

The deciles were estimated for the study area having 102 years (i.e., 1901 to 2002) of monthly rainfall data. Below Table 5.33 shows the detail classification of drought years under different class for Mehsana district.

Table 5.33: Drought years obtained using Deciles

Classification	**Range**	**Year**
Much Below Normal	1-2	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, 2002
Below Normal	3-4	1902, 1905, 1920, 1925, 1929, 1935, 1936, 1938, 1947, 1949, 1962, 1965, 1966, 1971, 1979, 1989, 1991, 1992, 1999, 2000,

The class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. From the analysis, the much below normal DI is concerned with value of 10 percent in the year 1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, and 2002 respectively which is 21 number of years.

1.3.5 Standardized Precipitation Index

The results of SPI 12 for Mehsana district is shown in below Table 5.34 of drought years under different class for Mehsana district.

Table 5.34: Drought years obtained using SPI 12 month time steps

Classification	**Range**	**Year**
Extremely Dry	-2 to less	1904 – 1905, 1911 – 1912, 1987 – 1988

Severe Dry	-1.5 to -1.99	1915 – 1916, 1918 – 1919, 1923 – 1924, 1948 – 1949, 1968 – 1969, 1972 – 1973, 1974 – 1975, 2002 – 2003,
Moderate Dry	-1.0 to -1.49	1901 – 1902, 1939 – 1940, 1940 – 1941, 1951 – 1952, 1957 – 1958, 1960 – 1961, 1969 – 1970, 1986 – 1987, 1995 – 1996

For Mehsana district, the SPI 12 values of extreme drought ranges from -2.38 in 1987 to -2.23 in 1904. The value of maximum severe drought occurred with the values of -1.59 in 2002 and minimum value was -1.72 in 1915. From the results it was observed that 1904 – 1905, 1911 – 1912, 1987 – 1988, 1915 – 1916, 1918 – 1919, 1923 – 1924, 1948 – 1949, 1968 – 1969, 1972 – 1973, 1974 – 1975, and 2002 – 2003 were the most intense drought affected years in the Mehsana district.

1.3.6 Reconnaissance Drought Index

The results of RDI 12 for Mehsana district for different drought class is shown in below Table 5.35.

Table 5.35: Drought years obtained using RDI 12 month time steps

Classification	**Range**	**Year**
Extreme Drought	-2 or less	1904 – 1905, 1911 – 1912, 1923 – 1924, 1987 – 1988
Severe Drought	-1.5 to -1.99	1915 – 1916, 1918 – 1919, 1948 – 1949, 1968 – 1969, 1972 – 1973, 1974 – 1975, 2002 – 2003
Moderate Drought	-1 to -1.49	1901 – 1902, 1939 – 1940, 1940 – 1941, 1951 – 1952, 1957 – 1958, 1960 – 1961, 1969 – 1970, 1986 – 1987, 1995 – 1996

The total number of dry years obtain for different category using Reconnaissance drought Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per RDI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 15 times and moderate drought has occurred 06 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 6 times, severe drought has occurred 3 time and moderate drought has occurred 5 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 4 times, severe drought has occurred 5 times and moderate drought has occurred 6 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 4 times in 102, severe drought has occurred 7 times in 102 years and Moderate drought has occurred 9 times in 102 years.

From the results it was observed that drought years were 1904 – 1905, 1911 – 1912, 1923 – 1924, 1987 – 1988, 1915 – 1916, 1918 – 1919, 1948 – 1949, 1968 – 1969, 1972 – 1973, 1974 – 1975, 2002 – 2003 which is most intense drought affected years. Also, moderate drought years as 1901 – 1902, 1939 – 1940, 1940 – 1941, 1951 – 1952, 1957 – 1958, 1960 – 1961, 1969 – 1970, 1986 – 1987, 1995 – 1996 in the Mehsana district.

1.3.7 Standardised Precipitation Evapotranspiration Index

The classification of drought years obtain using standardized precipitation evapotranspiration index (SPEI 12) is shown in below Table 5.36.

Table 5.36: Drought years obtained using SPEI for time steps 12 month

Classification	Range	Year
Extreme dry	≤ -2.0	NIL
Severe dry	-1.5 to -1.99	1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987
Moderate dry	-1.0 to -1.49	1901, 1939, 1940, 1951, 1957, 1960, 1968, 1969, 1986, 1995, 2002

From the above Table 5.36 of SPEI Index it was observed that severe drought condition occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987 moderate drought condition occurred during 1901, 1939, 1940, 1951, 1957, 1960, 1968, 1969, 1986, 1995, 2002. Also, from above table it was observed total 20 years as drought years that every 4 to 5 years drought condition was occurred in Mehsana district.

1.3.8 China Z Index and Modified China Z Index

The classification of drought years obtain using China- Z-index and Modified China Z-index and the number of years in each category are shown in below Table 5.37 and 5.38 respectively.

China Z index

Table 5.37: Drought years obtained using China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1948, 1951, 1965, 1968, 1969, 1972, 1986, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	1957, 1974
Moderate dry	-1.0 to -1.49	1940, 1960, 1985

Modified China Z Index

Table 5.38: Drought years obtained using Modified China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1948, 1951, 1965, 1968, 1969, 1972, 1986, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	1957, 1974
Moderate dry	-1.0 to -1.49	1940, 1960, 1985

The (1901-2002) viz., 102 historical years assessed using China Z index and Modified China Z index from the analysis, Dry years are observed as total 23 number of years. The extreme dry years as 1901, 1904, 1911, 1915, 1918, 1923, 1939, 1948, 1951, 1965, 1968, 1969, 1972, 1986, 1987, 1991, 1995, 2002. Also, moderate drought years as 1940, 1960, 1985 in Mehsana district.

1.3.9 Z- Score Index

The meteorological drought indices of Z score index for drought detection and monitoring in Mehsana district is carried out and results is shown in below Table 5.39.

Table 5.39: Drought years obtained using Z score index

Classification	Range	Year
Extreme dry	≤ -2.0	
Severe dry	-1.5 to -1.99	1904, 1911, 1915, 1918, 1923, 1948, 1974, 1987
Moderate dry	-1.0 to -1.49	1901, 1939, 1940, 1951, 1957, 1960, 1968, 1969, 1972, 1986, 1995, 2002

From this method, Out of the 102 study period dry years are observed in 20 years. The results shows that Severe drought conditions occurred during 1904, 1911, 1915, 1918, 1923, 1948, 1974, 1987 and Moderate dry years as 1901, 1939, 1940, 1951, 1957, 1960, 1968, 1969, 1972, 1986, 1995, 2002 in Mehsana district.

5.1.4 Estimation of various Meteorological Drought Indices in Patan district

The statistical parameters of the rainfall data for Patan for 102 years (i.e. 1901 to 2002) were analyzed and are given in Table 5.40, which indicates that there are high fluctuations in occurrence of rain ranging from maximum rainfall 1085.20 mm in 1956 and minimum rainfall 144.60 mm in 1974 in the study area.

Table 5.40: Seasonal Rainfall in mm for Patan district

Rainfall parameters	June	July	August	Sept	Winter	Pre-monsoon	SW monsoon
Mean Rainfall	60.71	203.06	153.48	85.30	1.05	2.45	125.64
Standard Deviation	56.71	131.25	109.72	97.75	2.41	5.85	98.86

The monthly analysis of rainfall for Patan district is given in Table 5.41. The percentage of drought in a month for January, the percentage of drought month is equal to 9.75 %. Also, the highest average rainfall was observed as 241.94 mm in the month of July in the span of 102 years. The months of March, November and December have 85, 78, 81 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 17, 20 respectively.

Table 5.41: Drought Analysis based on Monthly Rainfall for Patan district

Month	Mean, mm	Half of Average Rainfall, mm	No. of Drought Months	Percentage of Drought Months
Jan	1.27	0.64	72	9.75
Feb	0.85	0.42	75	10.16
Mar	2.73	1.37	82	11.11
Apr	0.09	0.05	80	10.84
May	4.54	2.27	70	9.48
Jun	60.71	30.36	39	5.28
Jul	203.06	101.53	25	3.38
Aug	153.48	76.74	26	3.52
Sep	85.30	42.65	50	6.77
Oct	14.92	7.46	63	8.53
Nov	5.68	2.84	77	10.43
Dec	0.72	0.36	79	10.70
			738	100

1.4.1 Percent of Normal

Table 5.42: Drought years obtained using percentage of normal method

Classification	Range	Year
Extremely Drought	≤ 40	1904, 1911, 1923, 1968, 1974, 1987
Severe Drought	40 to 55	1901, 1915, 1925, 1936, 1939, 1957, 1960, 1969, 1972, 2002
Moderate Drought	55 to 80	1902, 1918, 1929, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995, 1999

From the above Table 5.42 of Percent of normal index it was observed that extreme drought condition occurs in the year 1904, 1911, 1923, 1968, 1974, 1987 severe drought condition occurred during 1901, 1915, 1925, 1936, 1939, 1957, 1960, 1969, 1972, 2002 moderate drought condition occurred during 1902, 1918, 1929, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995, 1999.

During the period of (1901-1930) there were total nine (09 nos) drought events, for (1930-1960) there were five (11 drought events) and (1960-1990) total 11 drought events were observed. Also, from above Table 5.42 it was observed that every 4 to 6 years drought condition was occurred in Patan district.

1.4.2 Percentage of Departure from Mean for Annual Rainfall

The classification of drought years obtain using percentage of departure from mean for annual rainfall & for seasonal rainfall is shown in below Table 5.43 and 5.44 respectively.

Table 5.43: Drought years obtained using percentage of departure method for annual rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Moderate Drought	-25 to -50	1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995
Mild Drought	0.0 to -25	1903, 1905, 1920, 1930, 1932, 1938, 1952, 1953, 1965, 1978, 1979,1980, 1982, 1983, 1985, 1989, 1992, 1993, 1999, 2000

Percentage of Departure from Mean for Seasonal Rainfall

For seasonal rainfall departure analysis monsoon season rainfall month i.e., June to September is considered.

Table 5.44: Drought years obtained using percentage of departure method for seasonal rainfall

Classification	Range	Year
Severe Drought	-50 to -75	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Moderate Drought	-25 to -50	1918, 1935, 1936, 1940, 1947, 1948, 1951, 1966, 1979, 1982, 1985, 1986, 1991, 1995, 1999
Mild Drought	0.0 to -25	1902, 1903, 1905, 1920, 1929, 1930, 1938, 1949, 1952, 1962, 1965, 1978, 1980, 1983, 1989, 1992, 1993, 2000, 2001

From the above Table 5.43 and 5.44 it was observed that severe drought condition occurred during 1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002 and moderate drought condition occurred during 1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995. From this indices it was observed that there were 30 number year's identified as dry years during 102 years. Also, 20 number year's identified as mild dry years during 102 years.

1.4.3 Rainfall Anomaly Index

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The results for RAI is presented below Table 5.45 for Patan district.

Table 5.45: Drought years obtained using rainfall anomaly index

Classification	Range	Year
Extremely dry	≤ -3.0	NIL
Very dry	-2.0 to -2.99	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Moderate dry	-1.0 to -1.99	1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1957, 1962, 1966, 1986, 1991, 1995
Slight dry	-0.50 to -0.99	1903, 1905, 1920, 1938, 1979, 1982, 1983, 1985, 1989, 1992, 1993, 1999, 2000

From this results it is observed that extreme dry condition occurs in the year of 1901, 1904, 1911, 1915, 1923, 1925, 1939, 1960, 1968, 1969, 1972, 1974, 1987, and 2002 during this year the average rainfall is about 222.58 mm. Also, very dry condition occurred during 1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1957, 1962, 1966, 1986, 1991, 1995 years and during moderate dry years 1902, 1918, 1929, 1935, 1936, 1940, 1947, 1948, 1949, 1951, 1957, 1962, 1966, 1986, 1991, 1995 the average rainfall is around 307.94 mm during study period.

1.4.4 Deciles

The deciles were estimated for the study area having 102 years (i.e., 1901 to 2002) of monthly rainfall data. Below Table 5.46 shows the detail classification of drought years under different class for Patan district.

Table 5.46: Drought years obtained using Deciles

Classification	Range	Year
Much Below Normal	1-2	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1940, 1948, 1957, 1960, 1968, 1969, 1972, 1974, 1987,

		1991, 1995, 2002
Below Normal	3-4	1902, 1903, 1905, 1920, 1929, 1935, 1938, 1947, 1949, 1951, 1962, 1966, 1979, 1983, 1985, 1986, 1989, 1992, 1999, 2000

The class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. From the analysis, the much below normal DI is concerned with value of 10 percent in 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1940, 1948, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, and 2002 respectively which is 21 number of years.

1.4.5 Standardized Precipitation Index

The results of SPI 12 were estimated for 102 years (i.e., 1901 to 2002) of rainfall data. Below Table 5.47 shows the detail classification of drought years under different class for Patan district.

Table 5.47: Drought years obtained using SPI 12 month time steps

Classification	**Range**	**Year**
Extremely Dry	-2 to less	1910 – 1911, 1973 – 1974, 1986 – 1987
Severe Dry	-1.5 to -1.99	1900 – 1901, 1903 – 1904, 1922 – 1923, 1924 – 1925, 1967 – 1968, 1968 – 1969, 1971 – 1972
Moderate Dry	-1.0 to -1.49	1914 – 1915, 1935 – 1936, 1938 – 1939, 1956 – 1957, 1959 – 1960, 1994 – 1995, 2001 – 2002

For Patan district, the SPI 12 values of extreme drought ranges from -2.38 in 1987 to -2.23 in 1904. The value of maximum severe drought occurred with the values of -1.59 in 2002 and minimum value was -1.72 in 1915. From the results it was observed that 1910 – 1911, 1973 – 1974, 1986 – 1987, 1900 – 1901, 1903 – 1904, 1922 – 1923, 1924 – 1925, 1967 – 1968, 1968 – 1969, and 1971 – 1972 were the most intense drought affected years in the Patan district.

1.4.6 Reconnaissance Drought Index

The results of RDI 12 were estimated for 102 years (i.e., 1901 to 2002) of rainfall and PET data. Below Table 5.48 shows the detail classification of drought years under different class in Patan district.

Table 5.48: Drought years obtained using RDI 12 month time steps

Classification	**Range**	**Year**
Extreme Drought	-2 or less	1911 – 1912, 1974 – 1975, 1987 – 1988
Severe Drought	-1.5 to -	1901 – 1902, 1904 – 1905, 1915 – 1916, 1923 – 1924,

	1.99	1925 – 1926, 1968 – 1969, 1969 – 1970, 1972 – 1973
Moderate Drought	-1 to -1.49	1936 – 1937, 1939 – 1940, 1957 – 1958, 1960 – 1961, 1995 – 1996, 2002 – 2003

The total number of dry years obtain for different category using Reconnaissance drought Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per RDI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 0 times and moderate drought has occurred 27 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 6 times, severe drought has occurred 4 time and moderate drought has occurred 5 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 3 times, severe drought has occurred 3 times and moderate drought has occurred 10 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 3 times in 102, severe drought has occurred 8 times in 102 years and Moderate drought has occurred 6 times in 102 years.

From the results it was observed that during1911 – 1912, 1974 – 1975, 1987 – 1988, 1901 – 1902, 1904 – 1905, 1915 – 1916, 1923 – 1924, 1925 – 1926, 1968 – 1969, 1969 – 1970, 1972 – 1973 were the most intense drought affected years. Also, moderate drought years as 1936 – 1937, 1939 – 1940, 1957 – 1958, 1960 – 1961, 1995 – 1996, 2002 – 2003 in the Patan district.

1.4.7 Standardised Precipitation Evapotranspiration Index

The classification of drought years obtain using standardized precipitation evapotranspiration index (SPEI 12) is shown in below Table 5.49.

Table 5.49: Drought years obtained using SPEI 12 month time steps

Classification	**Range**	**Year**
Extreme dry	≤ -2.0	NIL
Severe dry	-1.5 to -1.99	1901, 1904, 1911, 1923, 1968, 1969, 1972, 1974, 1987
Moderate dry	-1.0 to -1.49	1915, 1925, 1936, 1939, 1957, 1960, 1991, 1995, 2002

From the above Table 5.49 of SPEI Index shows that severe drought condition occurred during 1901, 1904, 1911, 1923, 1968, 1969, 1972, 1974, 1987 moderate drought condition occurred during 1915, 1925, 1936, 1939, 1957, 1960, 1991, 1995,

2002. Also, from above Table 5.49 it was observed total 18 years as drought years that every 3 to 4 years drought condition was occurred in Patan district.

1.4.8 China Z Index and Modified China Z Index

The classification of drought years obtain using China- Z-index and Modified China Z-index and the number of years in each category are shown in below Table 5.50 and 5.51.

Table 5.50: Drought years obtained using China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	
Moderate dry	-1.0 to -1.49	1935, 1948, 1986

Modified China Z Index

Table 5.51: Drought years obtained using Modified China Z index

Classification	Range	Year
Extreme dry	≤ -2.0	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1935, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002
Severe dry	-1.5 to -1.99	1986
Moderate dry	-1.0 to -1.49	1940, 1948, 1966

The (1901-2002) viz., 102 historical years assessed using China Z index and Modified China Z index from the analysis, Dry years are observed as total 24 number of years. The extreme dry years as 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1935, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002. Also, moderate drought years as 1940, 1948, 1966 in Patan district.

1.4.9 Z- Score Index

The meteorological drought indices of Z score index for drought detection and monitoring in Patan district is carried out and result is shown in below Table 5.52.

Table 5.52: Drought years obtained using Z score index

Classification	Range	Year
Extreme dry	≤ -2.0	NIL
Severe dry	-1.5 to -1.99	1911, 1923, 1968, 1974, 1987
Moderate dry	-1.0 to -1.49	1901, 1904, 1915, 1925, 1936, 1939, 1957, 1960,

		1969, 1972, 1991, 1995, 2002

From this method, out of the 102 study period dry years are observed in 18 years. The results shows that Severe drought conditions occurred during 1911, 1923, 1968, 1974, 1987 and Moderate dry years as 1901, 1904, 1915, 1925, 1936, 1939, 1957, 1960, 1969, 1972, 1991, 1995, 2002 in Patan district.

5.1.5 Estimation of various Meteorological Drought Indices in Sabarkantha district

The statistical parameters of the rainfall data for Sabarkantha for 102 years (i.e. from1901 to 2002) were analyzed and results given in Table 5.53, which indicates that there are high fluctuations in occurrence of rainfall ranging from maximum rainfall 1490.45 mm in 1944 and minimum rainfall 304.63 mm in 1915 in the study area.

Table 5.53: Seasonal Rainfall in mm for Sabarkantha district

Rainfall parameters	June	July	August	Sept	Winter	Pre-monsoon	SW monsoon
Mean Rainfall	98.61	320.35	231.97	124.55	1.97	4.60	193.87
Standard Deviation	76.71	147.76	137.55	123.53	1.11	5.59	102.19

The monthly analysis of rainfall for Sabarkantha district is given in Table 5.54. The months of March, November and December have 79, 77 and 80 times drought months respectively, indicating that these months must be provided with assured Irrigation. The months of July and August had minimum number of drought months i.e., 09 and 13 respectively.

Table 5.54: Drought Analysis based on Monthly Rainfall for Sabarkantha district

Month	Mean, mm	Half of Average Rainfall, mm	No. of Drought Months	Percentage of Drought Months
Jan	2.76	1.38	76	11.18
Feb	1.18	0.59	72	10.59
Mar	1.13	0.56	79	11.62
Apr	1.62	0.81	70	10.29
May	11.06	5.53	64	9.41
Jun	98.61	49.31	34	5.00
Jul	320.35	160.18	13	1.91
Aug	231.98	115.99	9	1.32
Sep	124.56	62.28	43	6.32
Oct	11.74	5.87	63	9.26

Nov	5.96	2.98	77	11.32
Dec	1.89	0.94	80	11.76
			680	**100**

1.5.1 Percent of Normal

The monthly rainfall data of hundred and two years (1901 to 2002) was analyzed using percent of normal method. Meteorological records of Sabarkantha district shows that maximum rainfall 1490.44mm is in 1944 and minimum rainfall is 304.63 mm in 1915. The average annual rainfall of Sabarkantha district is 812.83 mm.

Table 5.55: Drought years obtained using percentage of normal method

Classification	Range	Year
Extremely Drought	≤ 40	1915
Severe Drought	40 to 55	1904, 1911, 1918, 1923, 1974, 1987, 2002
Moderate Drought	55 to 80	1901, 1902, 1905, 1925, 1936, 1939, 1940, 1948, 1951, 1965, 1968, 1969, 1972, 1985, 1986, 1991, 1995

From the above Table 5.55 it was observed that extreme drought condition occurs in the year 1915, severe drought condition occurred during 1904, 1911, 1918, 1923, 1974, 1987, and 2002, moderate drought condition occurred during 1901, 1902, 1905, 1925, 1936, 1939, 1940, 1948, 1951, 1965, 1968, 1969, 1972, 1985, 1986, 1991 and 1995.

During the period of (1901-1930) there were total nine (9 nos) drought events, for (1930-1960) there were five (5 drought events) and (1960-1990) total 6 drought events were observed. Also, from above Table 5.55 it was observed that every 4 to 5 years drought condition was occurred in Sabarkantha district.

1.5.2 Percentage of Departure from Mean for Annual Rainfall

The drought year's classification is shown in below Table 5.56 for the percentage departure of annual rainfall from mean for Sabarkantha district.

Table 5.56: Drought years obtained using percentage of departure

Classification	Range	Year
Severe Drought	-50 to -75	1904, 1911, 1915, 1923, 1974, 1987, 2002
Moderate Drought	-25 to -50	1901, 1918, 1936, 1939, 1940, 1948, 1951, 1960, 1965, 1968, 1969, 1972, 1985, 1986, 1991, 1995
Mild Drought	0.0 to -25	1902, 1903, 1905, 1907, 1925, 1928, 1929, 1930, 1931,

		1932, 1935, 1938, 1949, 1952, 1957, 1958, 1962, 1964, 1966, 1971, 1978, 1979, 1982, 1988, 1989, 1992, 1993, 1999, 2000, 2001
No Drought	0.0 or Above	1906, 1908, 1909, 1910, 1912, 1913, 1914, 1916, 1917, 1919, 1920, 1921, 1922, 1924, 1926, 1927, 1933, 1934, 1937, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1950, 1953, 1954, 1955, 1956, 1959, 1961, 1963, 1967, 1970, 1973, 1975, 1976, 1977, 1980, 1981, 1983, 1984, 1990, 1994, 1996, 1997, 1998

From the analysis it was observed that years 1904, 1911, 1915, 1923, 1974, 1987, 2002 as a severe drought & 1901, 1918, 1936, 1939, 1940, 1948, 1951, 1960, 1965, 1968, 1969, 1972, 1985, 1986, 1991, 1995 as a moderate drought occurred in Sabarkantha district.

Percentage of Departure from Mean for Seasonal Rainfall

For seasonal rainfall departure analysis monsoon season rainfall month i.e., June to September is considered. The results for seasonal rainfall departure from mean analysis is shown in below Table 5.57

Table 5.57: Drought years obtained using percentage of departure

Classification	Range	Year
Severe Drought	-50 to -75	1904, 1911, 1915, 1923, 1948, 1974, 1987
Moderate Drought	-25 to -50	1901, 1918, 1936, 1939, 1940, 1951, 1965, 1968, 1969, 1972, 1979, 1985, 1986, 1991, 1995, 1999, 2002
Mild Drought	0.0 to -25	1902, 1903, 1905, 1920, 1925, 1928, 1929, 1930, 1931, 1932, 1935, 1938, 1957, 1958, 1960, 1962, 1964, 1966, 1971, 1978, 1982, 1989, 1992, 1993, 1997, 2000, 2001

From the above Table 5.57 it was observed that severe drought condition occurred during 1904, 1911, 1915, 1923, 1948, 1974, 1987 and moderate drought condition occurred during 1901, 1918, 1936, 1939, 1940, 1951, 1965, 1968, 1969, 1972, 1979, 1985, 1986, 1991, 1995, 1999, 2002. From this indices it was observed that there were 24 number year's identified as dry years during 102 years.

1.5.3 Rainfall Anomaly Index

Rainfall anomaly index is obtained during a particular year by calculating maximum rainfall and mean annual rainfall. The mean value of the 10 highest and 10 lowest rainfall values is calculated. The results for RAI is presented below Table 5.58. From this results it is observed that extreme dry condition occurs in the year of 1904, 1911,

1915, 1923, 1974, and 1987 during this year the average rainfall is about 310 mm. Also, very dry condition occurred during 1918, 1948, 1951, 1968, 1969, 1972, 2002 years and during very dry years the average rainfall is around 390 mm during study period.

Table 5.58: Drought years obtained using rainfall anomaly index

Classification	Range	Year
Extremely dry	≤ -3.0	1904, 1911, 1915, 1923, 1974, 1987
Very dry	-2.0 to -2.99	1918, 1948, 1951, 1968, 1969, 1972, 2002
Moderate dry	-1.0 to -1.99	1901, 1902, 1905, 1925, 1936, 1939, 1940, 1957, 1960, 1962, 1964, 1965, 1966, 1979, 1985, 1986, 1991, 1992, 1995, 1999, 2000

1.5.4 Deciles

The deciles were estimated for the study area having 102 years of monthly rainfall data. It is seen that all the years are coming under the class of deciles 1-2 (20% lower), which is considered much below the normal and are drought affected years. Below Table 5.59 shows the detail classification of drought years under different class in Sabarkantha district.

From the analysis, the much below normal DI is concerned with value of 10 percent in 1901 – 1902, 1904 – 1905, 1911 – 1912, 1915 – 1916, 1918 – 1919, 1923 – 1924, 1936 – 1937, 1939 – 1940, 1940 – 1941, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1969 – 1970, 1972 – 1973, 1974 – 1975, 1985 – 1986, 1986 – 1987, 1987 – 1988, 1991 – 1992, 1995 – 1996, 2002 – 2003 years particular.

Table 5.59: Drought years obtained using Deciles

Classification	Range	Year
Much Below Normal	1-2	1901 – 1902, 1904 – 1905, 1911 – 1912, 1915 – 1916, 1918 – 1919, 1923 – 1924, 1936 – 1937, 1939 – 1940, 1940 – 1941, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1969 – 1970, 1972 – 1973, 1974 – 1975, 1985 – 1986, 1986 – 1987, 1987 – 1988, 1991 – 1992, 1995 – 1996, 2002 – 2003
Below Normal	3-4	1902 – 1903, 1905 – 1906, 1925 – 1926, 1928 – 1929, 1932 – 1933, 1957 – 1958, 1960 – 1961, 1962 – 1963, 1964 – 1965, 1965 – 1966, 1966 – 1967, 1971 – 1972, 1978 – 1979, 1979 – 1980, 1982 – 1983, 1989 – 1990, 1992 – 1993, 1999 – 2000, 2000 – 2001, 2001 – 2002

1.5.5 Standardized Precipitation Index

The SPI has been applied in the study area to quantify drought assessment for the period of 1901 to 2002. The estimated value of SPI values for different time scales 3, 6, 9 and 12 months calculated using DrinC software. Below Table 5.60 shows the results of drought years obtained using SPI 12 month time steps.

Table 5.60: Drought years obtained using SPI 12 month time steps

Classification	Range	Year
Extremely Dry	-2 to less	1911 – 1912, 1915 – 1916, 1923 – 1924, 1974 – 1975, 1987 – 1988
Severe Dry	-1.5 to -1.99	1904 – 1905, 1969 – 1970, 2002 – 2003
Moderate Dry	-1.0 to -1.49	1918 – 1919, 1936 – 1937, 1939 – 1940, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1972 – 1973, 1985 – 1986, 1986 – 1987

Also, from this Table 5.60 it is observed that Extreme dry condition occurs 5 times viz., 1911 – 1912, 1915 – 1916, 1923 – 1924, 1974 – 1975, 1987 – 1988, severe dry, moderate dry, near normal, moderate wet, very wet and extremely wet situations occurs 3, 9, 67, 12, 5 and 1 time respectively in present study area.

The total number of dry years obtain for different category using Standardized Precipitation Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per SPI 3, it is observed that extreme drought has occurred 4 times, severe drought has occurred 9 times and moderate drought has occurred 9 times in 102 years.
- As per SPI 6, it is observed that extreme drought has occurred 7 times, severe drought has occurred 1 time and moderate drought has occurred 6 times in 102 years.
- As per SPI 9, it is observed that extreme drought has occurred 3 times, severe drought has occurred 2 times and moderate drought has occurred 12 times in 102 years.
- As per SPI 12, it is observed that extreme drought has occurred 6 times in 102, severe drought has occurred 3 times in 102 years and moderate drought has occurred 8 times in 102 years.

For Sabarkantha district, the SPI12 values of extreme drought ranges from −2.41 in 1915 to −2.08 in 1911. The value of maximum severe drought occurred with the values of −1.98 in 1904 and minimum value was −1.52 in 1969. The value of moderate drought ranges from −1.49 in 1951 to −1.03 in 1986. From the results it

was observed that 1904, 1911, 1915, 1923, 1969, 1974, 1987, and 2002 were the most intense drought affected years in the Sabarkantha district

From the results it was observed that number of identified drought years increased with the increase of time step for SPI i.e., for 1-month time step and increased considerably with the increase of time step.

1.5.6 Reconnaissance Drought Index

The computation for RDI was carried out for drought assessment in Sabarkantha district using Drin C Software. Its range is similar to that of SPI. Its value -1 or less indicates dry condition.-1 to -1.49 moderately dry,-1.5 to -1.99 severely dry,-2 or less extremely dry. Below Table 5.61 shows the drought affected years using RDI 12.

Table 5.61: Drought years obtained using RDI 12 month time steps

Classification	Range	Year
Extreme Drought	-2 or less	1904 – 1905, 1911 – 1912, 1915 – 1916, 1923 – 1924, 1974 – 1975, 1987 – 1988
Severe Drought	-1.5 to -1.99	1951 – 1952, 1969 – 1970, 2002 – 2003
Moderate Drought	-1 to -1.49	1918 – 1919, 1936 – 1937, 1939 – 1940, 1948 – 1949, 1968 – 1969, 1972 – 1973, 1985 – 1986,1986 – 1987
Normal Conditions-Dry	0 to -0.99	1903 – 1904, 1906 – 1907, 1907 – 1908, 1909 – 1910, 1910 – 1911, 1912 – 1913, 1913 – 1914, 1914 – 1915, 1916 – 1917, 1920 – 1921, 1921 – 1922, 1922 – 1923, 1924 – 1925, 1929 – 1930, 1930 – 1931, 1931 – 1932, 1935 – 1936, 1941 – 1942, 1942 – 1943, 1943 – 1944, 1946 – 1947, 1947 – 1948, 1949 – 1950, 1950 – 1951, 1952 – 1953, 1953 – 1954, 1955 – 1956, 1958 – 1959, 1961 – 1962, 1967 – 1968, 1970 – 1971, 1976 – 1977, 1980 – 1981, 1981 – 1982, 1983 – 1984, 1984 – 1985, 1988 – 1989, 1990 – 1991, 1996 – 1997, 1997 – 1998, 1998 – 1999

From Table 5.61 it is observed that extreme dry condition occurs 6 times viz., 1904 – 1905, 1911 – 1912, 1915 – 1916, 1923 – 1924, 1974 – 1975, 1987 – 1988, severe dry, moderate dry, near normal wet, near normal-dry, moderate wet, severe wet situations occurs 3, 8, 26, 41, 14 and 4 time respectively in present study area.

The total number of dry years obtain for different category using Reconnaissance drought index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per RDI 3, it is observed that extreme drought has occurred 4 times, severe drought has occurred 9 times and moderate drought has occurred 9 times in 102 years.
- As per RDI 6, it is observed that extreme drought has occurred 7 times, severe drought has occurred 1 time and moderate drought has occurred 6 times in 102 years.
- As per RDI 9, it is observed that extreme drought has occurred 3 times, severe drought has occurred 2 times and moderate drought has occurred 12 times in 102 years.
- As per RDI 12, it is observed that extreme drought has occurred 6 times in 102, severe drought has occurred 3 times in 102 years and moderate drought has occurred 8 times in 102 years.

For Sabarkantha district, the RDI 12 values of extreme drought ranges from −2.65 in 1915 to −2.10 in 1904. The value of maximum severe drought occurred with the values of −1.83 in 2002 and minimum value was −1.54 in 1951. The value of moderate drought ranges from −1.47 in 1948 to −1.01 in 1986. From the results it was observed that 1904 – 1905, 1911 – 1912, 1915 – 1916, 1918 – 1919, 1923 – 1924, 1936 – 1937, 1939 – 1940, 1948 – 1949, 1951 – 1952, 1968 – 1969, 1969 – 1970, 1972 – 1973, 1974 – 1975, 1985 – 1986, 1986 – 1987, 1987 – 1988, and 2002 – 2003 were the most intense drought affected years in the Sabarkantha district.

1.5.7 Standardised Precipitation Evapotranspiration Index

Also, SPEI time series calculations are developed using SPEI Package (Beguería and Vicente-Serrano 2017) in R environment. The monthly PET is estimated using Thornthwaite method. Its range is similar to that of SPI and RDI. Its value -1 or less indicates dry condition.-1 to -1.49 moderately dry,-1.5 to -1.99 severely dry,-2 or less extremely dry. The SPEI values for Sabarkantha districts is computed for different time scale. Below Table 5.62 shows the drought affected years for SPEI 12.

Table 5.62: Drought years obtained using SPEI 12 month time steps

Condition	Range	Years
Extreme Drought	≤ -2.0	NIL
Severe Drought	-1.5 to -1.99	1904, 1911, 1915, 1923, 1974, 1987, 2002
Moderate Drought	-1.00 to -1.49	1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995

Also, from Table 5.62 it is observed that severe dry condition occurs 7 times viz., 1904, 1911, 1915, 1923, 1974, 1987, 2002. Moderate Dry situations occurs time 12

viz, 1918, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1985, 1986, 1995 respectively in present study area.

The total number of dry years obtain for different category using Standardized Precipitation Evapotranspiration Index for different time scales viz., 3, 6, 9 and 12 months is shown below.

- As per SPEI 3, it is observed that extreme drought has occurred 0 times, severe drought has occurred 0 times and moderate drought has occurred 18 times in 102 years.
- As per SPEI 6, it is observed that extreme drought has occurred 0 times, severe drought has occurred 4 time and moderate drought has occurred 16 times in 102 years.
- As per SPEI 9, it is observed that extreme drought has occurred 1 times, severe drought has occurred 7 times and moderate drought has occurred 11 times in 102 years.
- As per SPEI 12, it is observed that extreme drought has occurred 0 times in 102, severe drought has occurred 7 times in 102 years and moderate drought has occurred 12 times in 102 years.

For Sabarkantha district, the SPEI 12 values of maximum severe drought occurred with the values of −1.94 in 1915 and minimum value was −1.72 in 1904. The value of moderate drought ranges from −1.59 in 2002 to −1.01 in 1995. From the results it was observed that 1904, 1911, 1915, 1918, 1923, 1936, 1939, 1940, 1948, 1951, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995 and 2002 were the most intense drought affected years in the Sabarkantha district.

1.5.8 China Z Index and Modified China Z Index

Below Table 5.63 and 5.64 shows drought years obtained using China Z Index and Modified China Z Index.

China Z index

Table 5.63: Drought years obtained using China Z Index

Classification	Range	Year
Extreme Drought	≤ -2.0	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002
Severe Drought	-1.5 to -1.99	1901, 1939
Moderate Drought	-1.0 to -1.49	1936, 1940, 1986

Modified China Z Index

Table 5.64: Drought years obtained using Modified China Z index

Classification	Range	Year
Extreme Drought	≤ -2.0	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002
Severe Drought	-1.5 to -1.99	1901, 1939
Moderate Drought	-1.0 to -1.49	1936, 1940, 1986

The following conclusions can be drawn from this indices. There is no much deviation in the number of instances in each category between China- Z-index and Modified China Z-index. The extreme drought conditions occurs 17 times viz., 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1965, 1968, 1969, 1972, 1974, 1985, 1987, 1991, 1995, 2002, severe drought occurs for 2 years viz., 1901, 1939 and moderate drought for 3 years viz.,1936, 1940, 1986.

From this method, Out of the 102 historical years, normal moisture level has occurred in 62 to 65 years. Dry and wet periods are observed in 22 years and19 years respectively. Also, it was noted that 15 years have values that are higher than averages of the annual precipitations (7 are much above normal). On the other hand, 16 years are below these averages (8 of which are classified much below normal). All the drought indices, accounts a total severe drought frequency percentage 11.36% and 18.68%.

1.5.9 Z- Score Index

The statistical Z-Score, or Standard Score, can be used as another drought index. Drought years obtained using Z score index is shown below in Table 5.65

Table 5.65: Drought years obtained using Z score index

Classification	Range	Year
Extreme dry	≤ -2.0	NIL
Severe dry	-1.5 to -1.99	1904, 1911, 1915, 1923, 1974, 1987, 2002
Moderate dry	-1.0 to -1.49	1918, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1985, 1986

The study examined the performances of drought indices of Z score index for drought detection and monitoring in Sabarkantha district. The following conclusions can be drawn from this indices. Severe drought conditions occurred for 1904, 1911,

1915, 1923, 1974, 1987, 2002 and Moderate dry years as 1918, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1985, 1986 in Sabarkantha district. From this method, Out of the 102 historical years, normal moisture level has occurred in 66 years. Dry and wet periods are observed in 17 to 18 years respectively.

Both Z-Score and SPI can be used in drought analysis, the Z-Score is a general statistical measure that can be applied to various data types, whereas SPI is specifically designed for characterizing drought conditions based on precipitation data. SPI is widely used in meteorology and hydrology for drought monitoring and early warning systems.

5.1.6 Comparative Analysis of Meteorological drought indices over the study area

Various meteorological drought indices used to calculate number of drought years in the present study region using percent of normal (PN), percentage of departure from mean (PD), Deciles (DI), Rainfall anomaly index (RAI), standardized precipitation index (SPI), Reconnaissance drought index (RDI), China-Z index (CZI), modified CZI (MCZI) and Z-Score. The results of all above indices was observed and analysed for assessment of droughts in North Gujarat districts.

The monthly rainfall data for 102 years (i.e. 1901 to 2002) shows that the maximum rainfall is 1072.68 mm in 1917 and minimum rainfall is 115.23 mm in 1974 in Banaskantha district. Also, the maximum rainfall is 1261.90 mm in 1959 and minimum rainfall is 237.90 mm in 1911 in Gandhinagar district. Similarly there are high fluctuations of rainfall ranging from maximum rainfall is 1195.33 mm in 1959 and minimum rainfall is 214.01 mm in 1987 for the Mehsana district. Rainfall data of Patan district shows that maximum rainfall is 1085.20 mm in 1956 and minimum rainfall is 144.60 mm in 1974 was observed. For Sabarkantha district rainfall data shows that the highest average rainfall was observed as 320.35 mm in the month of July and lowest average rainfall was observed in the month of March as 1.1261 mm in the span of 102 years in Sabarkantha district.

The comparative study of monthly rainfall analysis for drought the result shows that for the months of March, November and December have 81, 81, 79 times respectively, indicating that these months must be provided with assured Irrigation. Similarly, the months of July and August had minimum number of drought months i.e., 17, 20 times respectively. Also, the percentage of drought in the month of October to march is 9% to 12% for all districts.

The comparative study of number of drought years obtained using various drought indices clearly revealed that all the methods yielded similar results, although at places marginal differences were observed in the number of drought years.

- The results of meteorological drought indices for **Banaskantha** district shows that extreme drought condition occurred during 1901, 1904, 1911, 1915, 1923, 1974, 1987, severe drought condition occurred during 1936, 1939, 1948, 1951, 1960, 1968, 1969, 2002, moderate drought condition occurred during 1902, 1905, 1918, 1920, 1925, 1930, 1932, 1935, 1940, 1949, 1957, 1962, 1972, 1985, 1986, 1991, 1995, 1999 years.

- **Gandhinagar** district shows that extreme drought condition occurs in the year 1911, 1918, 1987 severe drought condition occurred during 1904, 1915, 1923, 1948, 1951, 1968, 1972 moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002 years

- **Mehsana** district shows that extreme drought condition occurs in the year 1911, 1918, 1987 severe drought condition occurred during 1904, 1915, 1923, 1948, 1951, 1968, 1972 moderate drought condition occurred during 1901, 1925, 1936, 1939, 1940, 1947, 1957, 1960, 1965, 1969, 1971, 1974, 1985, 1986, 1991, 1995, 2002 years

- **Patan** district rainfall data analysed and it was observed that extreme drought condition occurs in the year 1904, 1911, 1923, 1968, 1974, 1987 severe drought condition occurred during 1901, 1915, 1925, 1936, 1939, 1957, 1960, 1969, 1972, 2002 moderate drought condition occurred during 1902, 1918, 1929, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1962, 1966, 1986, 1991, 1995, 1999. From this results it is observed that extreme dry condition the average rainfall is about 222.58 mm. Also, during moderate dry years the average rainfall is around 307.94 mm during study period.

- **Sabarkantha** district results shows that severe drought condition occurred during 1904, 1911, 1915, 1923, 1948, 1974, 1987 and moderate drought condition occurred during 1901, 1918, 1936, 1939, 1940, 1951, 1965, 1968, 1969, 1972, 1979, 1985, 1986, 1991, 1995, 1999, 2002. It was also observed that there were 24 number of year's identified as dry years during 102 years.

The Near normal conditions of drought where the amount of rainfall is below average values the identified average years for North Gujarat districts are as 1903, 1907, 1909, 1910, 1912, 1914, 1916, 1920, 1922, 1924, 1928, 1929, 1930, 1931, 1932, 1935, 1938, 1943, 1946, 1947, 1949, 1952, 1953, 1958, 1961, 1967, 1971, 1976, 1978, 1980, 1981, 1982, 1983, 1984, 1988, 1989, 1993, 1997, 2001, which comes out to be 49 years out of the total years considered.

A disadvantage of using the percent of normal index is that the mean, or average precipitation is often not the same as the median precipitation. Therefore SPI, RDI and SPEI indices should be used for drought monitoring.

Dividing the total no of years into 3 periods i.e., (1901-1930) as period 1, (1931-1960) as period 2, (1961-2002) as period 3, it can be noted that the frequency of drought during (1901-1930) there were around 8-10 drought years, during (1930-1960) total 6-9 drought years, during the period of (1960-1990) total 8-12 drought events. The severity of drought was 26% in North Gujarat district which is very high. Also, from meteorological drought indices, it is observed that every 4 to 6 years drought condition was occurred in North Gujarat district.

5.2 ESTIMATION OF DROUGHT BY DIFFERENT CLIMATIC INDEX OVER THE STUDY AREA

Drought year has been analyzed by three different climatic indexes viz., Mortone aridity index, Seleaninoy hydrothermic index and Donciu climatic index for the period of 1901 to 2002 in North Gujarat districts. The analysis was performed in yearly basis of rainfall data.

The correlation established between the assured rainfall (A %) for years and climatic indexes provide the polynomial expression, statistically very significant. It has quantified very significant correlation between annual rainfall assurance and climatic indices using logarithmic expression which is shown in Table 5.66

Table 5.66: Correlation between Annual Rainfall and the Climatic Indexes

Climatic index	**Symbol**	**Mathematical function**
Mortone aridity index	IdM	IdM = – 7.3566 lnA + 58.037
Seleaninov hydrotheremic index	His	IhS = – 0.4006 lnA + 3.1001
Donciu climate index	IcD	IcD = – 24.269 lnA + 191.17

Also, Precipitation Concentration Index is a metric used to assess the distribution of precipitation over time (1901 to 2002) in North Gujarat district for different seasons. It provides insights into whether precipitation is evenly distributed throughout the year or if it is concentrated in certain periods. This index helps in understanding the variability of precipitation and its potential impact on ecosystems, agriculture, and water resources.

A high PCI value indicates a more concentrated pattern of precipitation, with a few months receiving a significant amount of rainfall, while a low PCI suggests a more evenly distributed pattern.

5.2.1 Estimation of drought by climatic indices in Banaskantha district

Different climatic indices viz., Mortone aridity Index, Seleaninov hydrothermic index, and Donciu climate index used in present study for yearly drought assessment. Though the study gives an identification about the drought condition of the study area to face the drought adaptability and remedial measure for the alleviation of the drought for the reason concerned. With the help of annual rainfall assurance yearly drought analysis has been performed by using the climatic indexes.

The results of various climatic indices are shown below in Tables 5.67, 5.68 and 5.69 for Banaskantha district.

Table 5.67: Drought years obtain using Mortone Aridity Index for Banaskantha district

Classification	Range	Year
Excessive Droughty	<23	1904, 1974
Very Droughty	23-24	1901, 1911, 1915, 1923, 1939, 1969, 1987, 2002
Droughty	24-25	1925, 1936, 1948, 1951, 1960, 1968, 1972
Medium	25-29	1902, 1903, 1905, 1917, 1918, 1920, 1928, 1929, 1930, 1932, 1935, 1938, 1940, 1942, 1947, 1949, 1952, 1953, 1955, 1957, 1962, 1965, 1966, 1971, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000
Rainy	29-33	1906, 1907, 1909, 1910, 1912, 1914, 1922, 1931, 1941, 1943, 1958, 1963, 1964, 1970, 1976, 1978, 1981, 1984, 1988, 1994, 1997, 2001
Very Rainy	33-40	1913, 1916, 1924, 1926, 1927, 1934, 1944, 1946, 1950, 1954, 1956, 1959, 1967, 1975, 1977, 1990, 1996
Excessive Rainy	>40	1908, 1919, 1921, 1933, 1937, 1945, 1961, 1973, 1998

Table 5.68: Drought years obtain using Seleaninov Hydrotheremic Index for Banaskantha district

Classification	Range	Year
Excessive Droughty	< 1.0	NIL
Very Droughty	1.0 – 1.1	1904, 1974, 1987
Droughty	1.1 – 1.3	1901, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 2002
Medium	1.3 – 1.4	1902, 1905, 1918, 1930, 1932, 1940, 1949, 1957, 1962, 1965, 1966, 1979, 1985, 1986, 1991, 1992, 1995, 1999,

		2000
Rainy	1.4 – 1.6	1903, 1906, 1912, 1917, 1920, 1928, 1929, 1931, 1935, 1938, 1942, 1947, 1952, 1953, 1955, 1958, 1963, 1964, 1970, 1971, 1980, 1982, 1983, 1984, 1989, 1993, 2001
Very Rainy	1.6 – 2.0	1907, 1909, 1910, 1913, 1914, 1916, 1922, 1924, 1926, 1927, 1941, 1943, 1944, 1946, 1954, 1956, 1959, 1967, 1975, 1976, 1977, 1978, 1981, 1988, 1990, 1994, 1996, 1997
Excessive Rainy	>2.0	1908, 1919, 1921, 1933, 1934, 1937, 1945, 1950, 1961, 1973, 1998

Table 5.69: Drought years obtain using Donciu Climate Index for Banaskantha district

Classification	**Range**	**Year**
Excessive Droughty	<65	NIL
Very Droughty	65-70	NIL
Droughty	70-80	1901, 1904, 1911, 1915, 1923, 1939, 1948, 1960, 1968, 1969, 1974, 1987, 2002
Medium	80-95	1902, 1903, 1905, 1917, 1918, 1920, 1925, 1928, 1929, 1930, 1932, 1935, 1936, 1938, 1940, 1942, 1947, 1949, 1951, 1952, 1953, 1957, 1962, 1965, 1966, 1971, 1972, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000
Rainy	95-100	1906, 1912, 1931, 1955, 1958, 1963, 1964, 1970, 1984, 2001
Very Rainy	100-110	1907, 1909, 1910, 1914, 1922, 1926, 1941, 1943, 1956, 1959, 1976, 1978, 1981, 1988, 1994, 1997
Excessive Rainy	>110	1908, 1913, 1916, 1919, 1921, 1924, 1927, 1933, 1934, 1937, 1944, 1945, 1946, 1950, 1954, 1961, 1967, 1973, 1975, 1977, 1990, 1996, 1998

- Mortone Aridity Index shows excessive droughty conditions for 2 times, very droughty for 8 times and droughty for 7 times, medium dry conditions for 37 times and excessive rainy years for 9 times in Banaskantha district.

- Seleaninov Hydrotheremic Index shows very droughty conditions for 3 times, droughty conditions for 14 times, medium dry conditions for 19 times and excessive rainy years for 11 times in Banaskantha district.

- Donciu Climate Index shows droughty conditions for 13 times, medium dry conditions for 40 times and excessive rainy years for 23 times in Banaskantha district.

The comparative analysis shows that droughty condition occurred 7 times viz., 1925, 1936, 1948, 1951, 1960, 1968, and 1972. Very droughty condition occurred 8 times viz., 1901, 1911, 1915, 1923, 1939, 1969, 1987, and 2002. Also, excessive droughty occurred 2 times viz., 1904, 1974. The results also shows that 15.3% years falls under dry category and medium dry condition shows 31.3% years and excessive rainy condition shows 14.3% in Banaskantha district.

Below Figure 5.11 shows the trend of these three indices with annual rainfall, wherein the data ranging from 0 to 1200 represents annual rainfall and the data ranging from 0 to 200 represents various climatic indices.

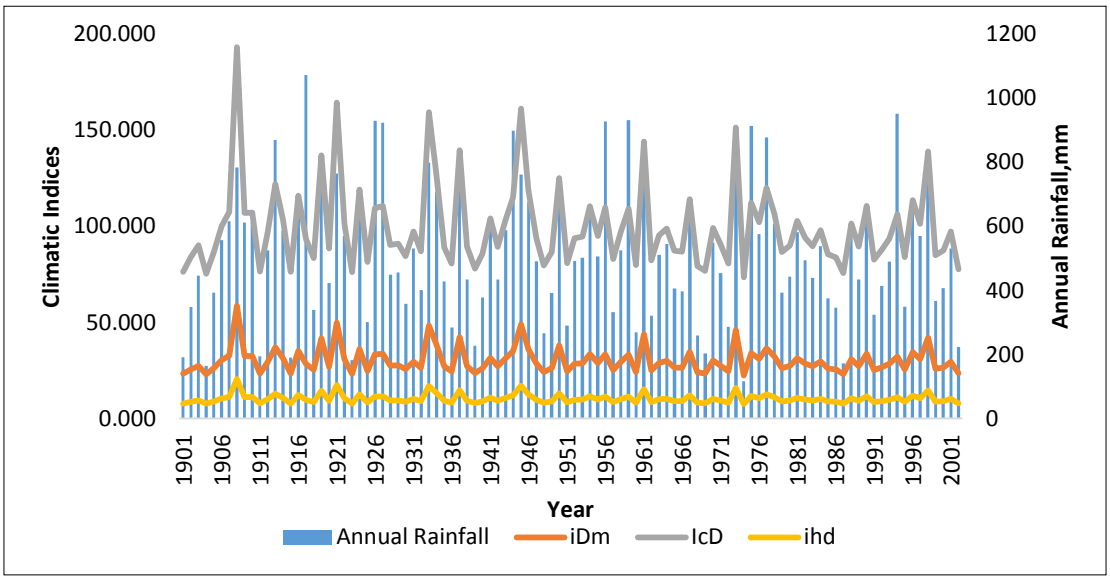


Figure 5.11: Climatic Index and Annual Rainfall for Banaskantha district

Results of Precipitation Concentration Index for Banaskantha district

The results of Precipitation Concentration Index for annual seasons and for various seasons viz., winter (D-J-F), spring (M-A-M), summer (J-J-A), autumn (S-O-N), and on supra-seasonal scales for wet (October to March) and dry (April to September) for Banaskantha district is shown in below Figure 5.12.

From the Figure 5.12 it was observed that summer season PCI index shows 23.5% uniform, 56.9% moderate uniform, 17.6% as irregular precipitation and 2% as strong irregular precipitation distribution over 1901 to 2002. Also, during April to September months there is 47.1% irregular precipitation trend was observed.

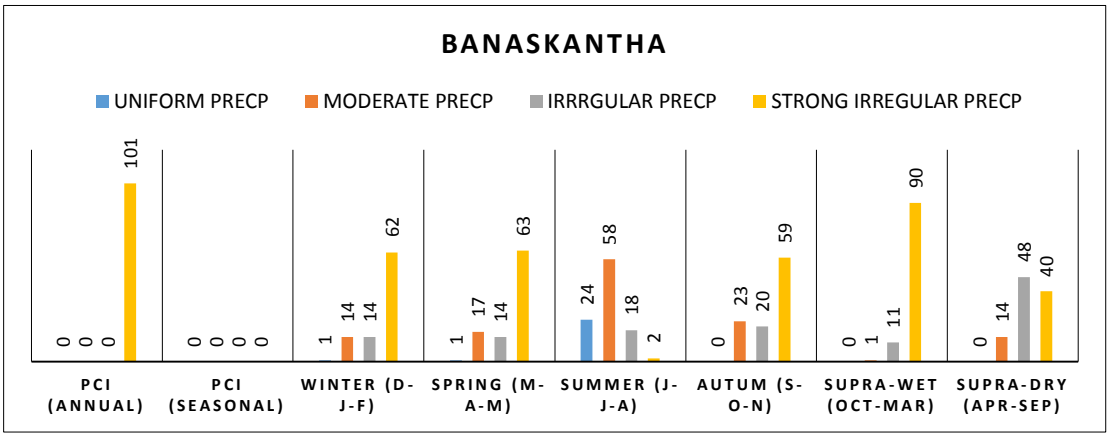


Figure 5.12: Precipitation Concentration Index for various seasons for Banaskantha district

Results of Modified Fournier Index for Banaskantha district

Below Table 5.70 and Figure 5.13 shows total number of years under different classification as per MFI index viz., very low(0-60), low(60-90), moderate(90-120), severe(120-160) and very severe (>160). If the value of MFI is more than 160 which means there is high rainfall erosivity in that year and if the value is less than 60 which means very low rainfall erosivity and resulted as low rainfall and drought conditions.

The results shows that total 03 years having very low and 08 years having low rainfall erosivity and 13 years as moderate rainfall erosivity during (1901 to 2002).The corresponding years for low erosivity as 1901, 1904, 1911, 1915,1923, 1939, 1962, 1969, 1974, 1987 and 2002. The average rainfall during these years as 207.01 mm whereas annual average rainfall for entire set of data considered the district is around 520.10 mm.

Table 5.70: Modified Fournier Index Classification for Banaskantha district

Classification	No. of years	Years
Very Low	3	1915,1974, 2002
Low	8	1901, 1904, 1911, 1923, 1939, 1962, 1969, 1987
Moderate	13	1936, 1940, 1942, 1948, 1951, 1957, 1960, 1972, 1979, 1983, 1985, 1986, 1999
Severe	22	
Very severe	56	

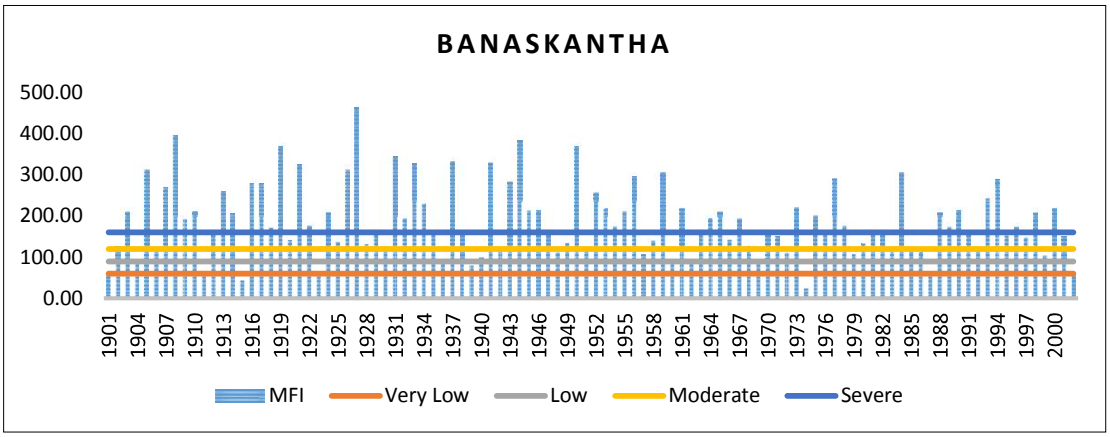


Figure 5.13: Modified Fournier Index for Banaskantha district

5.2.2 Estimation of drought by climatic indices in Gandhinagar district

The results of various climatic indices are shown in below Tables5.71, 5.72 and 5.73 for Gandhinagar district.

Table 5.71: Drought years obtain using Mortone Aridity Index for Gandhinagar district

Classification	Range	Year
Very Droughty	23-24	1904, 1911, 1918, 1923, 1968, 1972, 1987
Droughty	24-25	1915, 1948 1951, 1960, 1965, 1974, 1995, 2002
Medium	25-29	1901, 1902, 1903, 1905, 1916, 1920, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1952, 1957, 1964, 1966, 1969, 1971, 1978, 1979, 1980, 1982, 1984, 1985, 1986, 1989, 1991, 1992, 1993, 1997, 1999, 2000, 2001

Table 5.72: Drought years obtain using Seleaninov Hydrotheremic Index for Gandhinagar district

Classification	Range	Year
Droughty	1.1-1.3	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987
Medium	1.3-1.4	1901, 1939, 1940, 1951, 1957, 1960, 1965, 1974, 1985, 1986, 1995, 2002,

Table 5.73: Drought years obtain using Donciu Climate Index for Gandhinagar district

Classification	Range	Year
Droughty	70-80	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1968, 1972, 1987, 2002
Medium	80-95	1901, 1902, 1903, 1905, 1916, 1920, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1952, 1957,

		1960, 1964, 1965, 1966, 1969, 1971, 1974, 1978, 1979, 1980, 1982, 1984, 1985, 1986, 1989, 1991, 1992, 1993, 1995 1997, 1999, 2000, 2001

- Mortone Aridity Index shows very droughty condition for 7 times, droughty condition for 8 times, medium dry conditions for 37 times and excessive rainy years for 10 times in Gandhinagar district.

- Seleaninov Hydrotheremic Index shows droughty conditions for 9 times, medium dry conditions for 12 times and excessive rainy years for 13 times in Gandhinagar district.

- Donciu Climate Index shows droughty conditions for 11 times, medium dry conditions for 41 times and excessive rainy years for 27 times in Gandhinagar district.

From the analysis it is clearly revealed that all the methods yielded similar results, although at marginal differences were observed in the number of droughty years. Droughty condition occurred 7 times viz. 1904, 1911, 1918, 1923, 1968, 1972, 1987. Very droughty condition occurred 8 times viz., 1915, 1948 1951, 1960, 1965, 1974, 1995, and 2002. The results also shows that 11.43% years falls under dry category and medium dry condition shows 29.40% years and excessive rainy condition shows 16.3% in Gandhinagar district.

Below Figure 5.14 shows the trend of these three indices with annual rainfall wherein the data ranging from 0 to 1400 represents annual rainfall and the data ranging from 0 to 200 represents various climatic indices.

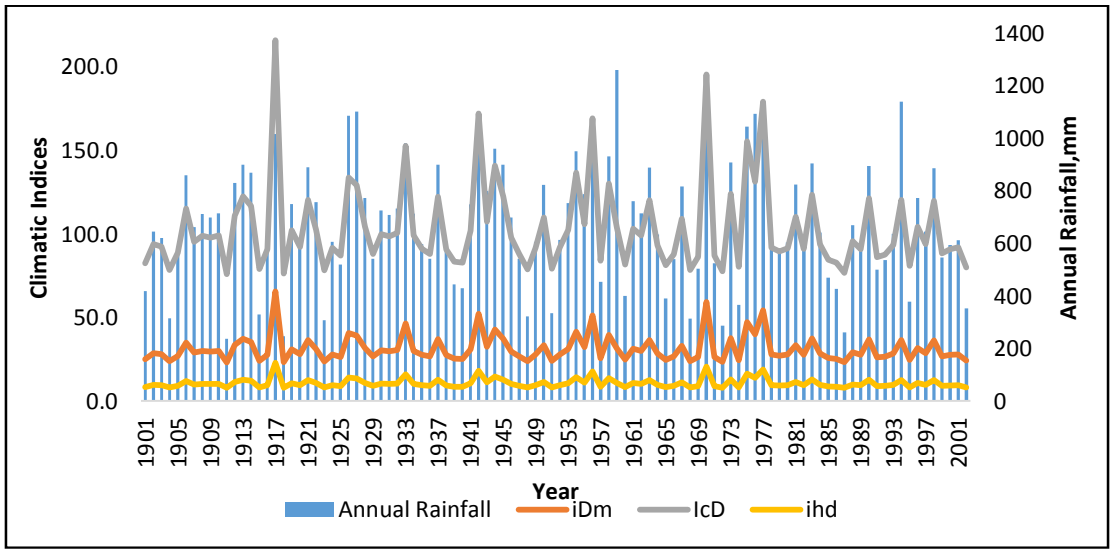


Figure 5.14: Climatic Index and Annual Rainfall for Gandhinagar district

Results of Precipitation Concentration Index for Gandhinagar district

The results of Precipitation Concentration Index for annual season and for various seasons for Gandhinagar district is shown in below Figure 5.15.

For summer season PCI index shows that 20.59% uniform, 70.59% moderate uniform, 6.86% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 54.90% irregular precipitation trend was observed.

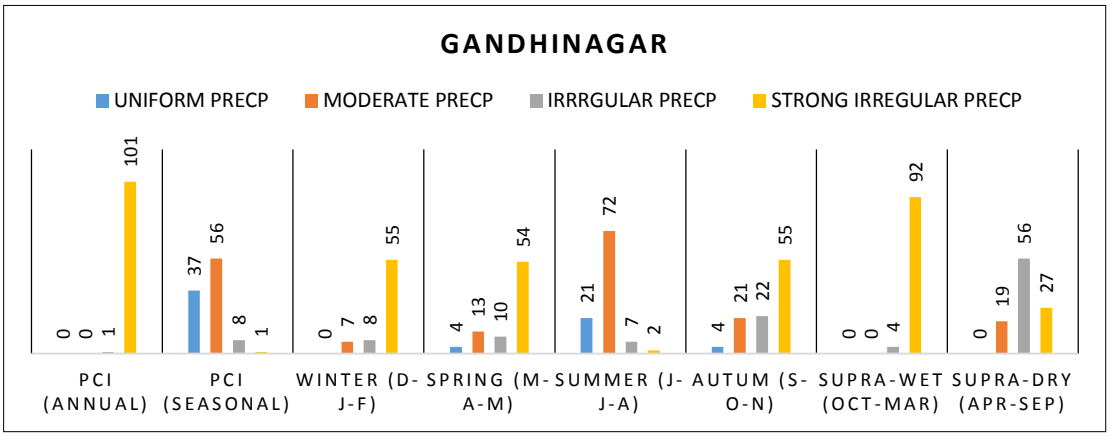


Figure 5.15: Precipitation Concentration Index for various seasons for Gandhinagar district

Results of Modified Fournier Index for Gandhinagar district

Below Table 5.74 and Figure 5.16 shows various number years under different classification as per MFI index viz., very low(0-60), low(60-90), moderate(90-120), severe(120-160) and very severe (>160). The results shows that total 5 years having very low and low rainfall erosivity and 07 years as moderate rainfall erosivity during (1901-2002) the corresponding years for low erosivity as 1911, 1915, 1918, 1948, 1974. The average rainfall during these years as 300.70 mm whereas annual average rainfall for entire set of data considered is around 677.50 mm.

Table 5.74: Modified Fournier Index Classification for Gandhinagar district

Classification	No. of years	Years
Very Low	0	
Low	5	1911, 1915, 1918, 1948, 1974
Moderate	7	1904, 1923, 1940, 1960, 1972, 1987, 2002
Severe	10	1901, 1936, 1939, 1951, 1957, 1968, 1969, 1971, 1982, 1995
Very severe	80	

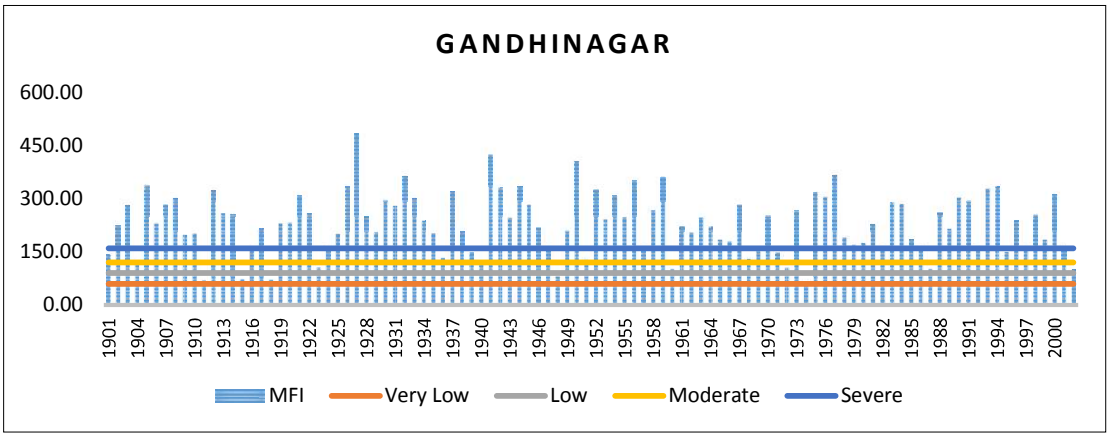


Figure 5.16: Modified Fournier Index for Gandhinagar district

5.2.3 Estimation of drought by climatic indices in Mehsana district

The results of various climatic indices are shown below in Tables 5.75, 5.76 and 5.77 for Mehsana district.

Table 5.75: Drought years obtain using Mortone Aridity Index for Mehsana district

Classification	Range	Year
Very Droughty	23-24	1904, 1911, 1915, 1918, 1923, 1948, 1974, 1987
Droughty	24-25	1901, 1951, 1968, 1969, 1972, 1995, 2002
Medium	25-29	1902, 1903, 1905, 1920, 1925, 1929, 1930, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1952, 1957, 1960, 1962, 1964, 1965, 1966, 1971, 1978, 1979, 1980, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1999, 2000, 2001

Table 5.76: Drought years obtain using Seleaninov Hydrotheremic Index for Mehsana district

Classification	Range	Year
Droughty	1.1-1.3	1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987
Medium	1.3-1.4	1901, 1936, 1939, 1940, 1951, 1957, 1960, 1965, 1968, 1969, 1985, 1986, 1991, 1995, 2002

Table 5.77: Drought years obtain using Donciu Climate Index for Mehsana district

Classification	Range	Year
Droughty	70-80	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1974, 1987, 2002
Medium	80-95	1901, 1902, 1903, 1905, 1920, 1925, 1929, 1930, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1951, 1952, 1957, 1960, 1962, 1964, 1965, 1966, 1969, 1971, 1978, 1979, 1980, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000,2001

- Mortone Aridity Index shows drought conditions for 15 times, medium dry conditions for 35 times and excessive rainy years for 9 times in Mehsana district.

- Seleaninov Hydrotheremic Index shows drought conditions for 9 times, medium dry conditions for 15 times and excessive rainy years for 11 times in Mehsana district.

- Donciu Climate Index shows drought conditions for 11 times, medium dry conditions for 39 times and excessive rainy years for 26 times in Mehsana district.

Comparative study of number of drought years obtained through various indices is shows that droughty condition occurred 10 times viz. 1904, 1911, 1915, 1918, 1923, 1948, 1974, and 1987. Very droughty condition occurred 8 times viz. 1901, 1951, 1968, 1969, 1972, 1995, 2002. The results also shows that 11.40% years falls under dry category and medium dry condition shows 29.06% years and excessive rainy condition shows 14.96% in Mehsana district.

Below Figure 5.17 shows the trend of these three indices with annual rainfall, wherein the data ranging from 0 to 1200 represents annual rainfall and the data ranging from 0 to 160 represents various climatic indices.

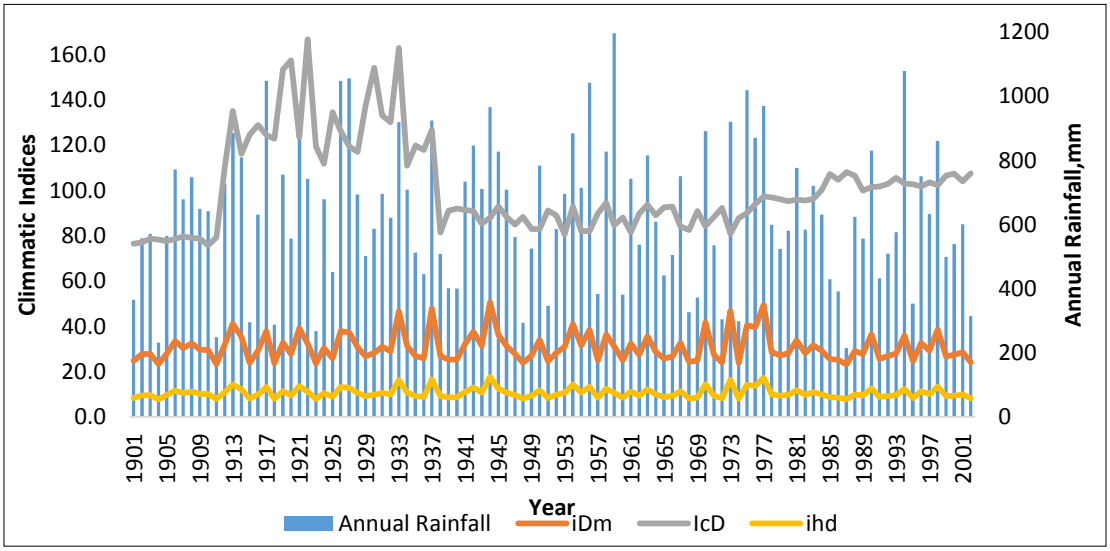


Figure 5.17: Climatic Index and Annual Rainfall for Mehsana district

Results of Precipitation Concentration Index for Mehsana district

The results of Precipitation Concentration Index for annual and for various seasons winter (D-J-F), spring (M-A-M), summer (J-J-A), autumn (S-O-N), and on supra

seasonal scales for wet (October to March) and dry (April to September) for Mehsana district is shown in below Figure 5.18.

The precipitation concentration index shows that 27.45% uniform, 64.71% moderate uniform, 5.88% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 57.84% irregular precipitation trend was observed.

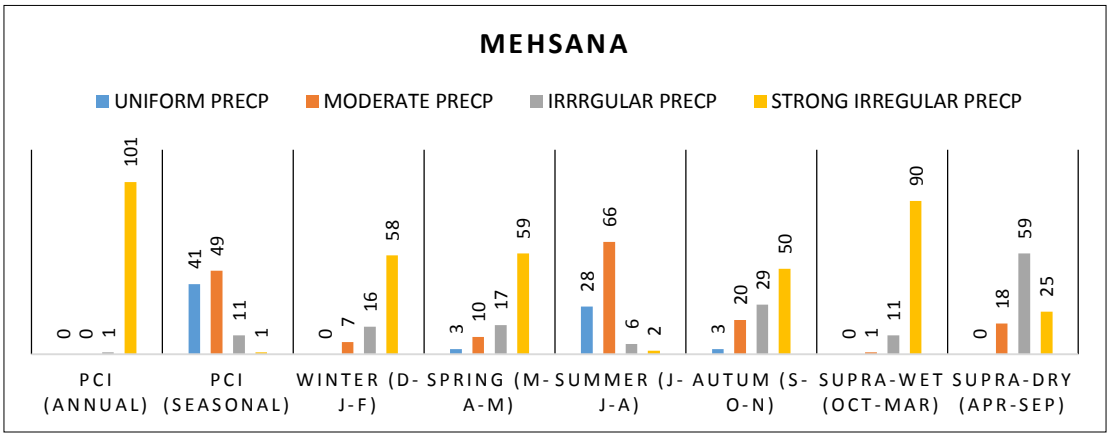


Figure 5.18: Precipitation Concentration Index for various seasons for Mehsana district

Results of Modified Fournier Index for Mehsana district

Below Table 5.78 and Figure 5.19 shows various number years under different classification as per MFI index viz., very low(0-60), low(60-90), moderate(90-120), severe(120-160) and very severe (>160). The results shows that1974 years having very low erosivity and1911, 1915, 1923, 1948, 2002 having low rainfall erosivity and 10 years as moderate rainfall erosivity during (1901 to 2002). The average rainfall during these years as 283.33 mm whereas annual average rainfall for the entire set of data considered is around 632.50 mm.

Table 5.78: Modified Fournier Index Classification for Mehsana district

Classification	No. of years	Years
Very Low	1	1974
Low	5	1911, 1915, 1923, 1948, 2002
Moderate	10	1901, 1904, 1918, 1936, 1940, 1957, 1960, 1969, 1972, 1987
Severe	13	1939, 1947, 1951, 1962, 1968, 1971, 1979, 1986, 1992, 1995, 1997, 1999, 2001
Very severe	73	

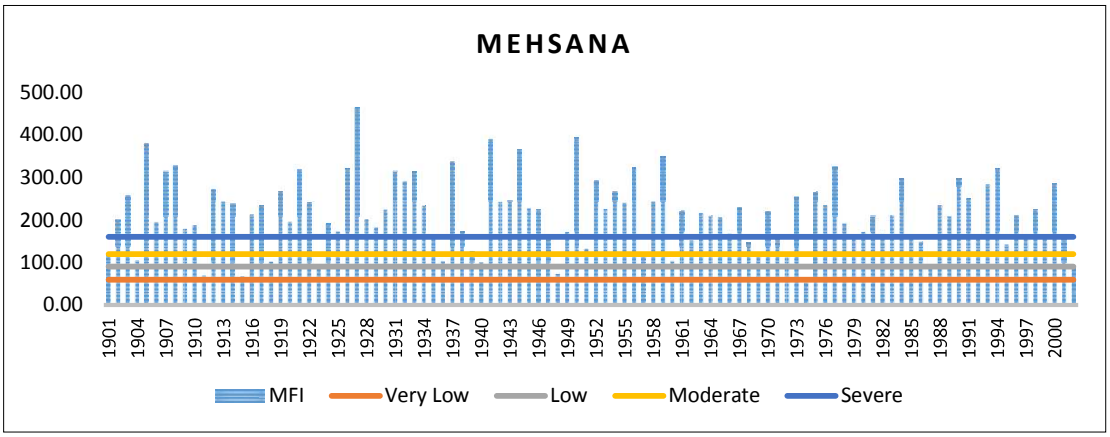


Figure 5.19: Modified Fournier Index for Mehsana district

5.2.4 Estimation of drought by climatic indices in Patan district

The results of various climatic indices are shown below in Tables 5.79, 5.80 and 5.81 for Patan district.

Table 5.79: Drought years obtain using Mortone Aridity Index for Patan district

Classification	Range	Year
Very Droughty	23-24	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1968, 1969, 1972
Droughty	24-25	1936, 1957, 1960, 1991, 1995, 2002, 1974, 1987
Medium	25-29	1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1953, 1956, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1992, 1993, 1999, 2000

Table 5.80: Drought years obtain using Seleaninov Hydrotheremic Index for Patan district

Classification	Range	Year
Droughty	1.1-1.3	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1935, 1936, 1939, 1940, 1948, 1951, 1957, 1960, 1966, 1968, 1969, 1972, 1974, 1986, 1987, 1991, 1995, 2002
Medium	1.3-1.4	

Table 5.81: Drought years obtain using Donciu Climate Index for Patan district

Classification	Range	Year
Droughty	70-80	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Medium	80-95	1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1936, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1956, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986,

		1989, 1991, 1992, 1993, 1995, 1999, 2000

- Mortone Aridity Index shows very droughty conditions for 10 times, droughty conditions for 8 times, medium dry conditions for 32 times and excessive rainy years for 6 times in Patan district.

- Seleaninov Hydrotheremic Index shows droughty conditions for 25 times, medium conditions for 15 times and excessive rainy years for 8 times in Patan district.

- Donciu Climate Index shows droughty conditions for 15 times, medium conditions for 34 times and excessive rainy years for 23 times in Patan district.

From the analysis it was observed that droughty condition occurred 10 times viz. 1901, 1904, 1911, 1915, 1923, 1925, 1939, 1968, 1969, and 1972. Very droughty condition occurred 8 times viz 1936, 1957, 1960, 1991, 1995, 2002, 1974, and 1987. The average result shows that 18.93 % years falls under dry category and medium dry condition shows 30.39 % years and excessive rainy condition shows 12.03 % in Patan district.

Below Figure 5.20 shows the trend of these three indices with annual rainfall, wherein the data ranging from 0 to 1200 represents annual rainfall and the data ranging from 0 to 200 represents various climatic indices.

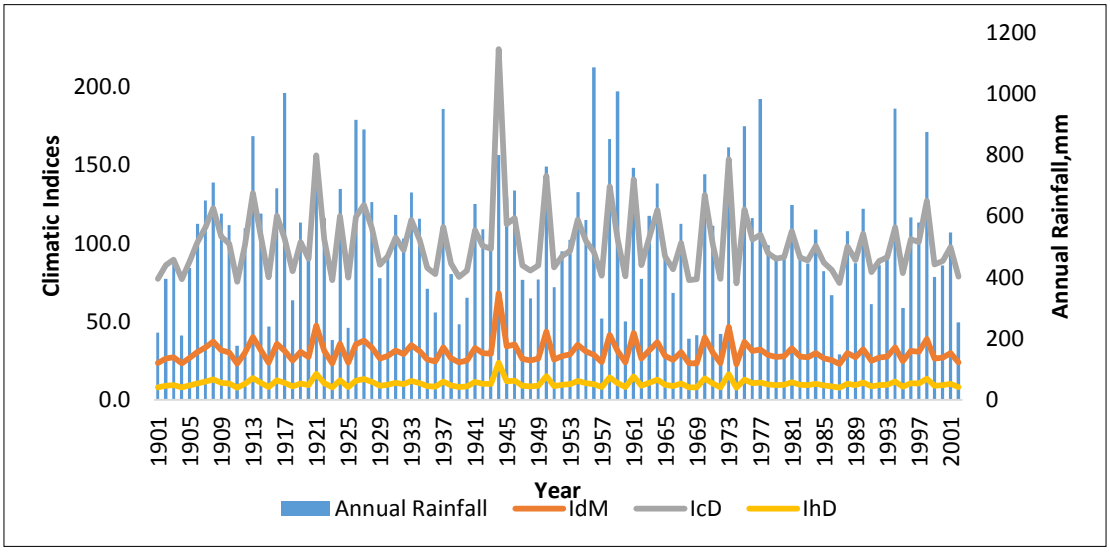


Figure 5.20: Climatic Index and Annual Rainfall for Patan district

Results of Precipitation Concentration Index for Patan district

The results of Precipitation Concentration Index for annual and for various seasons viz., winter (D-J-F), spring (M-A-M), summer (J-J-A), autumn (S-O-N), and on supra seasonal scales for wet (October to March) and dry (April to September) for Mehsana district is shown in below Figure 5.21.

The precipitation concentration index shows that summer season is 20.60% uniform, 62.70% moderate uniform, 13.70% as irregular precipitation and 2.90% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 55.90% irregular precipitation trend was observed.

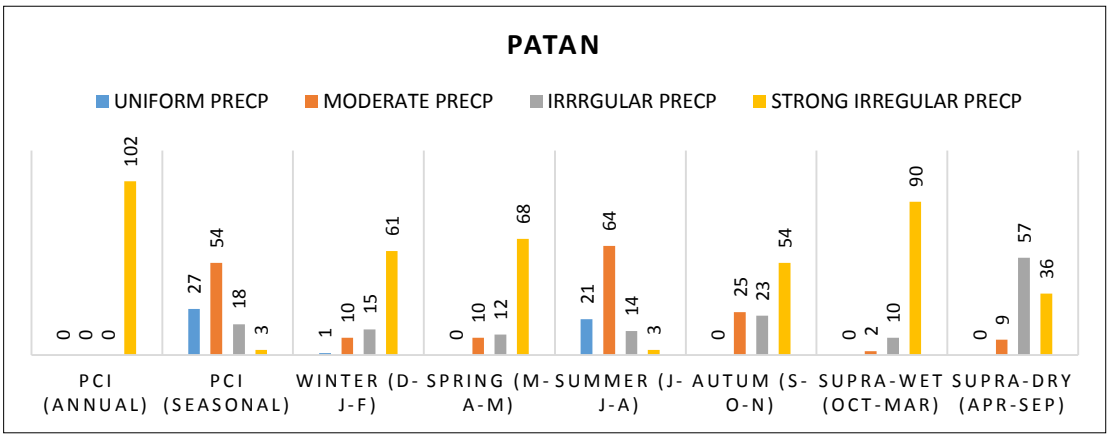


Figure 5.21: Precipitation Concentration Index for various seasons for Patan district

Results of Modified Fournier Index for Patan district

Below Table 5.82 and Figure 5.22 shows various number years under different classification as per MFI index viz., very low(0-60), low(60-90), moderate(90-120), severe(120-160) and very severe (>160).

The results shows 1923, 1974 years having very low and1901, 1911, 1915, 1925, 1936, 1939, 1940, 1957, 1960, 1969, 1972, 1987, 2002 (13 years) having low rainfall erosivity and 06 years as moderate rainfall erosivity during (1901 to 2002). The average rainfall during these years as 236.86 mm whereas annual average rainfall for entire set of data considered is around 533.37 mm.

Table 5.82: Modified Fournier Index Classification for Patan district

Classification	No. of years	Years
Very Low	2	1923, 1974
Low	13	1901, 1911, 1915, 1925, 1936, 1939, 1940, 1957, 1960, 1969, 1972, 1987, 2002
Moderate	6	1906, 1948, 1962, 1968, 1995, 1999

Severe	19	
Very severe	62	

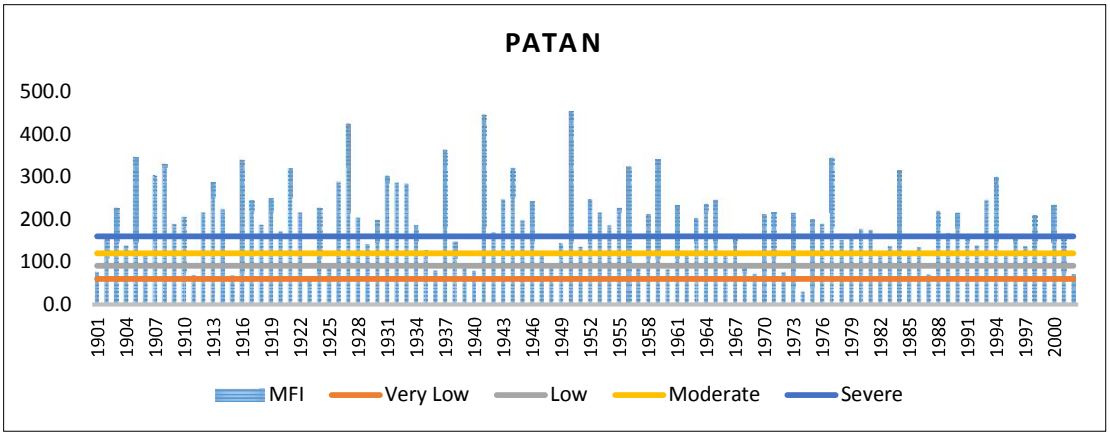


Figure 5.22: Modified Fournier Index for Patan district

5.2.5 Estimation of drought by climatic indices in Sabarkantha district

The results of various climatic indices are shown below in Tables 5.83, 5.84 and 5.85 for Sabarkantha district.

Table 5.83: Drought years obtain using Mortone Aridity Index for Sabarkantha district

Classification	Range	Year
Very Droughty	23-24	1904, 1911, 1915, 1923, 1974, 1987
Droughty	24-25	1918, 1948, 1951, 1969, 2002
Medium	25-29	1901, 1902, 1905, 1925, 1928, 1929, 1930, 1932, 1935, 1936, 1938, 1939, 1940, 1949, 1957, 1958, 1960, 1962, 1964, 1965, 1966, 1968, 1971, 1972, 1978, 1979, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2001

Table 5.84: Drought years obtain using Seleaninov Hydrotheremic Index for Sabarkantha district

Classification	Range	Year
Droughty	1.1-1.3	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1974, 1987, 2002
Medium	1.3-1.4	1901, 1902, 1925, 1936, 1939, 1940, 1957, 1960, 1962, 1964, 1965, 1966, 1968, 1972, 1979, 1985, 1986, 1991, 1992, 1995, 1999

Table 5.85: Drought years obtain using Donciu Climate Index for Sabarkantha district

Classification	Range	Year
Droughty	70-80	1904, 1911, 1915, 1923, 1974, 1987, 2002

Medium	80-95	1901, 1902, 1905, 1918, 1925, 1928, 1929, 1930, 1932, 1935, 1936, 1938, 1939, 1940, 1948, 1951, 1957, 1958, 1960, 1962, 1964, 1965, 1966, 1968, 1969, 1971, 1972, 1978, 1979, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2001

- Mortone Aridity Index shows very droughty conditions for 6 times, droughty conditions for 5 times, medium dry conditions for 37 times and excessive rainy years for 9 times in Sabarkantha district.

- Seleaninov Hydrotheremic Index shows droughty conditions for 11 times, medium conditions for 21 times and excessive rainy years for 16 times in Sabarkantha district.

- Donciu Climate Index shows droughty conditions for 7 times, medium dry conditions for 40 times and excessive rainy years for 26 times in Sabarkantha district.

The average results of these three indices shows that 18.93 % years falls under dry category and medium dry condition shows 30.39 % years and excessive rainy condition shows 12.03 % in Sabarkantha district.

Below Figure 5.23 shows the trend of these three indices with annual rainfall, wherein the data ranging from 0 to 1500 represents annual rainfall and the data ranging from 0 to 200 represents various climatic indices.

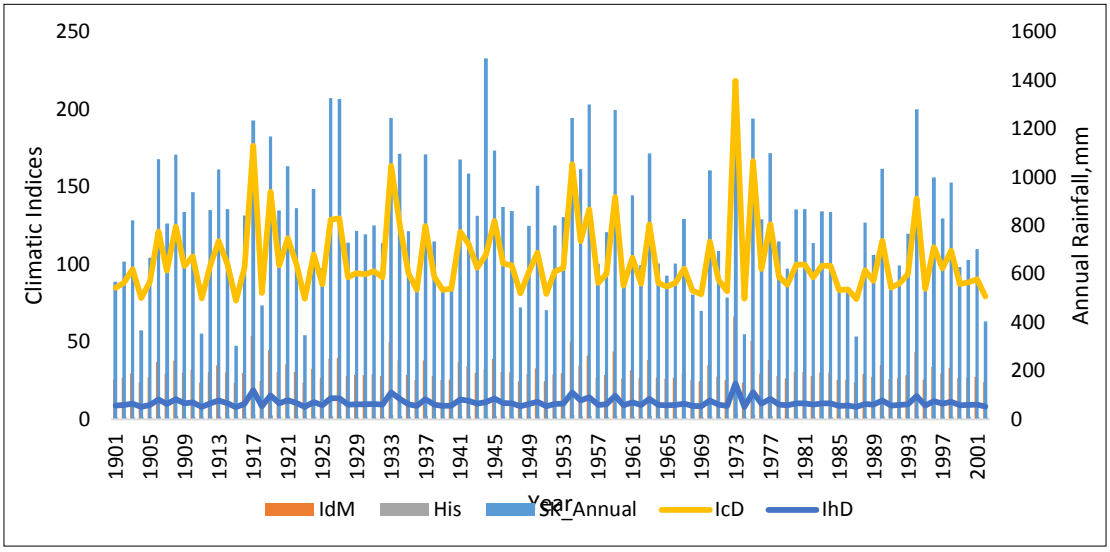


Figure 5.23: Climatic Index and Annual Rainfall of Sabarkantha district

Results of Precipitation Concentration Index for Sabarkantha district

The results of Precipitation Concentration Index for annual and for various seasons winter (D-J-F), spring (M-A-M), summer (J-J-A), autumn (S-O-N), and on supra seasonal scales for wet (October to March) and dry (April to September) for Mehsana district is shown in below Figure 5.24.

The precipitation concentration index shows that in summer season is 26.50% uniform, 66.70% moderate uniform, 5.90% as irregular precipitation and 1.0% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 53.90% irregular precipitation trend was observed.

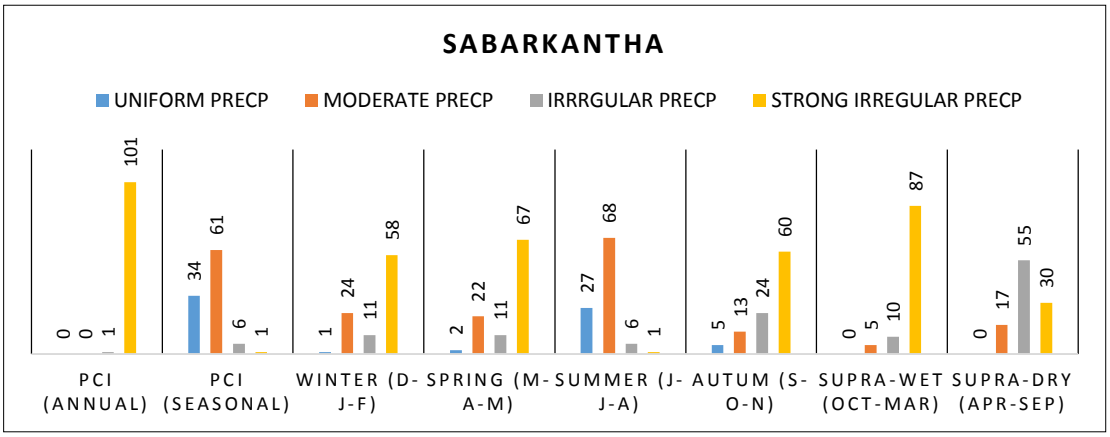


Figure 5.24: Precipitation Concentration Index for various seasons for Sabarkantha district

Results of Modified Fournier Index for Sabarkantha district

Below Table 5.86 and Figure 5.25 shows various number years under different classification as per MFI index viz., very low(0-60), low(60-90), moderate(90-120), severe(120-160) and very severe (>160). The results shows that total 02no of years having very low rainfall erosivity and 02 years as moderate rainfall erosivity during (1901 to 2002) the corresponding years as 1915, 1974. The average rainfall during these years as 327.75 mm whereas annual average rainfall for the entire set of data considered around 812.27 mm.

Table 5.86: Modified Fournier Index Classification for Sabarkantha district

Classification	No. of years	Years
Very Low	0	
Low	2	1915, 1974
Moderate	2	1911, 2002
Severe	7	1904, 1923, 1936, 1940, 1948, 1969, 1987
Very severe	91	

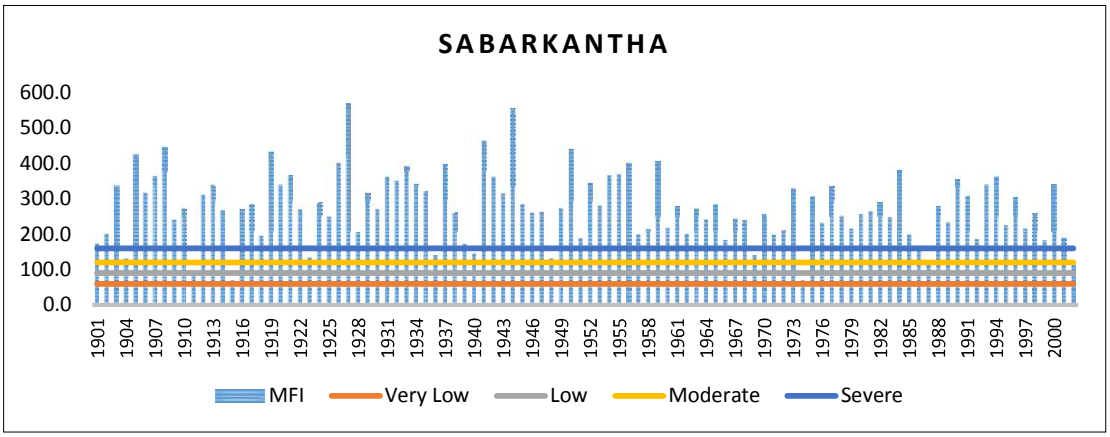


Figure 5.25: Modified Fournier Index for Sabarkantha district

5.2.6 Comparative analysis of Climatic indices over North Gujarat region

Climatic drought indices are used to quantify and characterize drought conditions based on meteorological data. These indices help in assessing the different drought years under various drought classification these assessment is important for improvement in management strategies and policy development which lacking in numbers of under privilege drought-prone and economically backward regions, and such studies are exaggerated the spatial, temporal, and trend behaviour of drought events through the different climatological drought index values in North Gujarat region

The Precipitation Concentration Index (PCI) is a metric designed to quantify the temporal distribution of precipitation within a specified period. It assesses whether precipitation is evenly distributed or if it tends to concentrate within a shorter timeframe. The Modified Fournier Index (MFI) is another tool used to evaluate the distribution of precipitation over time. This information is useful in hydrological, water resources and environment management programs. It is also known that PCI is related to intensity of rainfall.

- The results of **Banaskantha** district shows that 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987 and 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1917, 1918, 1920, 1928, 1929, 1930, 1932, 1935, 1938, 1940, 1942, 1947, 1949, 1952, 1953, 1955, 1957, 1962, 1965, 1966, 1971, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 23.5% uniform, 56.9% moderate uniform, 17.6% as irregular precipitation and 2% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 47.1% irregular precipitation trend was observed.

- The results of **Gandhinagar** district shows that 1904, 1911, 1915, 1918, 1923, 1948 1951, 1960, 1965, 1968, 1972, 1974, 1987, 1995, 2002 years were severely affected by drought. Also, 1901, 1902, 1903, 1905, 1916, 1920, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1949, 1952, 1957, 1964, 1966, 1969, 1971, 1978, 1979, 1980, 1982, 1984, 1985, 1986, 1989, 1991, 1992, 1993, 1997, 1999, 2000, 2001 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 20.59% uniform, 70.59% moderate uniform, 6.86% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 54.90% irregular precipitation trend was observed.

- The results of **Mehsana** district shows that 1901, 1904, 1911, 1915, 1918, 1923, 1936, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 2002 years were severely affected by drought. Also,1902, 1903, 1905, 1910, 1916, 1920, 1925, 1929, 1930, 1932, 1935, 1938, 1947, 1949, 1952, 1962, 1964, 1966, 1971, 1978, 1979, 1980, 1982, 1984, 1988, 1989, 1992, 1993, 1997, 1999, 2000, 2001 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 27.45% uniform, 64.71% moderate uniform, 5.88% as irregular precipitation and 1.96% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 57.84% irregular precipitation trend was observed.

- The results of **Patan** district shows that 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, 2002 years were severely affected by drought. Also, 1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1953, 1956, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1992, 1993, 1999, 2000 years were medium dry condition during the study period. The rainfall variability shows that for summer season is 20.60% uniform, 62.70% moderate uniform, 13.70% as irregular precipitation and 2.90% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 55.90% irregular precipitation trend was observed.

- The results of **Sabarkantha** district shows that 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1974, 1987, 2002 years were severely affected by drought. Also, 1901, 1902, 1905, 1925, 1928, 1929, 1930, 1932, 1935 1936, 1938, 1939, 1940, 1949, 1957, 1958, 1960, 1962 1964, 1965, 1966, 1968, 1971, 1972, 1978, 1979, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2001 years were medium dry condition during the study period. The

rainfall variability shows that for summer season is 26.50% uniform, 66.70% moderate uniform, 5.90% as irregular precipitation and 1.0% as strong precipitation distribution over 1901 to 2002 study period. Also, during April to September months there is 53.90% irregular precipitation trend was observed.

From the above all results it was concluded that Patan district had more dry year with highest frequency about 18.9% of extreme and 30.39% of medium dry events whereas Sabarkantha and Gandhinagar district had least percentage of dry years which is about 9.47%, 11.43% of extreme dry and 26.78%, 29.40% medium dry events during study period. Also, Patan district had minimum excessive rainy years which is about 12.03% compared to other districts.

In summary, both the Precipitation Concentration Index (PCI) and the Modified Fournier Index along with three climatic index are valuable tools for assessing the distribution of precipitation over time. The results will help professionals in various fields make informed decisions regarding water resource management, flood risk, and agricultural planning based on the temporal characteristics of precipitation.

5.3 ESTIMATION OF VARIOUS ARIDITY INDEX OVER THE STUDY AREA

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate. This study provides a preliminarily idea about the climate of North Gujarat districts. Different Aridity index viz., UNESCO Aridity index, De Martonne Aridity index, Erinc Aridity index, Thornthwaite Precipitation Effectiveness index, and Thornthwaite Moisture index are used in present study. These indices helpful to determine the arid, semi arid years. Also, the trend of this indices with rainfall and temperature data is also studied.

Due to rapid growth of population, massive deforestation and anthropogenic activities, noticeable change in climate conditions is being observed in North Gujarat districts. Increased in arid, semi-arid years due to climate change is a growing environmental problem of the agricultural country like India. It is essential to assess and monitor aridity to combat the probable land degradation and drought desertification. Identification of arid and semi-arid regions on climatic basis is the first essential step in any project of land reclamation for agricultural and other purposes.

5.3.1 Estimation of various aridity index over Banaskantha district

Northern parts of the Gujarat districts have variable types of climate.i.e dry semi-arid to very humid. Most of the rainfed regions also come under the humid zone and agriculture commodities of this region depends upon rainfall. The results will be

useful in future for planning, designing and operating irrigation system and crop planning too.

UNESCO Aridity index, Erinc AI is an indicator of climatic conditions in most arid and semi-arid regions. It helps in identifying and interpreting large scale trend in temperature and precipitation; and thus, classifying region into different climatic classes. As per UNESCO aridity index semi-arid ranges from 0.20-0.50, dry sub humid ranges from0.50-0.65. Erinc Aridity index values classified as Erinc value <8 then hyper arid and Erinc value between 8-15 then classified as arid year.

The results of UNESCO AI and Erinc AI Index for Banaskantha district is shown in below Tables are 5.87 and 5.88 respectively.

Table 5.87: UNESCO AI Index for Banaskantha district

Climate Class	**AI Values**	**Year**
Semi arid	0.2-0.5	1901, 1902, 1903, 1904, 1905, 1911, 1915, 1918, 1920, 1923, 1925, 1928, 1929, 1930, 1932, 1935, 1936, 1938, 1939, 1940, 1942, 1947, 1948, 1949, 1951, 1952, 1953, 1955, 1957, 1960, 1962, 1965, 1966, 1968, 1969, 1971, 1972, 1974, 1979, 1980, 1982, 1983, 1985, 1986, 1987, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2002
Dry sub humid	0.50-0.65	1906, 1907, 1909, 1910, 1912, 1914, 1922, 1931, 1941, 1943, 1954, 1958, 1963, 1964, 1970, 1976, 1978, 1981, 1984, 1988, 1990, 1996, 1997, 2001

The results of UNESCO AIfor Banaskantha district shows that52.0% years assemiarid, 23.50 % years falls under Dry subhumid and 24.50% years as humid over 1901-2002 study period.

Table 5.88: Erinc Aridity Index for Banaskantha district

Climate Class	**Im Values**	**Year**
Hyper Arid	<8	1901, 1904, 1911, 1915, 1923, 1939, 1948, 1960, 1968, 1969, 1974, 1987, 2002
Arid	8-15	1902, 1903, 1905, 1918, 1920, 1925, 1928, 1929, 1930, 1932, 1935, 1936, 1938, 1940, 1942, 1947, 1949, 1951, 1952, 1953, 1955, 1957, 1962, 1963, 1965, 1966, 1971, 1972, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000

The results of Erinc Aridity index for Banaskantha district, shows that 12.75% years falls under hyper arid and 40.20% years as arid. The hyper arid years as 1901, 1904,

1911, 1915, 1923, 1939, 1948, 1960, 1968, 1969, 1974, 1987, 2002 during this years the annual rainfall is about 204.60 mm and average temperature during this time around 35.60ºc. The annual average rainfall of district is around 625 mm during study period of 1901 to 2002.

Thornthwaite based the effectiveness of precipitation on an index (the P/E index), which is the sum of the 12 monthly P/E ratios.The results of Thornthwaite's Precipitation Effectiveness Index for Banaskantha district is shown in below Table 5.89

Table 5.89: Thornthwaite's Precipitation Effectiveness Index for Banaskantha district

Climate Class	**PE Values**	**Year**
Arid	<16	1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Semi-arid	16-31	1902, 1903, 1905, 1912, 1918, 1920, 1928, 1929, 1930, 1931, 1932, 1935, 1938, 1940, 1942, 1947, 1949, 1952, 1953, 1955, 1957, 1958, 1962, 1963, 1964, 1965, 1966, 1970, 1971, 1979, 1980, 1982, 1983, 1984, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2001

The results of Thornthwaite based the effectiveness of precipitation index shows that 16.66 % years falls under arid and 43.33 % years as semi-arid. The arid years as 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1968, 1969, 1972, 1974, 1987, 2002 during this years the annual rainfall is about 225.60 mm.

The Thornthwaite moisture index is a useful indicator of the supply of water (precipitation) in an area relative to the demand for water under prevailing climatic conditions (potential Evapotranspiration). Below Table 5.90 shows that results of Thornthwaite Moisture Index for Banaskantha district

Table 5.90: Thornthwaite Moisture Index for Banaskantha district

Climate Class	**Moisture Index (Im, %)**	**Year**
Hyper Arid	<-90	
Arid	-90 to -80	1974
Dry Semi-Arid	-79 to -56	1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1962, 1968, 1969, 1972, 1987, 1991, 2002

The results of Thornthwaite moisture index shows that arid years as 1974 during this years the annual rainfall is about 115.20 mm which very less than the average rainfall of banaskantha district. Also, 18.62% years as dry semi arid which are as

1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1948, 1951, 1960, 1962, 1968, 1969, 1972, 1987, 1991, 2002 years.

De Martonne aridity is defined as the ratio of precipitation to mean temperature. These index used to classify the climates of various regions, because the ratio of precipitation to temperature provides a method for determining an area's climate regime. Below Table 5.91 shows results of De Martonne's Aridity Index for Banaskantha district

Table 5.91: De Martonne's Aridity Index for Banaskantha district

Climate Class	**AI Values**	**Year**
Arid	≤5	1904, 1923, 1974, 1987
Semi-arid	5-12	1901, 1902, 1905, 1911, 1915, 1918, 1920, 1925, 1930, 1932, 1935, 1936, 1938, 1939, 1940, 1942, 1948, 1949, 1951, 1957, 1960, 1962, 1965, 1966, 1968, 1969, 1972, 1979, 1980, 1985, 1986, 1989, 1991, 1992, 1995, 1999, 2000, 2002

The results of De Martonne's Aridity indices shows that 4% years comes under arid and 37 % years as semi-arid. The arid years as 1904, 1923, 1974, 1987. So remaining 40% years falls under arid or semi arid years in Banaskantha district.

Similarly Graphical representation of aridity indices is shown in below Figures 5.26 to 5.30.

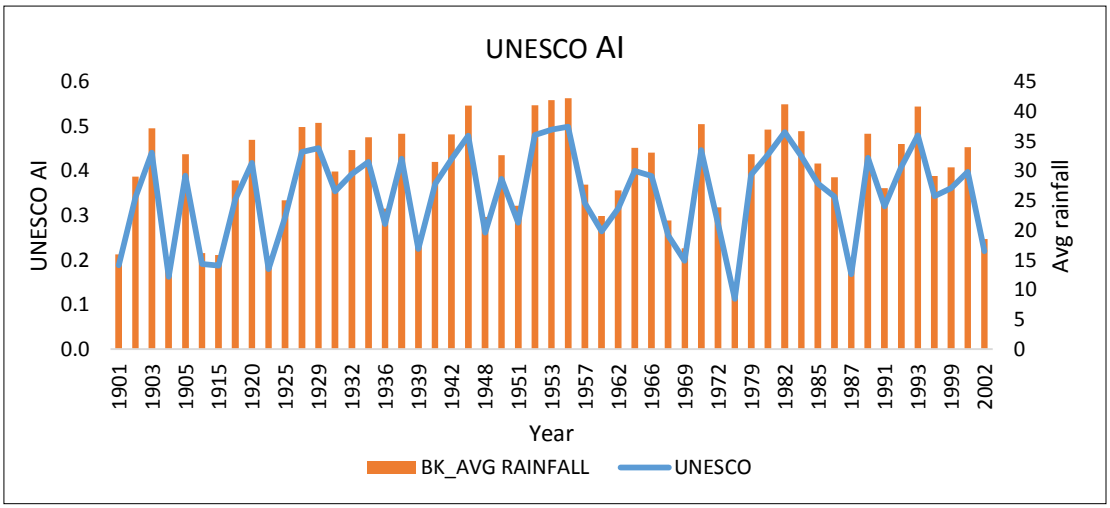


Figure 5.26: Graphical representation of UNESCO AI of Banaskantha district

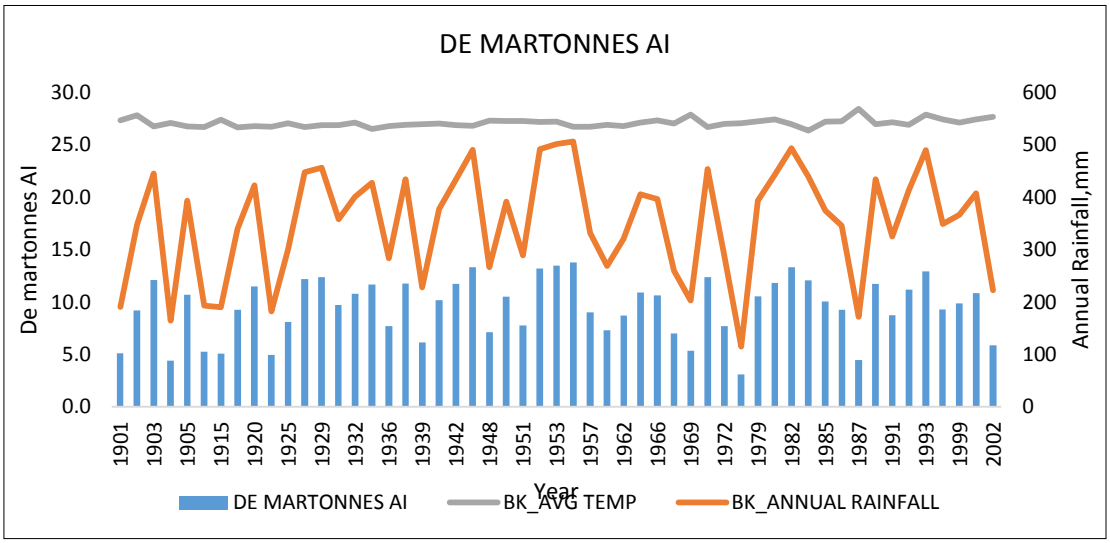


Figure 5.27: Graphical representation of De Martonne's AI of Banaskantha district

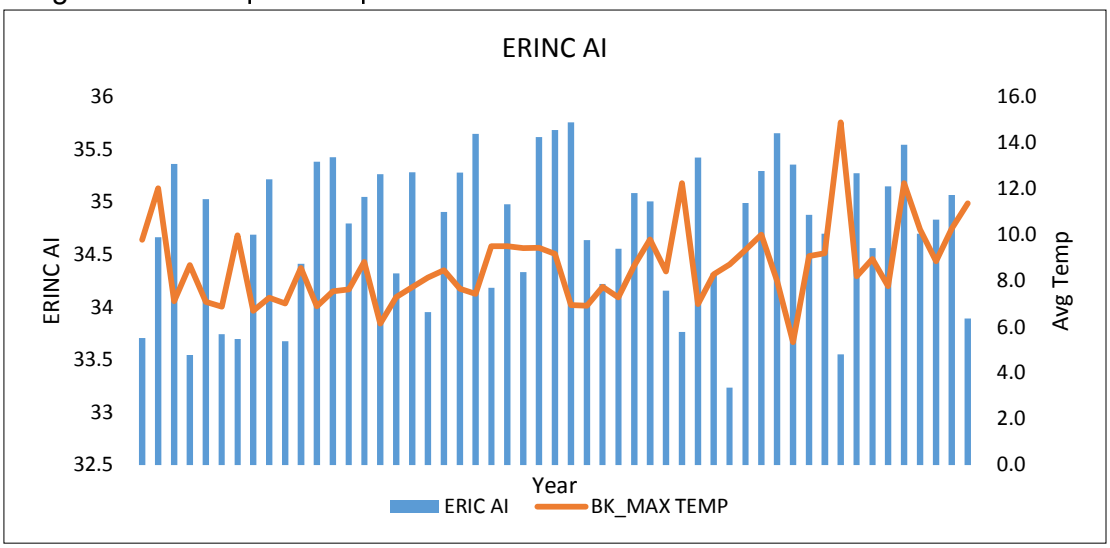


Figure 5.28: Graphical representation of Erinc AI of Banaskantha district

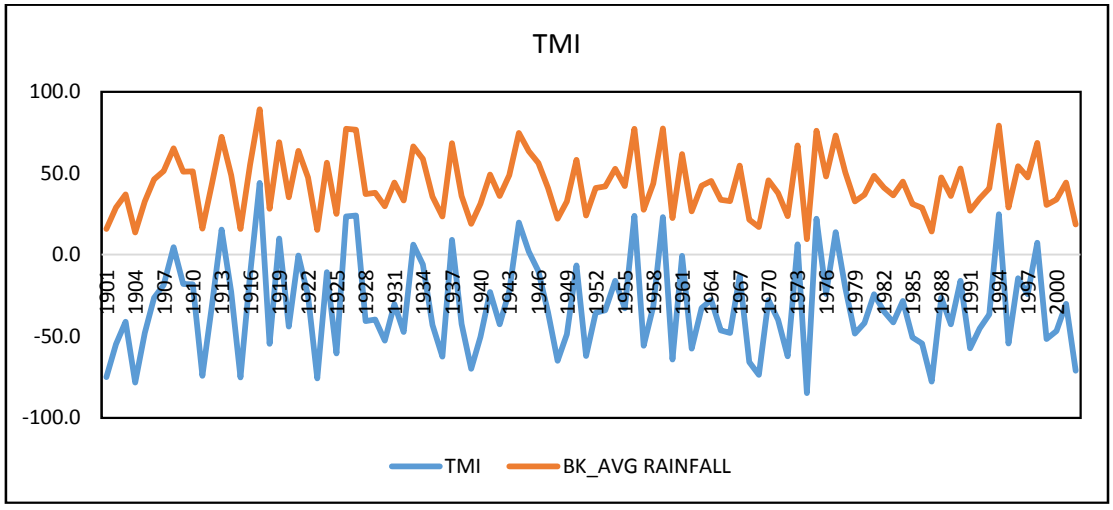


Figure 5.29: Graphical representation of TMI of Banaskantha district

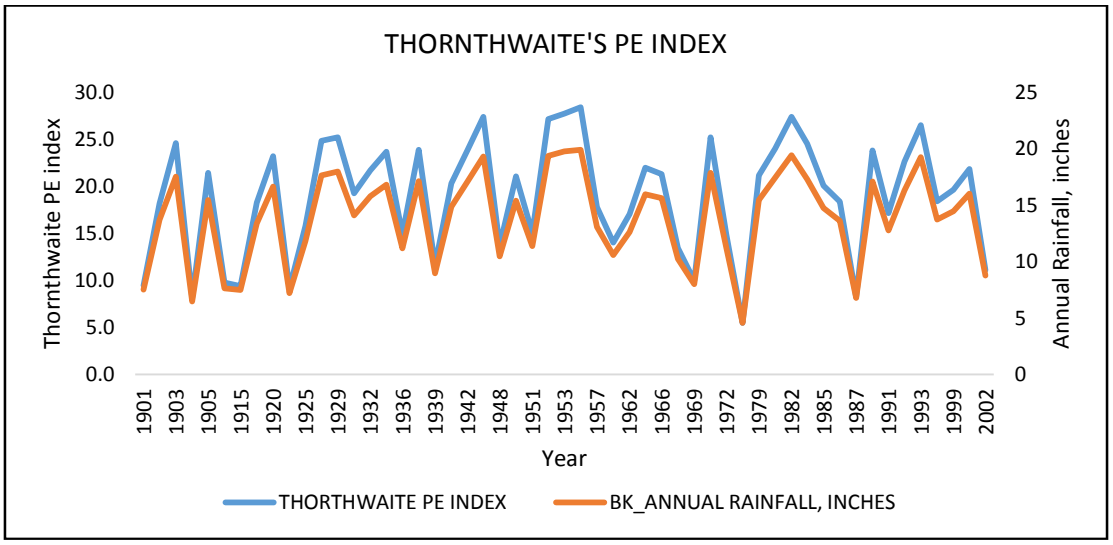


Figure 5.30: Graphical representation of Thornthwaite PE Index of Banaskantha district

The comparative study of Banaskantha district shows that 5 to 18% of the year is arid while 35% area is humid. This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

This clearly indicates that this agro climatic region faces only short term dryness during the decade. But it should be noted that agricultural practices are affected by short term dryness. So utmost care should still be taken for mitigating drought to improve the productivity from agriculture.

5.3.2 Estimation of various aridity index over Gandhinagar district

The results of Gandhinagar district for various aridity indices are shown below section.

Table 5.92: UNESCO AI Index for Gandhinagar district

Climate Class	**AI Values**	**Year**
Semi arid	0.20-0.50	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1972, 1974, 1985, 1986, 1987, 1995, 2002
Dry sub humid	0.50-0.65	1902, 1903, 1905, 1916, 1920, 1924, 1925, 1929, 1935, 1936, 1938, 1947, 1949, 1952, 1964, 1966, 1969, 1971, 1978, 1979, 1980, 1982, 1984, 1989, 1991, 1992, 1993, 1997, 1999, 2000, 2001

The results of UNESCO AI for Gandhinagar district is shown in above Table 5.92. From the analysis it was observed that 20.60% years falls undersemiarid, 30.40% years falls under dry subhumid and 49.0% years as humid.

Table 5.93: Erinc Aridity Index for Gandhinagar district

Climate Class	**Im Values**	**Year**
Hyper Arid	<8	1911, 1918, 1987
Arid	8-15	1901, 1904, 1915, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1991, 1995, 2002

The results of Erinc Aridity index shown in above Table 5.93 for Gandhinagar district. From the analysis it was observed that 3% years falls under hyper arid and 20% years as arid years. The hyper arid years as 1911, 1918, 1987 during this years the annual rainfall is about 235.2 mm and during arid years the average rainfall is 395.23 mm. The annual average rainfall of the district is around 680.65 mm and the average temperature of the district is 34.9^{o}C.

Table 5.94: Thornthwaite's Precipitation Effectiveness Index for Gandhinagar district

Climate Class	**PE Values**	**Year**
Arid	<16	1911, 1918, 1972, 1987
Semi-arid	16-31	1901, 1904, 1915, 1923, 1925, 1929, 1936, 1939, 1940, 1947, 1948, 1951, 1957, 1960, 1965, 1966, 1968, 1969, 1971, 1974, 1985, 1986, 1991, 1992, 1995, 1999, 2002

The results of Thornthwaite based the effectiveness of precipitation index is shown in above Table 5.94 from the analysis it was observed 4% years falls under arid and 26.50% years as semi-arid. The arid years as 1911, 1918, 1972, 1987 during this years the annual rainfall is about 220.65 mm. The semi arid years as 1901, 1904, 1915, 1923, 1925, 1929, 1936, 1939, 1940, 1947, 1948, 1951, 1957, 1960, 1965, 1966, 1968, 1969, 1971, 1974, 1985, 1986, 1991, 1992, 1995, 1999, 2002 which is 27 years.

Table 5.95: Thornthwaite Moisture Index for Gandhinagar district

Climate Class	**Moisture Index (Im, %)**	**Year**
Hyper Arid	<-90	
Arid	-90 to -80	
Dry Semi-Arid	-79 to -56	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987

The results of Thornthwaite moisture index is shown in above Table 5.95 for Gandhinagar district. From the analysis it was observed 9% year's falls dry semi-arid. The annual rainfall is about 225.60 mm. The dry semi-arid years are as 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972 and 1987.

Table 5.96: De Martonne's Aridity Index for Gandhinagar district

Climate Class	**AI Values**	**Year**
Arid	≤5	
Semi-arid	5-12	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1986, 1987, 1995, 2002

The results of De Martonne's Aridity index is shown in above Table 5.96 for Gandhinagar district. From the analysis it was observed that 20% years comes under semi-arid. The arid years as 1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1986, 1987, 1995, 2002 during this years the annual rainfall is about 345.90 mm which 350 mm less than the average rainfall of Gandhinagar district.

The Graphical representation of all indices is shown in below Figures 5.31 to 5.35 for Gandhinagar district.

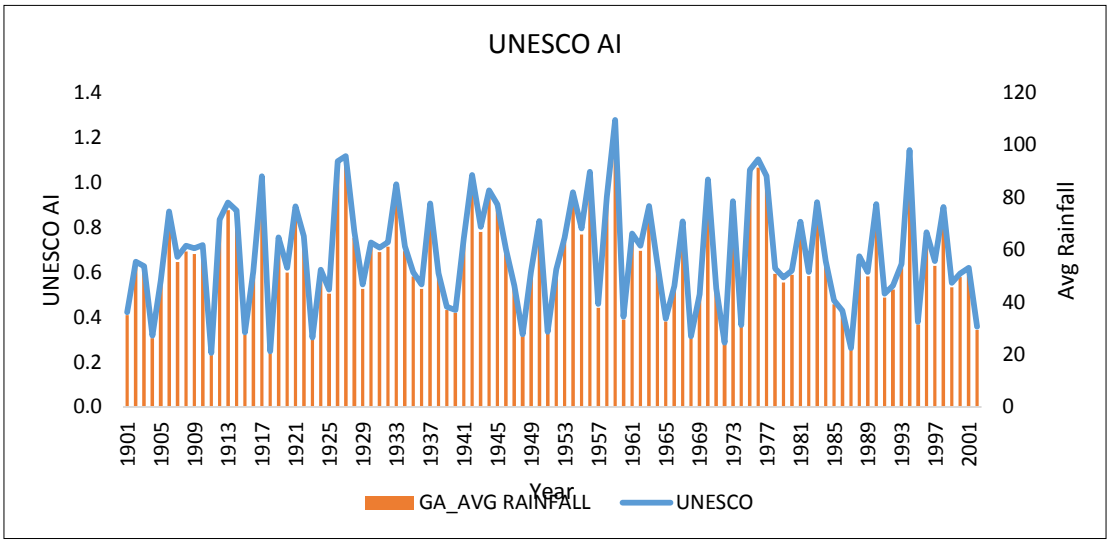


Figure 5.31: Graphical representation of UNESCO AI of Gandhinagar district

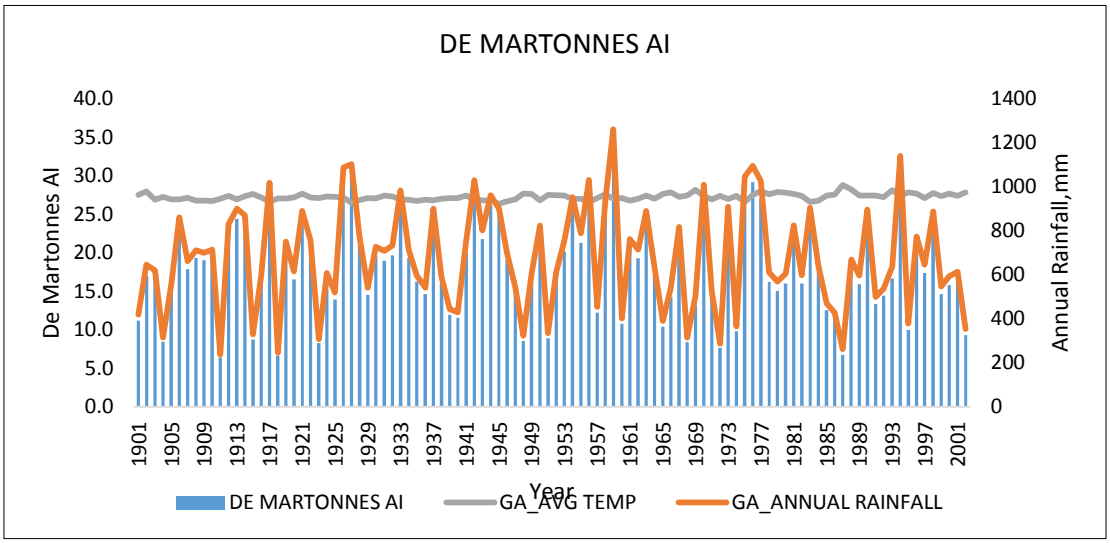


Figure 5.32: Graphical representation of De Martonne's AI of Gandhinagar district

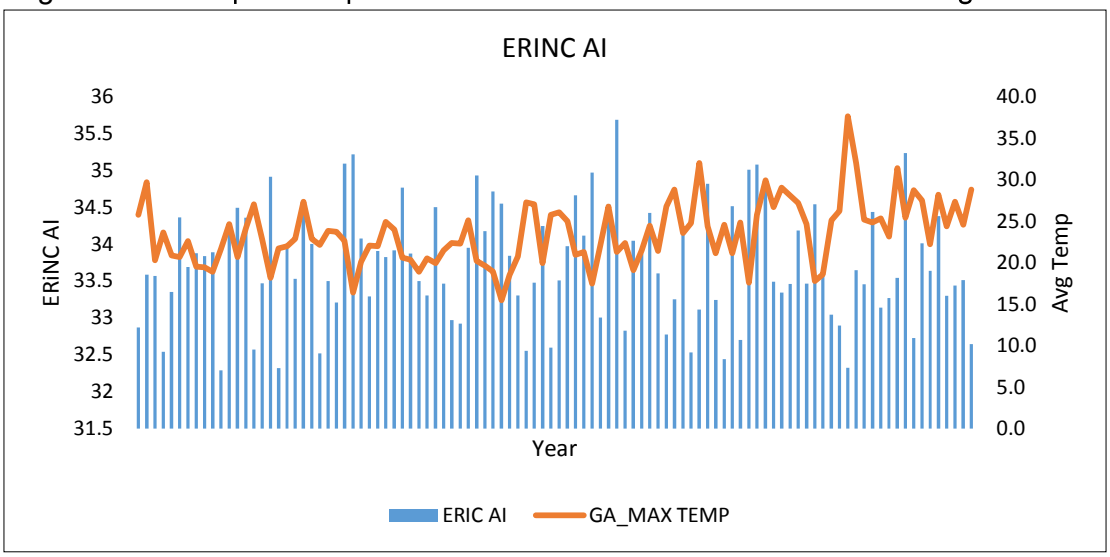


Figure 5.33: Graphical representation of Erinc AI of Gandhinagar district

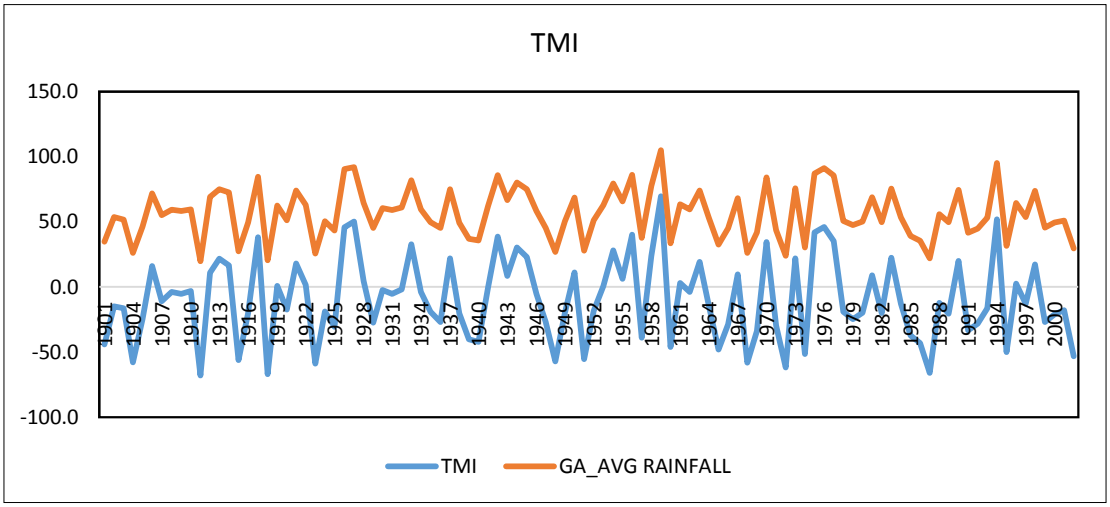


Figure 5.34: Graphical representation of TMI of Gandhinagar district

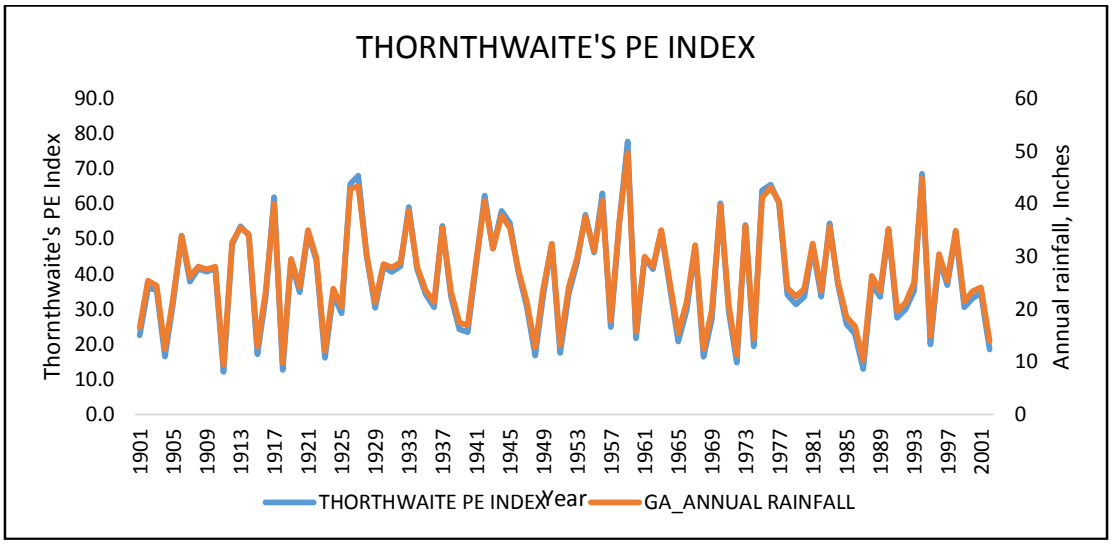


Figure 5.35: Graphical representation of Thornthwaite PE Index of Gandhinagar district

The comparative study of Gandhinagar district shows that 4% of the years is arid years while 25% area is semi-arid years. The arid years as 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1987 in present study region. The annual average rainfall of district is 235.9 mm. This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region. So utmost care should still be taken for mitigating drought to improve the productivity from agriculture.

5.3.3 Estimation of various aridity index over Mehsana district

The results of Mehsana district for various aridity indices are shown below section.

Table 5.97: UNESCO AI Index for Mehsana district

Climate Class	AI Values	Year
Semi arid	0.20-0.50	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1966, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 1999, 2002
Dry sub humid	0.50-0.65	1902, 1903, 1905, 1910, 1916, 1920, 1929, 1930, 1932, 1935, 1938, 1947, 1949, 1952, 1962, 1964, 1971, 1978, 1979, 1980, 1982, 1984, 1988, 1989, 1992, 1993, 1997, 2000, 2001

The results of UNESCO AI for Mehsana district is shown in above Table 5.97. From the analysis it was observed that 26.50% years falls under semiarid, 28.40 % years falls under dry subhumid and 45.10% years as humid.

Table 5.98: Erinc Aridity Index for Mehsana district

Climate Class	Im Values	Year
Hyper Arid	<8	1904, 1911, 1923, 1987
Arid	8-15	1901, 1915, 1918, 1925, 1929, 1936, 1938, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1966, 1968, 1969, 1972, 1974, 1985, 1986, 1991, 1992, 1995, 1999, 2002

For Mehsana district the results of Erinc Aridity indices shown in above Table 5.98 from the analysis it was observed that 4% years falls under hyper arid and 26% years as arid. The hyper arid years as 1904, 1911, 1923, 1987 during this years the annual rainfall is about 240.2 mm and during Arid years the average rainfall is 390.30 mm. The annual average rainfall of the district is around 695.20 mm and the average temperature of the district is 35.3^{o}C.

Table 5.99: Thornthwaite's Precipitation Effectiveness Index for Mehsana district

Climate Class	PE Values	Year
Arid	<16	1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987
Semi-arid	16-31	1901, 1902, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1949, 1951, 1957, 1960, 1962, 1965, 1966, 1968, 1969, 1971, 1979, 1985, 1986, 1991, 1992, 1995, 1999, 2000, 2002

The results of Thornthwaite based the effectiveness of precipitation indices is shown in above Table 5.99 from the analysis it was observed that 9% years falls under arid and 28% years as semi-arid. The arid years as 1904, 1911, 1915, 1918, 1923, 1948, 1972, 1974, 1987 during this years the annual rainfall is about 240.5 mm. The semi arid years as 1901, 1902, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1949, 1951, 1957, 1960, 1962, 1965, 1966, 1968, 1969, 1971, 1979, 1985, 1986, 1991, 1992, 1995, 1999, 2000, 2002 which is 28 years.

Table 5.100: Thornthwaite Moisture Index for Mehsana district

Climate Class	Moisture Index (Im, %)	Year
Hyper Arid	<-90	
Arid	-90 to -80	
Dry Semi-Arid	-79 to -56	1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1974, 1987, 2002

The results of Thornthwaite moisture index is shown in above Table 5.100 from the analysis it was observed that 11% year's falls dry semi-arid. The annual rainfall is about 235.2 mm. The years are as 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1974, 1987 and 2002.

Table 5.101: De Martonne's Aridity Index for Mehsana district

Climate Class	**AI Values**	**Year**
Arid	≤5	
Semi-arid	5-12	1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 2002

The results of De Martonne's Aridity index is shown in above Table 5.101 from the analysis it was observed that 23 % years comes under semi-arid. The semi-arid years as 1901, 1904, 1911, 1915, 1918, 1923, 1939, 1940, 1948, 1951, 1957, 1960, 1965, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1991, 1995, 2002 during this years the annual rainfall is about 245.90 mm which 375 mm less than the average rainfall of Mehsana district.

The Graphical representation of all indices is shown in below Figures 5.36 to 5.40 for Mehsana district.

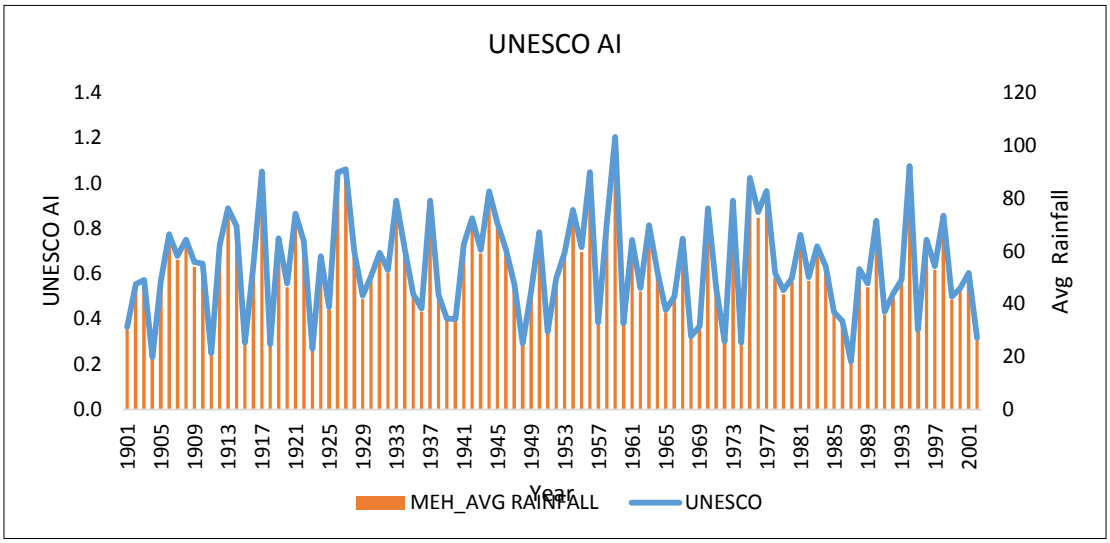


Figure 5.36: Graphical representation of UNESCO AI of Mehsana district

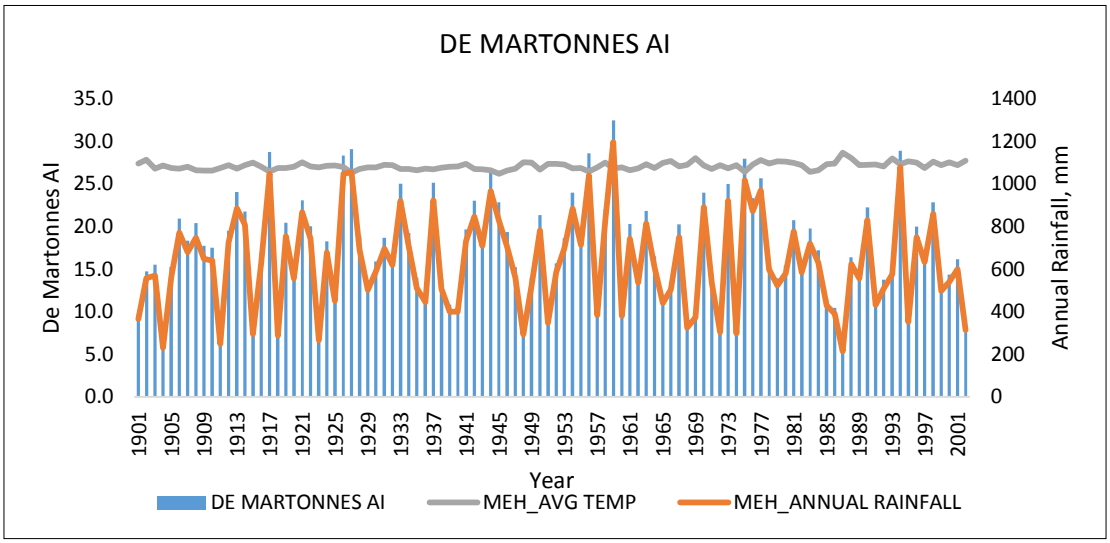


Figure 5.37: Graphical representation of De Martonne's AI of Mehsana district

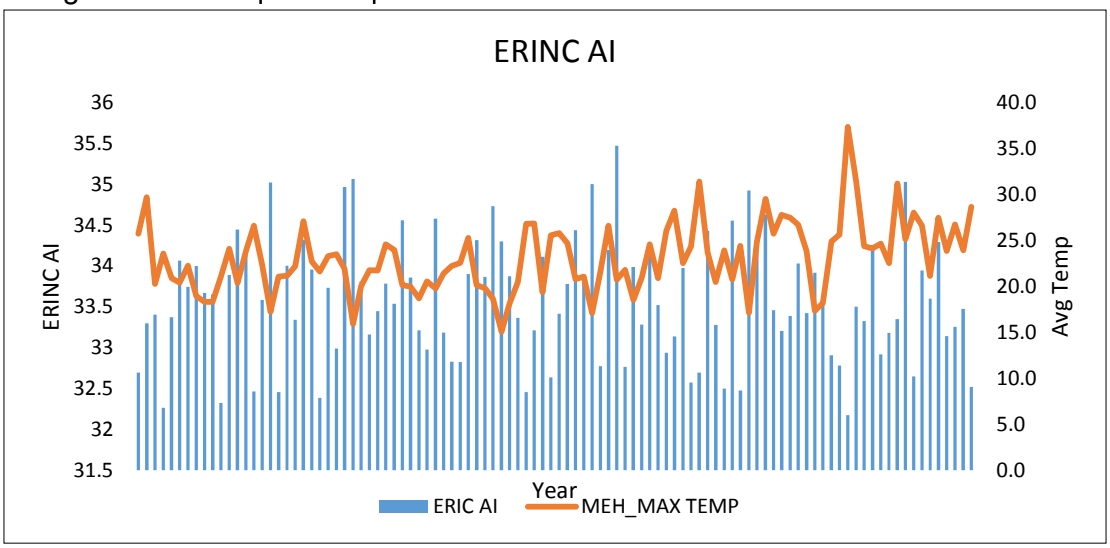


Figure 5.38: Graphical representation of Erinc AI of Mehsana district

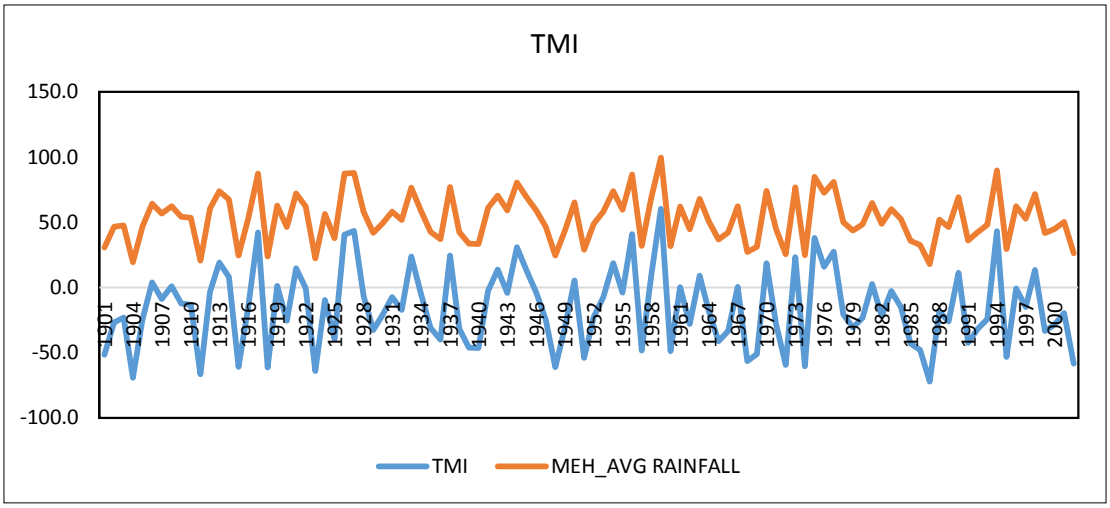


Figure 5.39: Graphical representation of TMI of Mehsana district

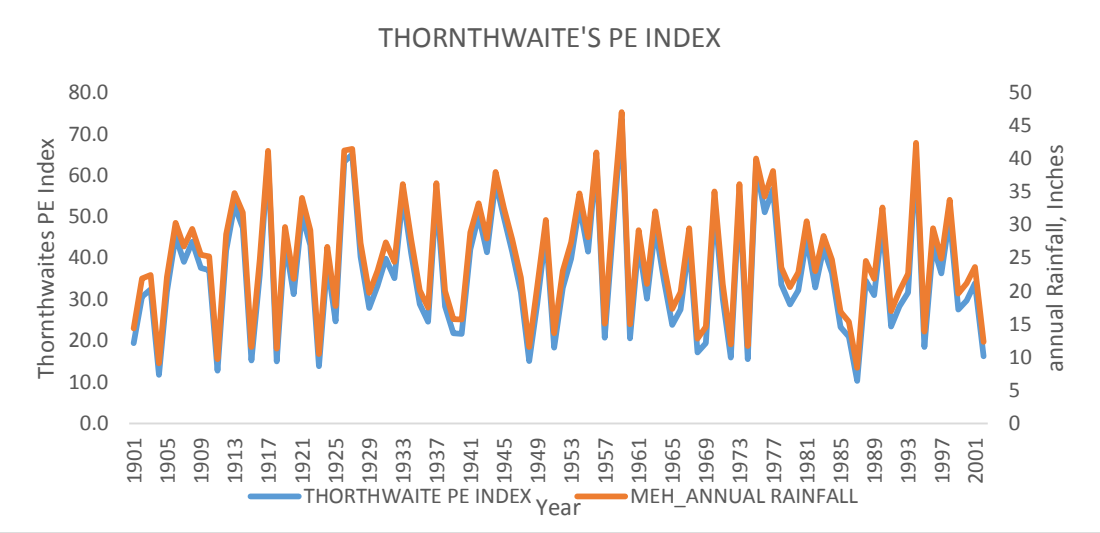


Figure 5.40: Graphical representation of Thornthwaite PE Index of Mehsana district

The comparative study of Mehsana district shows that6% to 10% of the yeas is arid while 23% to 28% year is semi-arid. The arid years as 1904, 1911, 1915, 1918, 1923, 1948, 1968, 1972, 1974, 1987, 2002 in present study region. The annual average rainfall of district is 680 mm.

5.3.4 Estimation of various aridity index over Patan district

The results of Patan district for various aridity indices are shown below section.

Table 5.102: UNESCO AI Index for Patan district

Climate Class	AI Values	Year
Semi arid	0.20-0.50	1901, 1902, 1903, 1904, 1905, 1911, 1915, 1918, 1920, 1923, 1925, 1929, 1930, 1935, 1936, 1938, 1939, 1940, 1947, 1948, 1949, 1951, 1952, 1957, 1960, 1962, 1965, 1966, 1968, 1969, 1972, 1974, 1979, 1980, 1982, 1983, 1985, 1986, 1987, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2002
Dry sub humid	0.50-0.65	1906, 1907, 1909, 1910, 1912, 1914, 1919, 1922, 1928, 1931, 1932, 1934, 1941, 1942, 1943, 1953, 1955, 1963, 1967, 1971, 1976, 1978, 1981, 1984, 1988, 1990, 1996, 1997, 2001

The results of UNESCO AI for Patan district is shown in above Table 5.102. From the analysis it was observed that 46.10% years falls under semiarid, 28.40 % years falls under dry subhumid and 25.50% years as humid over 1901-2002 study period.

Table 5.103: Erinc Aridity Index for Patan district

Climate Class	Im Values	Year
Hyper Arid	<8	1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002
Arid	8-15	1902, 1903, 1905, 1918, 1920, 1929, 1930, 1935, 1936, 1938, 1940, 1947, 1948, 1949, 1951, 1952, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000

The results of Erinc Aridity for Patan district is shown in above Table 5.103 from the analysis it was observed that 14.70 % years falls under hyper arid and 32.35 % years as arid. The hyper arid years as 1901, 1904, 1911, 1915, 1923, 1925, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 2002 during this years the annual rainfall is about 210.5 mm and during arid years the average rainfall is 390.65 mm. The annual average rainfall of the district is around 600 mm and the average temperature of the district is 34.3^{o}C.

Table 5.104: Thornthwaite's Precipitation Effectiveness Index for Patan district

Climate Class	PE Values	Year
Arid	<16	1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1995, 2002
Semi-arid	16-31	1902, 1903, 1905, 1918, 1920, 1929, 1930, 1932, 1935, 1938, 1940, 1943, 1947, 1948, 1949, 1951, 1952, 1953, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1988, 1989, 1991, 1992, 1993, 1999, 2000, 2001

The results of Thornthwaite based the effectiveness of precipitation indexis shown in above Table 5.104 from the analysis it was observed that 16.66% years falls under arid and 35.29% years as semi-arid. The arid years as 1901, 1904, 1911, 1915, 1923, 1925, 1936, 1939, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1995, 2002 during this years the annual rainfall is about 215.35 mm. The semi arid years as 1902, 1903, 1905, 1918, 1920, 1929, 1930, 1932, 1935, 1938, 1940, 1943, 1947, 1948, 1949, 1951, 1952, 1953, 1962, 1965, 1966, 1978, 1979, 1980, 1982, 1983, 1985, 1986, 1988, 1989, 1991, 1992, 1993, 1999, 2000, 2001which is 36 years.

Table 5.105: Thornthwaite Moisture Index for Patan district

Climate Class	Moisture Index (Im, %)	Year
Hyper Arid	<-90	
Arid	-90 to -80	1974, 1987

Dry Semi-Arid	-79 to -56	1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1957, 1960, 1968, 1969, 1972, 1991, 1995, 2002

The results of Thornthwaite moisture index isshown in above Table 5.105 from the analysis it was observed that 17.64% year's falls dry semi-arid. The annual rainfall is about 240.10 mm. The years are as 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1957, 1960, 1968, 1969, 1972, 1991, 1995 and 2002.

Table 5.106: De Martonne's Aridity Index for Patan district

Climate Class	**AI Values**	**Year**
Arid	≤5	1911, 1974, 1987
Semi-arid	5-12	1901, 1902, 1904, 1905, 1915, 1918, 1923, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1948, 1949, 1951, 1957, 1960, 1962, 1966, 1968, 1969, 1972, 1985, 1986, 1991, 1992, 1995, 1999, 2000, 2002

The results of De Martonne's Aridity index is shown in above Table 5.106 from the analysis it was observed that 33 % years comes under semi-arid. The semi-arid years as 1901, 1902, 1904, 1905, 1915, 1918, 1923, 1925, 1929, 1935, 1936, 1938, 1939, 1940, 1947, 1948, 1949, 1951, 1957, 1960, 1962, 1966, 1968, 1969, 1972, 1985, 1986, 1991, 1992, 1995, 1999, 2000 and 2002 during this years the annual rainfall is about 150.30 mm which 550 mm less than the average rainfall of Patan district.

The Graphical representation of all indices is shown in below Figures 5.41 to 5.45 for Patan district.

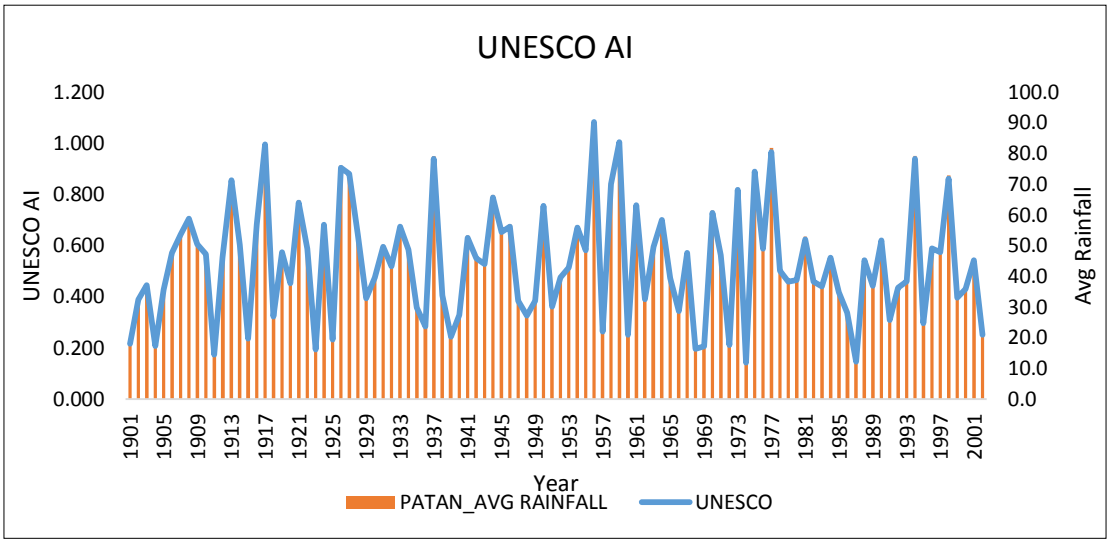


Figure 5.41: Graphical representation of UNESCO AI of Patan district

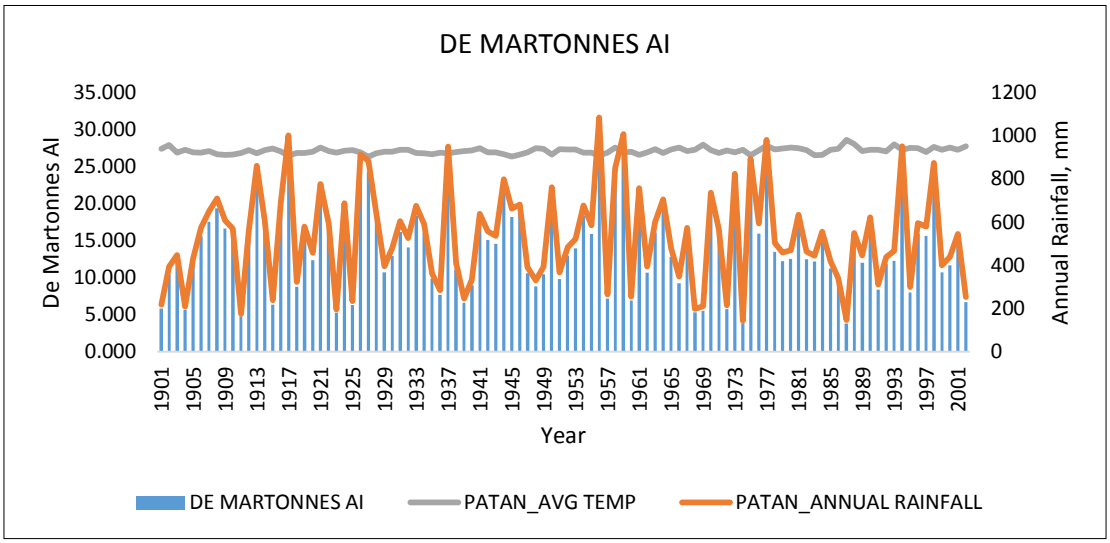


Figure 5.42: Graphical representation of De Martonne's AI of Patan district

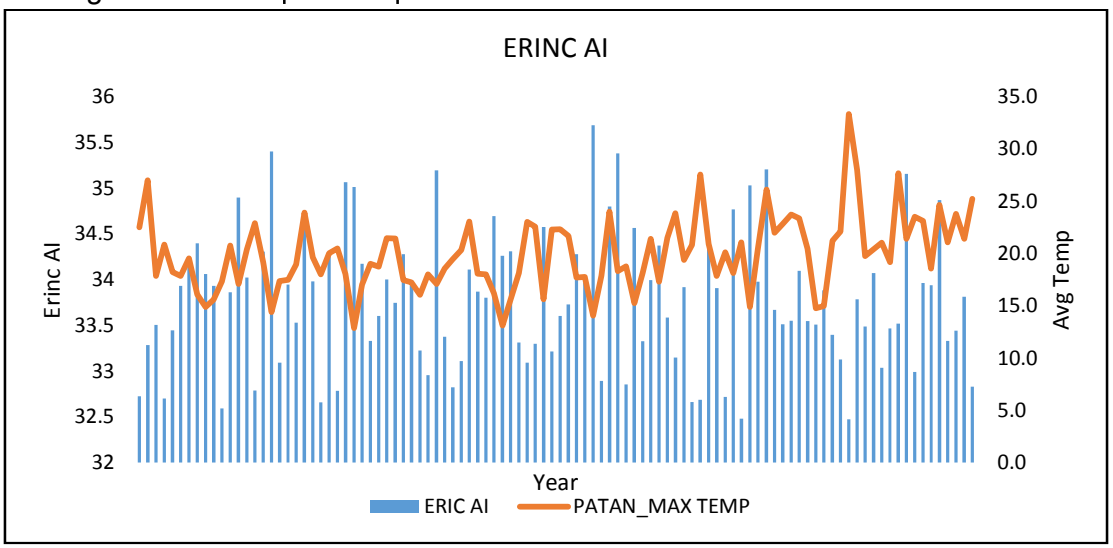


Figure 5.43: Graphical representation of Erinc AI of Patan district

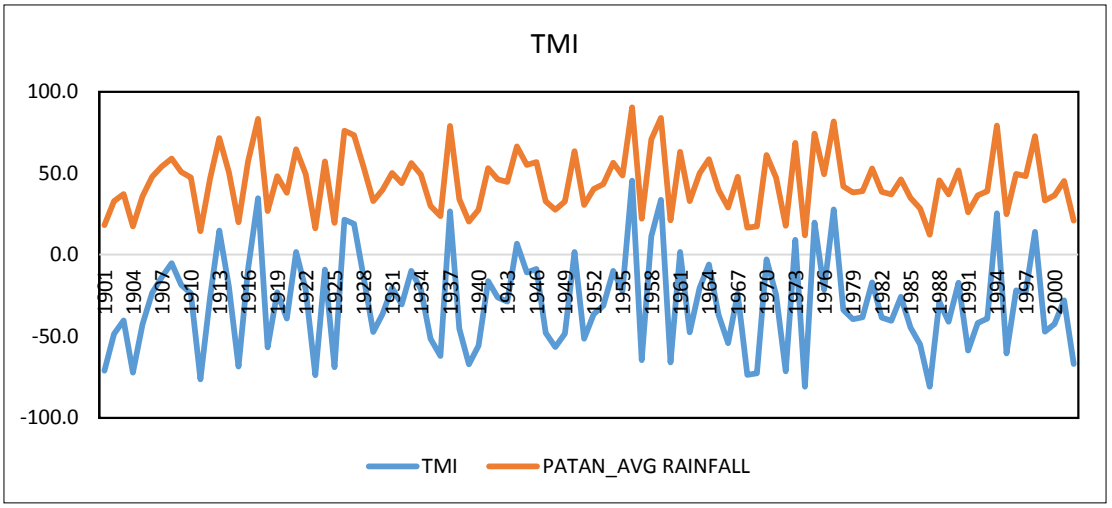


Figure 5.44: Graphical representation of TMI of Patan district

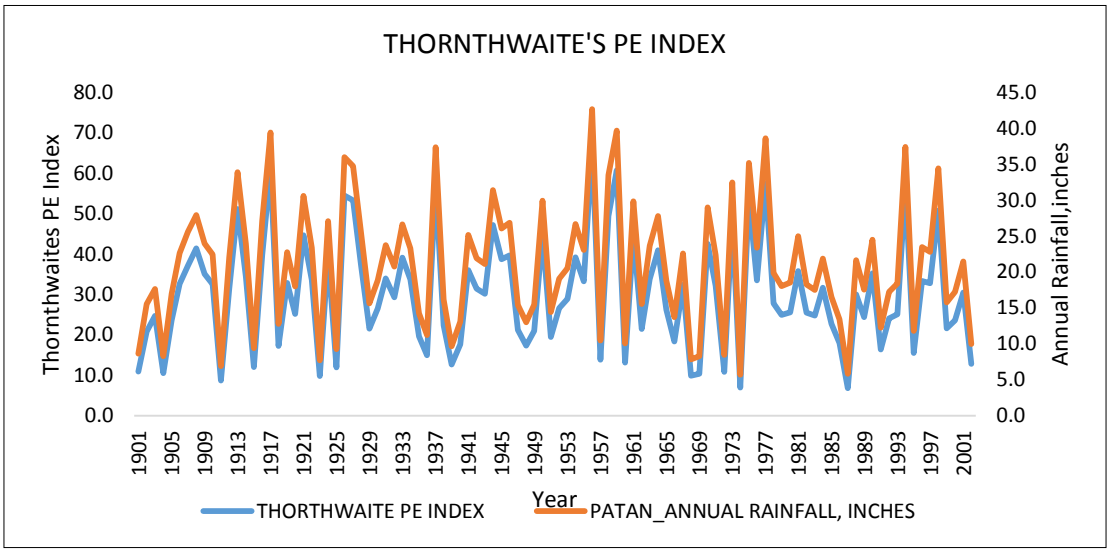


Figure 5.45: Graphical representation of Thornthwaite PE Index of Patan district

The comparative study of Patan district shows that 10% to 15% of the year is arid while 25 to 30% year is semi-arid. The arid years in Patan district are 1901, 1904, 1911, 1915, 1918, 1923, 1925, 1936, 1939, 1948, 1957, 1960, 1968, 1969, 1972, 1974, 1987, 1991, 1995, and 2002. The annual average rainfall of district is 620 mm. This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

5.3.5 Estimation of various aridity index over Sabarkantha district

The results of Sabarkantha district for various aridity indices are shown below section.

Table 5.107: UNESCO AI Index for Sabarkantha district

Climate Class	AI Values	Year
Semi arid	0.20-0.50	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1974, 1987, 2002
Dry sub humid	0.50-0.65	1906, 1907, 1909, 1910, 1912, 1914, 1919, 1922, 1928, 1931, 1932, 1934, 1941, 1942, 1943, 1953, 1955, 1963, 1967, 1971, 1976, 1978, 1981, 1984, 1988, 1990, 1996, 1997, 2001

The results of UNESCO AI for Sabarkantha district is shown in above Table 5.107. From the analysis it was observed that 10.80% years falls under semiarid, 19.60% years falls under dry subhumid and 69.60% years as humid over 1901-2002 study period.

Table 5.108: Erinc Aridity Index for Sabarkantha district

Climate Class	Im Values	Year
Hyper Arid	<8	
Arid	8-15	1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1972, 1974, 1987, 2002
Semi-arid	15-23	1901, 1902, 1905, 1925, 1928, 1930, 1932, 1936, 1938, 1939, 1940, 1957, 1958, 1960, 1962, 1964, 1965, 1966, 1968, 1971, 1978, 1979, 1982, 1985, 1986, 1989, 1991, 1992, 1993, 1995, 1999, 2000, 2001

The results of Erinc Aridity index is shown in above Table 5.108 for Sabarkantha district. From the analysis it was observed that 11.8% years falls under arid and 32.35% years as semi-arid. The arid years as 1904, 1911, 1915, 1918, 1923, 1948, 1951, 1969, 1972, 1974, 1987 and 2002 during this years the annual rainfall is about 400 mm and during semi-arid years the average rainfall is 650 mm. The annual average rainfall of the district is around 850 mm and the average temperature of the district is 36.5^{o}C.

Table 5.109: Thornthwaite's Precipitation Effectiveness Index for Sabarkantha district

Climate Class	PE Values	Year
Arid	<16	1915
Semi-arid	16-31	1904, 1911, 1918, 1923, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, 2002

The results of Thornthwaite based the effectiveness of precipitation index is shown in above Table 5.109 from the analysis it was observed that 16.66% years falls under semi-arid. The semi-arid years as 1904, 1911, 1918, 1923, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, 2002 during this years the annual rainfall is about 450.30 mm and annual average rainfall is 850 mm in present study region.

Table 5.110: Thornthwaite Moisture Index for Sabarkantha district

Climate Class	Moisture Index (Im, %)	Year
Hyper Arid	<-90	
Arid	-90 to -80	
Dry semi-arid	-79 to -56	1915
Wet semi-arid	-55 to -26	1904, 1911, 1918, 1923, 1936, 1939, 1948, 1951,

		1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, 2002

The results of Thornthwaite moisture index is shown in above Table 5.110 from the analysis it was observed that 16.66% years having wet semi-arid. The years are as 1904, 1911, 1918, 1923, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995, 2002.Also, the results of de Martonne's Aridity Index for Sabarkantha district is shown in below Table 5.111

Table 5.111: De Martonne's Aridity Index for Sabarkantha district

Climate Class	**AI Values**	**Year**
Arid	≤5	
Semi-arid	5-12	1904, 1911, 1915, 1923, 1969, 1974, 1987, 2002

The Graphical representation of all indices is shown in below Figures 5.46 to 5.50 for Sabarkantha district.

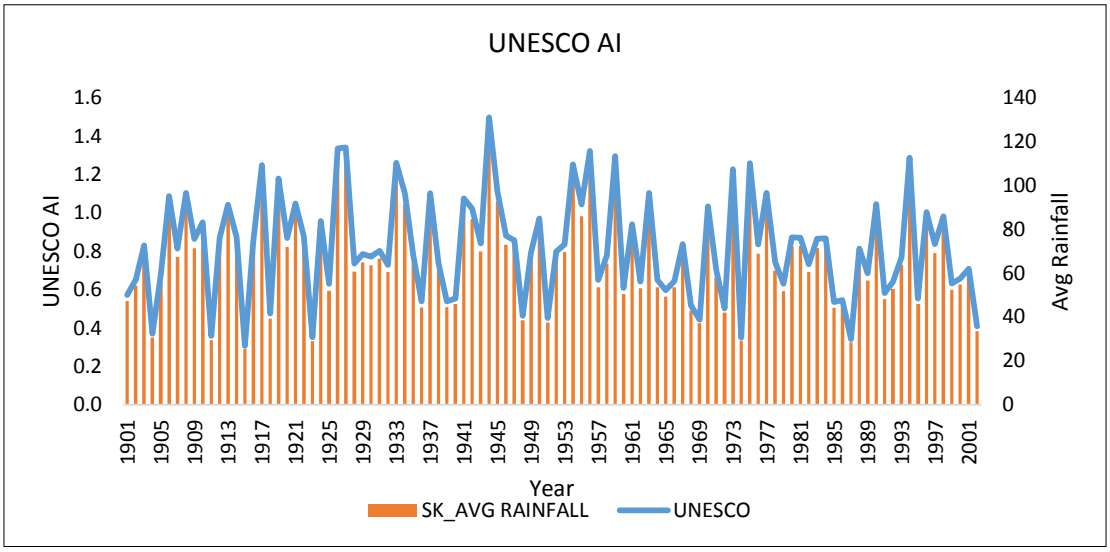


Figure 5.46: Graphical representation of UNESCO AI of Sabarkantha district

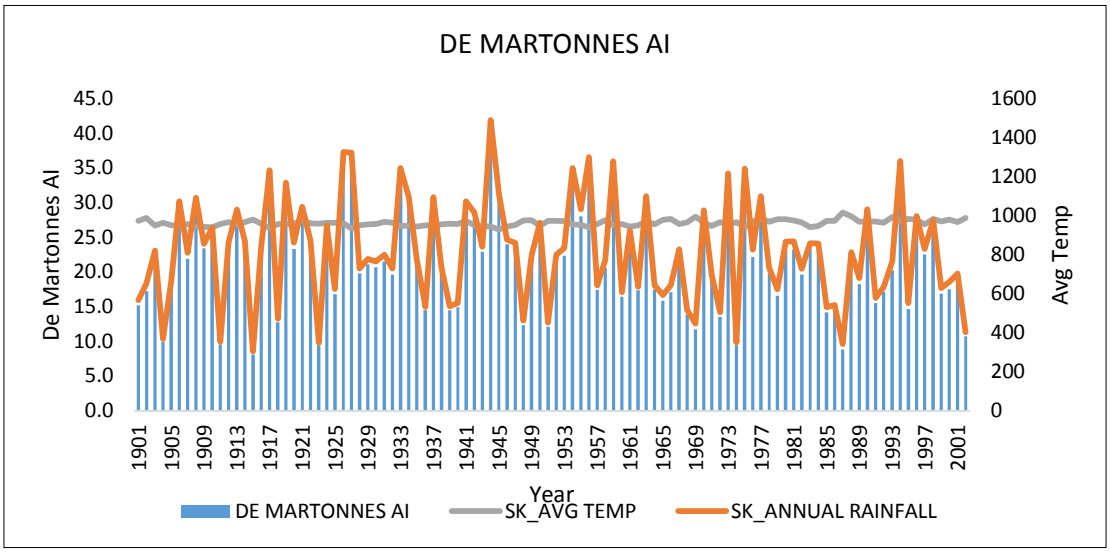


Figure 5.47: Graphical representation of De Martonne's AI of Sabarkantha district

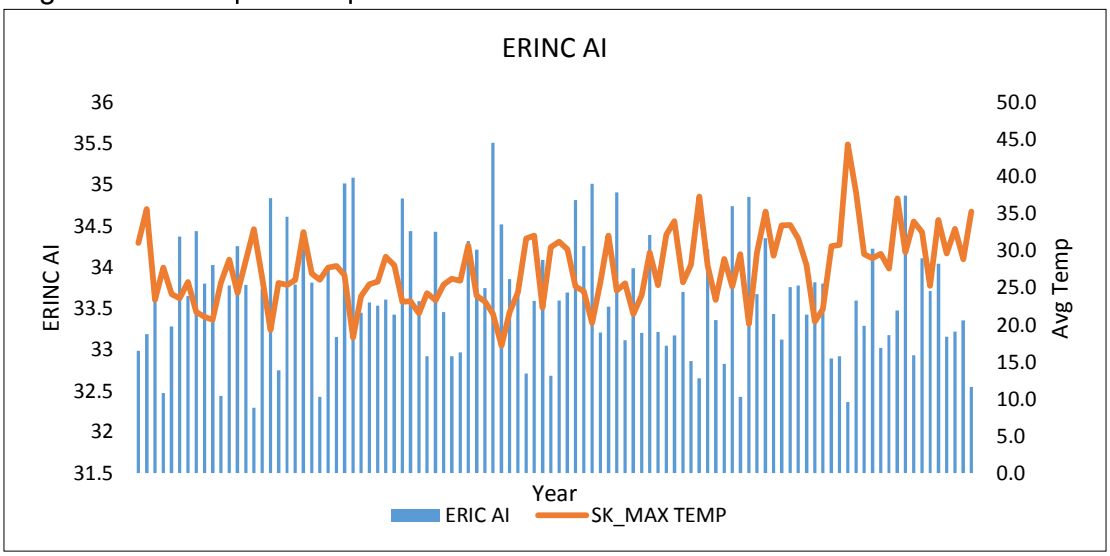


Figure 5.48: Graphical representation of Erinc AI of Sabarkantha district

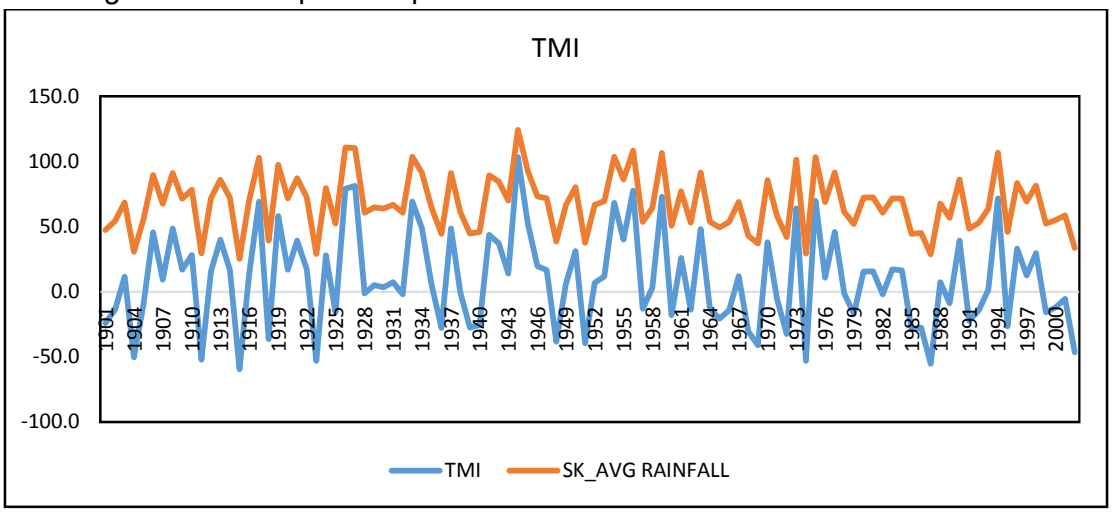


Figure 5.49: Graphical representation of TMI of Sabarkantha district

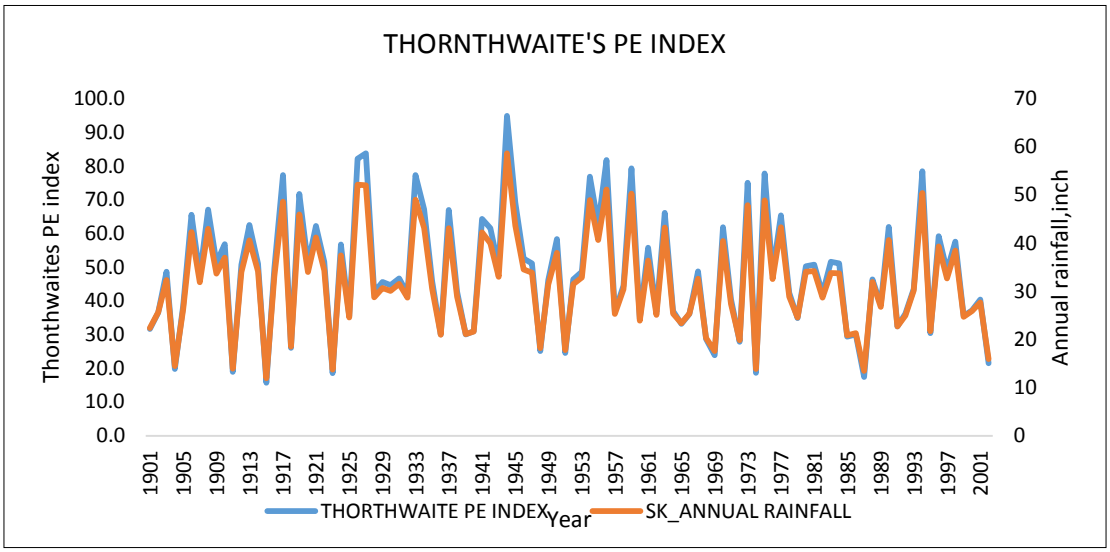


Figure 5.50: Graphical representation of Thornthwaite PE Index of Sabarkantha district

The comparative study of Sabarkantha district shows that 8% to 10% of the district is arid while 15% area is semi-arid. The arid years as 1904, 1911, 1915, 1918, 1923, 1936, 1939, 1948, 1951, 1968, 1969, 1972, 1974, 1985, 1986, 1987, 1995 and 2002 in present study region. The annual average rainfall of district is 850 mm.

This study will be a good predicator for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

5.3.6 Comparative analysis of aridity index over North Gujarat region

The aridity index is valuable for assessing the potential for drought in a region because it gives an indication of the moisture/water deficit or surplus in an area. In regions with low aridity indices, there may be a higher susceptibility to drought, while areas with high aridity indices are less prone to drought conditions.

The Comparative analysis of different aridity indices used in North Gujarat region is shown below.

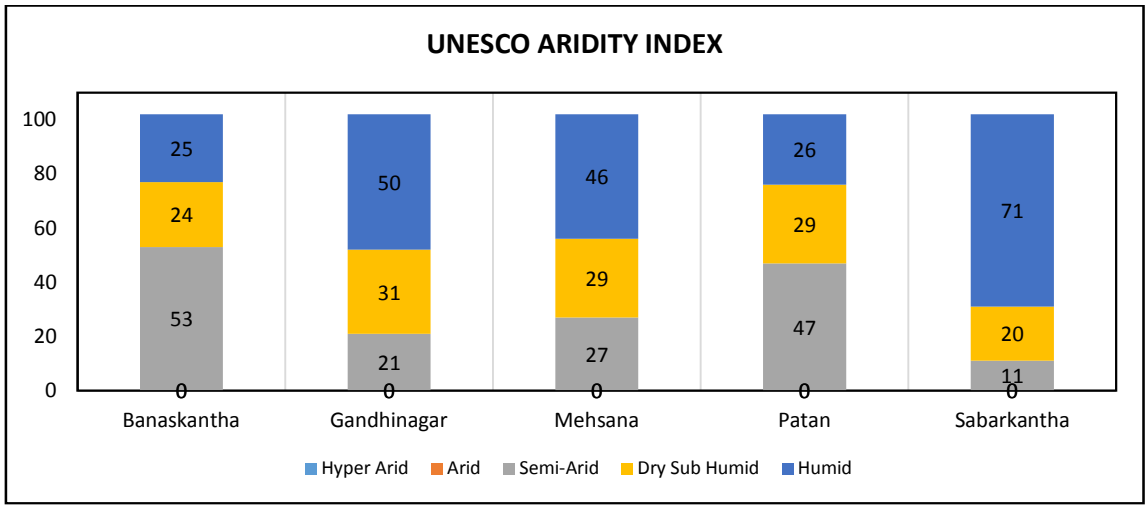


Figure 5.51: Graphical representation of UNESCO Aridity Index over North Gujarat region

From the above Figure 5.51 it was observed that Sabarkantha district is more humid compared to other North Gujarat district. The district having 71 years humid, 20 years as dry sub humid and 11 years as semi-arid. Whereas Banaskantha district having highest number of semi-arid year with 53 years and Gandhinagar having least number of semi-arid years as 21.

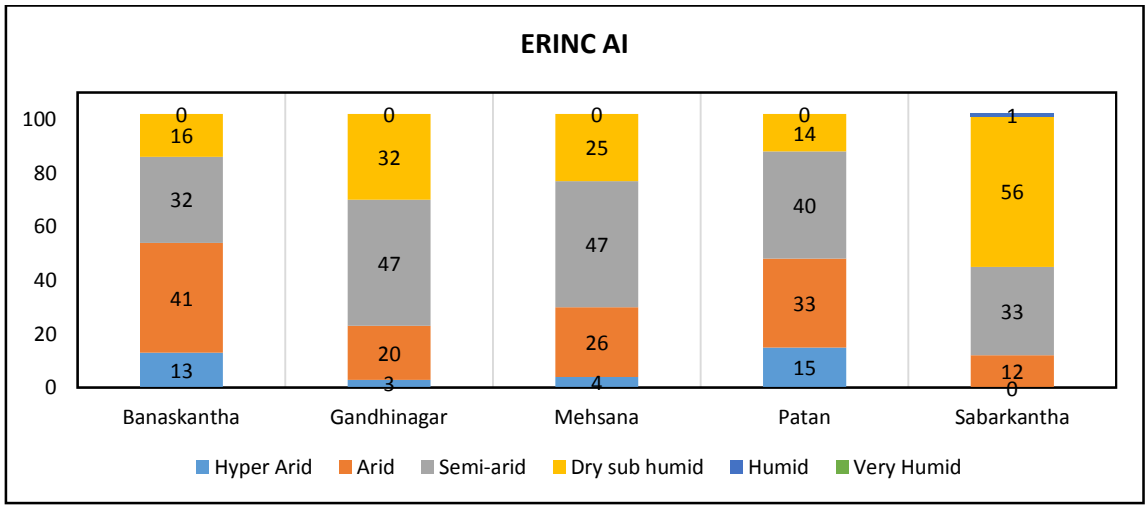


Figure 5.52: Graphical representation of Erinc Aridity Index over North Gujarat region

The comparative results of Erinc aridity index is shown in above Figure 5.52 from this it was concluded that Banaskantha district is very humid whereas Gandhinagar is less humid number of years. Also, Sabarkantha district having highest number of years 56 with dry sub humid category and Patan district having 14 number of years.

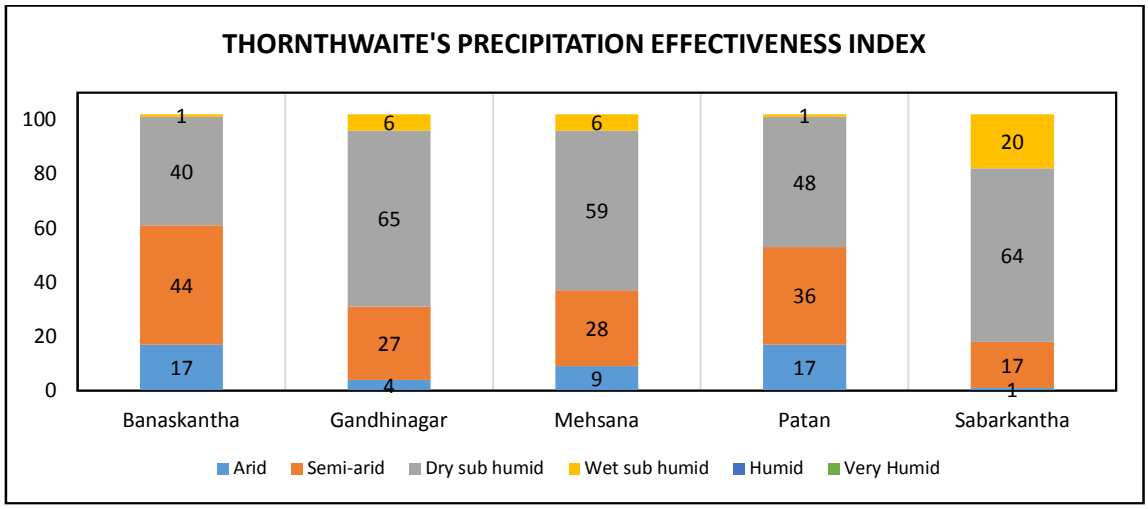


Figure 5.53: Graphical representation of Thornthwaite's Precipitation Effectiveness Index over North Gujarat region

The Comparative analysis of Thornthwaite's precipitation effectiveness index over North Gujarat districts is shown in above Figure 5.53. From this it is concluded that Banaskantha district is more humid whereas Gandhinagar district is less humid with 17 years and 4 years respectively over 1901 to 2002 study period. Also, Sabarkantha district having highest number of years with dry sub humid (64 years).

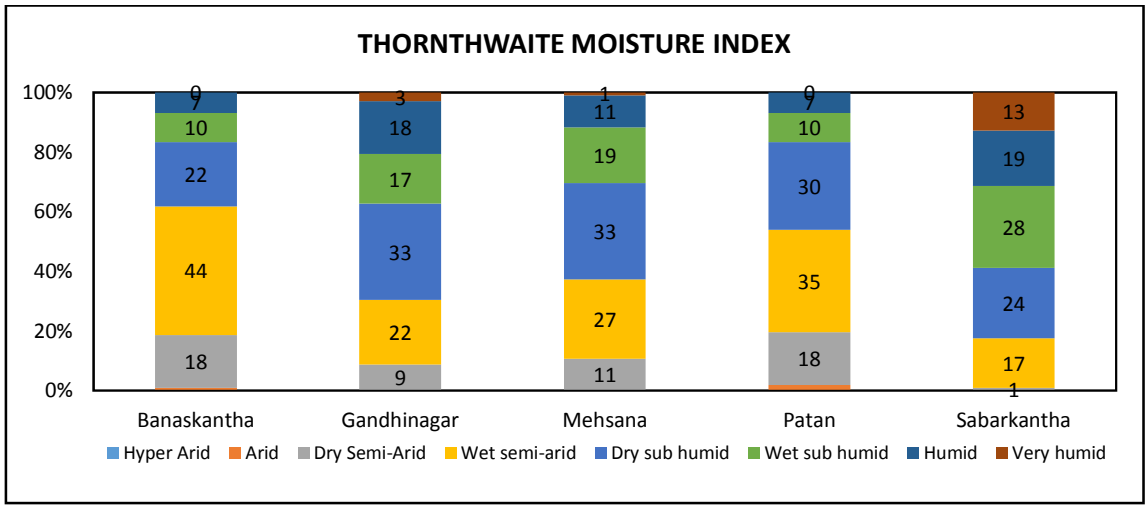


Figure 5.54: Graphical representation of Thornthwaite Moisture Index over North Gujarat region

The comparative results of Thornthwaite Moisture Index is shown in above Figure 5.54 from this it was concluded that Banaskantha, Patan and Sabarkantha district having 18% years as dry semi-arid.Also,20 to 25% years as humid in North Gujarat district.

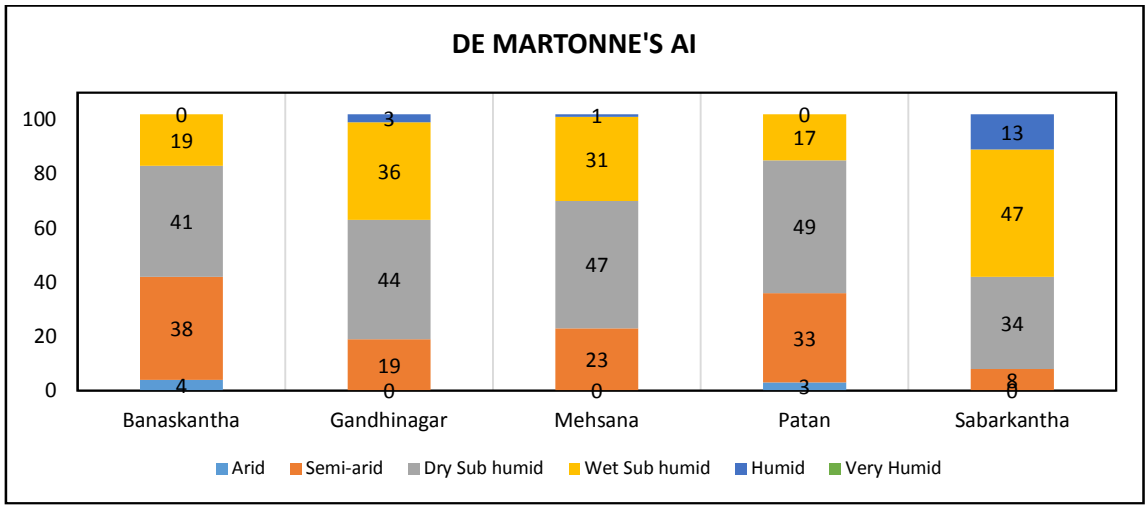


Figure 5.55: Graphical representation of De Martonne's AI Index over North Gujarat region

The results of De Martonne's AI Index over North Gujarat region is shown in above Figure 5.55. The results shows that Sabarkantha district has 8 to 10% of the district is arid while 15% area is semi-arid. Also, Gandhinagar district is less semi-arid with 19% of the total study area.

5.4 FREQUENCY ANALYSIS OF METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

Drought frequency was calculated for the different drought classes for various drought indices. Frequency of meteorological drought indices shows that the occurrence duration and percentage of drought events over a given time period.

Understanding the frequency of meteorological drought events is crucial for water resource management, agriculture, and disaster preparedness. It helps stakeholders assess the risk and impact of drought, plan for water resource management, and make informed decisions on water allocation, agricultural practices, and drought mitigation strategies.

Percent of Normal Index

Table 5.112: Frequency Analysis of Percent of Normal Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely Drought	7	3	3	6	1
Severe Drought	8	7	9	10	7
Moderate Drought	18	17	17	16	17

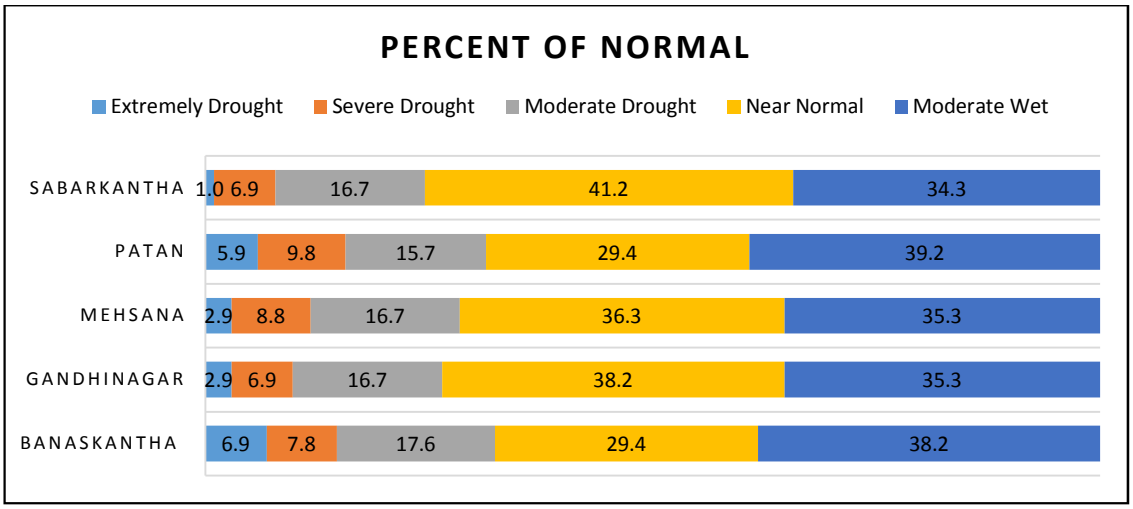


Figure 5.56: Frequency Analysis of PN

The results of frequency analysis of Percent of Normal index is shown above Table 5.112 and the graphical represent of percentage distribution under each class is shown in above Figure 5.56.

The results shows that Banaskantha district having 32% of drought events where Gandhinagar districts having 27% years as drought years. Also, from the analysis it was observed that Banaskantha and Patan had extreme droughts (7 and 6 events, respectively), while Gandhinagar and Mehsana had 3 events during 102 years. Similarly, for severe drought events Banaskantha, Mehsana and Patan (8, 9 and 10 events respectively). From the analysis it is observed that Sabarkantha and Gandhinagar have less percentage of drought frequency which about 8% and 10% while Banaskantha and Patan have more drought events.

Percentage of Departure from Mean Index

Table 5.113: Frequency Analysis of Percentage of Departure from Mean Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Severe Drought	10	10	10	15	7
Moderate Drought	18	13	15	15	16
Mild Drought	26	31	29	20	29

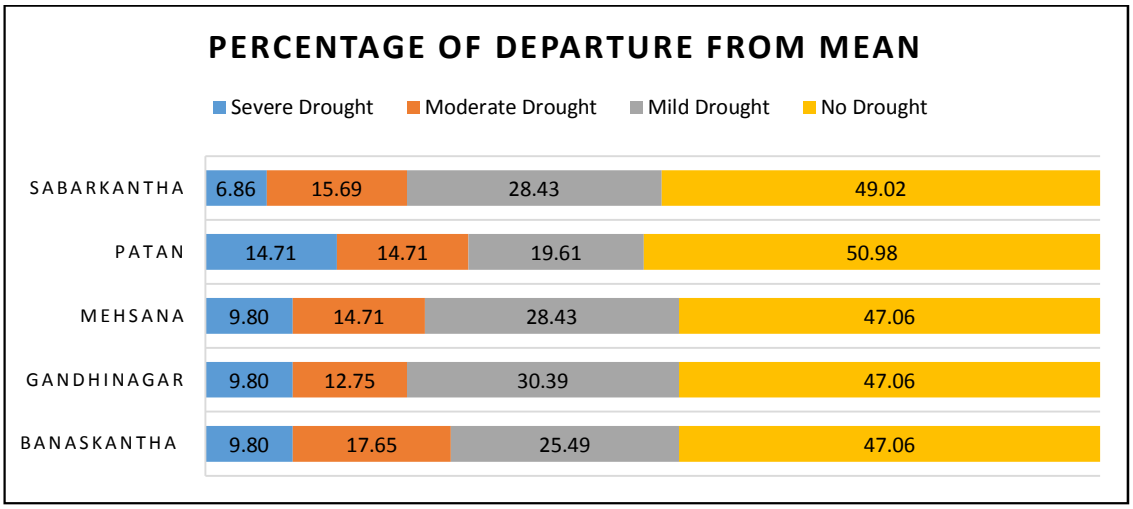


Figure 5.57: Frequency Analysis of PD

The results of frequency analysis of Percentage of Departure from Mean Index is shown above Table 5.113 and the graphical represent of percentage distribution under each class is shown in above Figure 5.57.

The results shows that Banaskantha and Patan had more droughts events (28 and 30 events, respectively), while Gandhinagar and Mehsana had 23 and 25 events during 102 years. While Sabarkantha had 23 events of drought (7 and 16 years).Sabarkantha district has highest amount of rainfall during study period of 102 years. From the graph it is observed that Sabarkantha and Gandhinagar have less percentage of drought frequency which about 22% and 21% while Banaskantha and Patan have 27% and 29% more drought events.

Rainfall Anomaly Index

The results of frequency analysis of Rainfall Anomaly Index is shown below Table 5.114 and the graphical represent and percentage distribution under each class is shown in Figure 5.58.

Table 5.114: Frequency Analysis of Rainfall Anomaly Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely dry	0	3	2	0	1
Very dry	10	12	12	14	10
Moderate dry	18	16	14	16	21
Slight dry	17	15	14	13	8
Normal	23	17	17	24	30

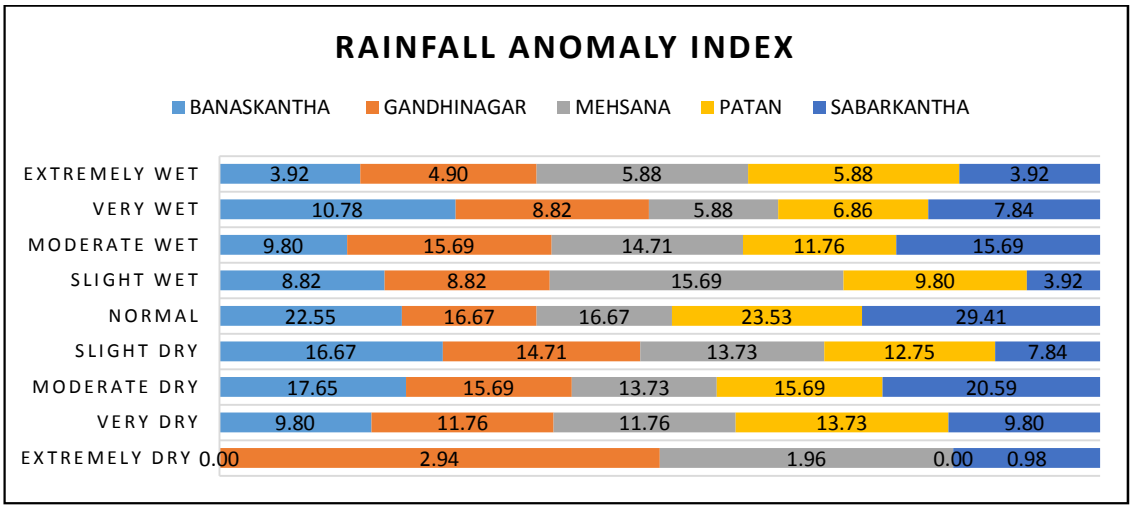


Figure 5.58: Frequency Analysis of RAI

The Sabarkantha district results shows that very dry years as 10 years (9.8%), Moderate dry years as 21 years (20.59%), Slight dry year as 8 years (7.8%), Extreme wet years as 4 years (3.9%), Very wet years as 8 number of years (7.84%). Similar for other class and districts the results as shows in above Table 4.3 and Figure 4.3. From the above index it was observed that Banaskantha district had less number of very dry and extreme wet as 3.92% and 9.80% respectively. Also, Sabarkantha district had highest percentage of moderate drought as 20.59%.

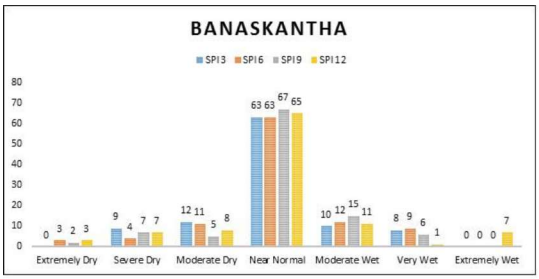
Standardised Precipitation Index

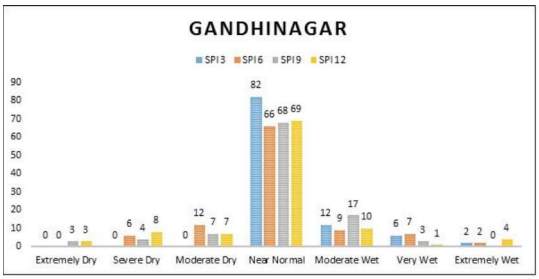
The results of frequency analysis of Standardised Precipitation Index is shown below Table 5.115 and the graphical represent and percentage distribution under each class is shown in Figure 5.59.

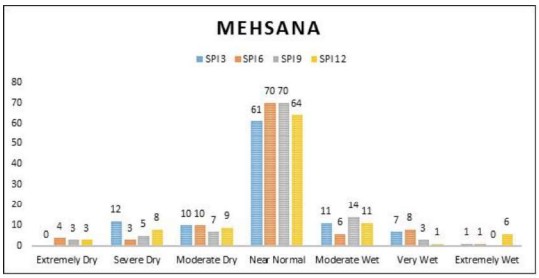
The standardized precipitation index (SPI) is used for drought estimation, which serves as an ideal tool for drought monitoring and analysis. The SPI has been computed for four time scales, viz., 3- (3m-SPI), 6- (6m-SPI), 9- (9m-SPI) and 12-month time scale (12m-SPI). Multiple time scales are used to determine the drought occurrence.

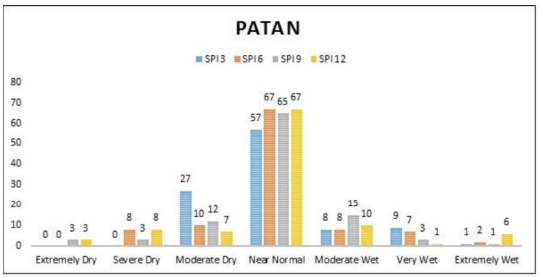
Table 5.115: Frequency Analysis of Standardised Precipitation Index

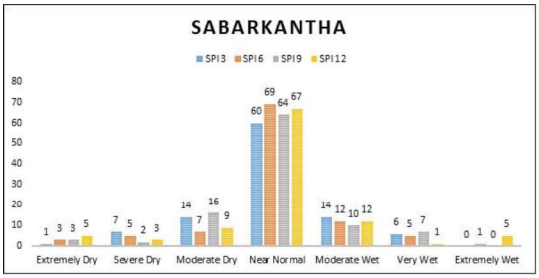
Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely Dry	3	3	3	3	5
Severe Dry	7	8	8	8	3
Moderate Dry	8	7	9	7	9
Near Normal	65	69	64	67	67











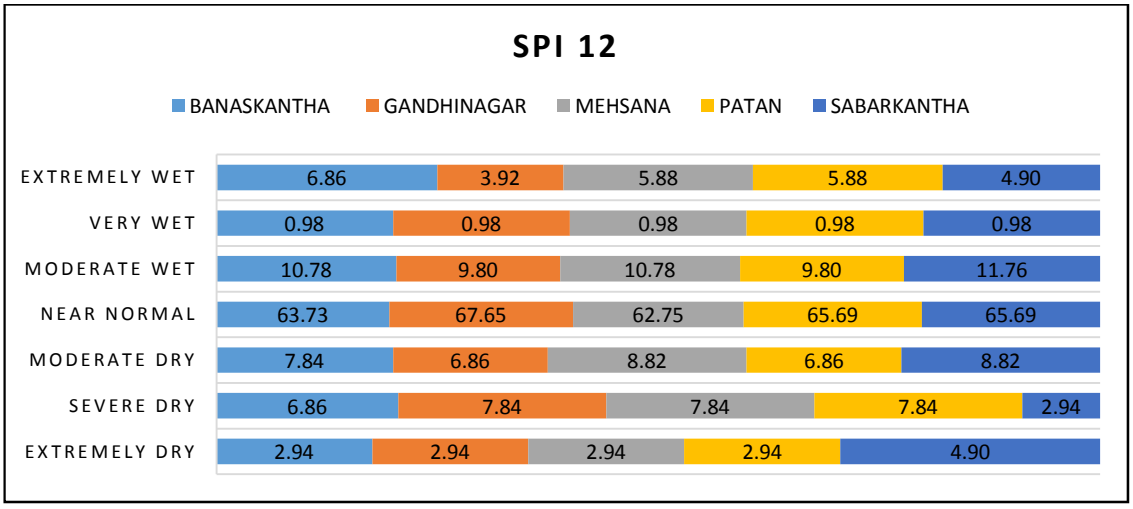


Figure 5.59: Frequency Analysis of SPI 3, 6, 9, 12

The results of Banaskantha district shows that extreme wet (7 years), Moderate wet (11 years) whereas Moderate dry and severe dry as 8 years and 7 years respectively. So around 18% years as dry condition and 16% years as wet condition in study region.

From the above Table 5.115 and Figure 5.59 it was observed that in Sabarkantha district is less affected by severe drought condition as only 3% whereas other districts having 8% years. For 12 month SPI it was observed that 60% to 67% of the years were classified as near normal condition. While the percentages ranged from 6% to 9% for moderately drought and for severely drought conditions as 2% to 8% in particular north Gujarat region. It is observed 65% years in North Gujarat district having near normal condition, 18% years as drought affected and 16% as wet condition during study period viz. 1901 to 2002.

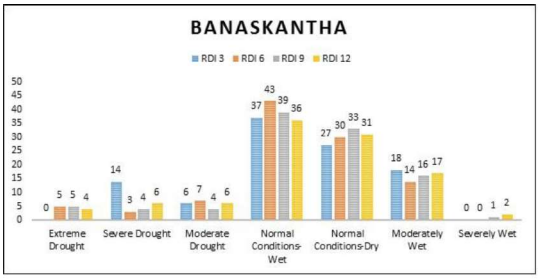
Reconnaissance Drought Index

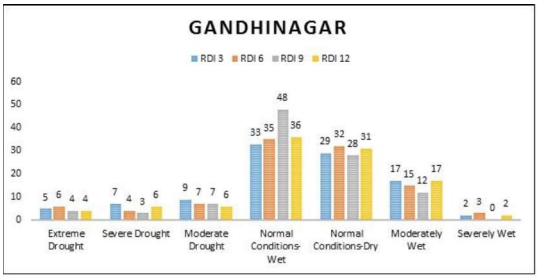
The results of frequency analysis of Reconnaissance Drought Index is shown below Table 5.116 and the graphical represent and percentage distribution under each class is shown in Figure 5.60.

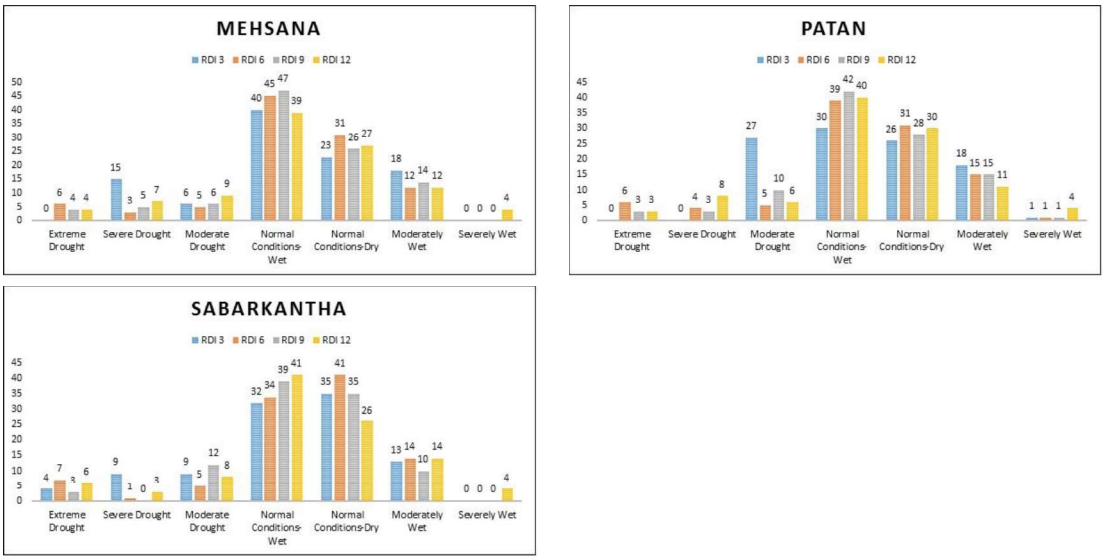
The RDI has been computed for four time scales, viz., 3- (3m-RDI), 6- (6m-RDI), 9- (9m-RDI) and 12-month time scale (12m-RDI). Multiple time scales are used to determine the drought occurrence.

Table 5.116: Frequency Analysis of Reconnaissance Drought Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extreme Drought	4	4	4	3	6
Severe Drought	6	6	7	8	3
Moderate Drought	6	6	9	6	8
Normal Conditions-Dry	31	31	27	30	26







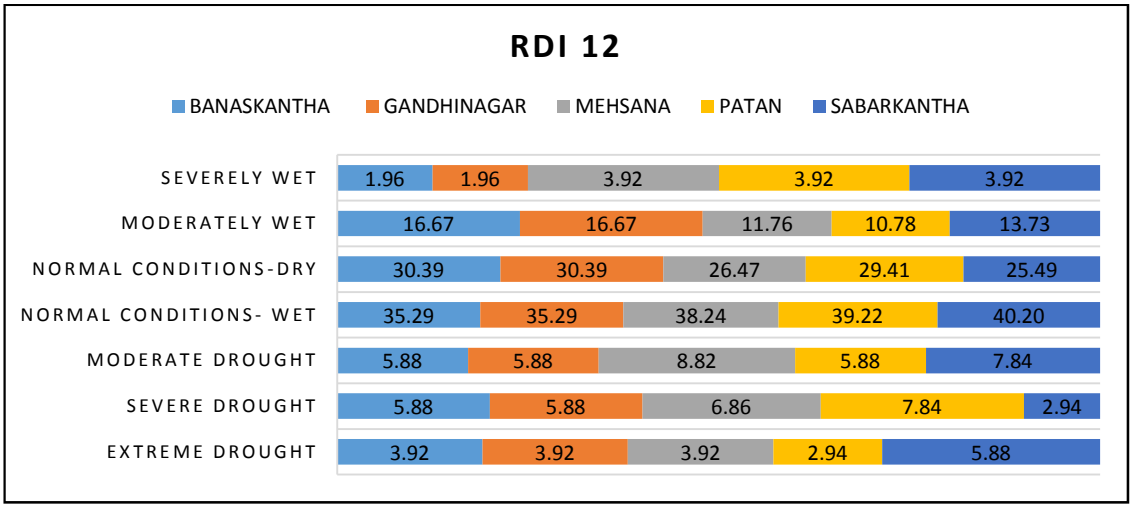


Figure 5.60: Frequency Analysis of RDI 3, 6, 9, 12

The results of Banaskantha district shows that severe wet (2 years), Moderate wet (17 years) whereas extreme dry and severe dry as 4 years and 6 years respectively. So around 19% years as dry condition and 16% years as wet condition in study region.

From the above Table 5.116 and Figure 5.60 it was observed that in Sabarkantha district is less affected by severe drought condition as only 3% whereas other districts having 5 to 8% years. For 12 month RDI it was observed that 25% to 30% of the years were classified as near normal- dry condition. While the percentages ranged from 5% to 8% for moderately drought and for severely drought conditions as 3% to 7% in particular North Gujarat region. It is observed 35 to 40% years in North Gujarat district having near normal-wet condition, 18% years as drought affected and 16% as wet condition during study period.

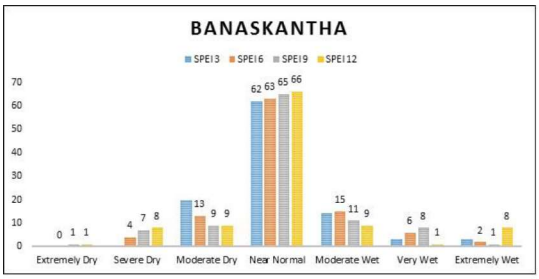
Standardised Precipitation Evapotranspiration Index

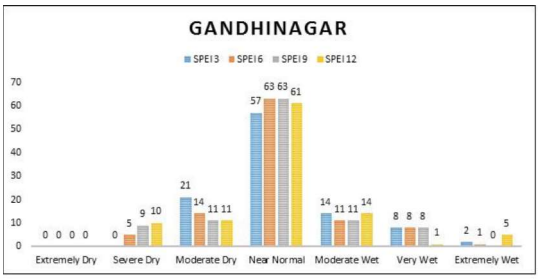
The results of frequency analysis of Standardised Precipitation Evapotranspiration Index is shown below Table 5.117 and the graphical represent and percentage distribution under each class is shown in Figure 5.61.

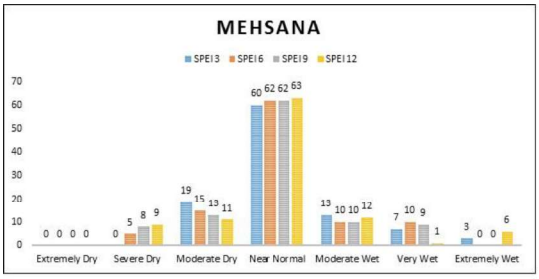
The results of standardized precipitation index (SPEI) has been computed for four time scales, viz., 3- (3m-SPEI), 6- (6m-SPEI), 9- (9m-SPEI) and 12-month time scale (12m SPEI) .

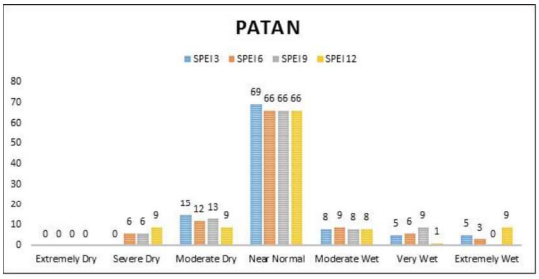
Table 5.117: Frequency Analysis of Standardised Precipitation Evapotranspiration Index

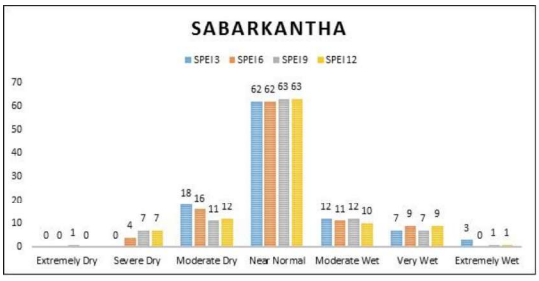
Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely Dry	1	0	0	0	0
Severe Dry	8	10	9	9	7
Moderate Dry	9	11	11	9	12
Near Normal	66	61	63	66	63











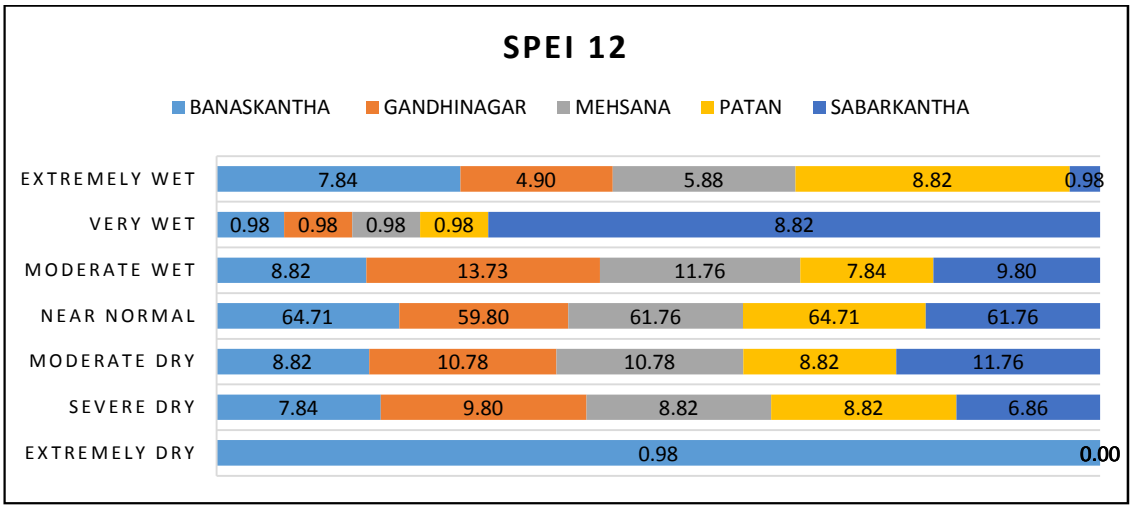


Figure 5.61: Frequency Analysis of SPEI 3, 6, 9, 12

The results of Banaskantha district shows that extreme wet (8 years), Moderate wet (9 years) whereas extreme dry and severe dry as 1 years and 8 years respectively. Where, Patan district shows severe dry and moderate dry as 9 years, moderate wet and extreme wet years as 9 years.

From the above Table 5.117 and Figure 5.61 it was observed that in Sabarkantha district is less affected by severe drought condition as only 6% whereas other districts having 8 to 10% years. For 12 month SPEI it was observed that 60% to 65% of the years were classified as near normal. While the percentages ranged from 5% to 8% for moderately drought and for severely drought conditions as 3% to 7% in particular north Gujarat region. It is observed 35 to 40% years in north Gujarat district having near normal-wet condition, 18% years as drought affected and 16% as wet condition during study period.

China Z Index

The results of frequency analysis of China Z Index is shown below Table 5.118 and the graphical represent and percentage distribution under each class is shown in Figure 5.62.

Table 5.118: Frequency Analysis of China Z Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely Dry	20	17	18	19	17
Severe Dry	0	3	2	0	2
Moderate Dry	4	2	3	3	3
Near Normal	57	55	58	61	56

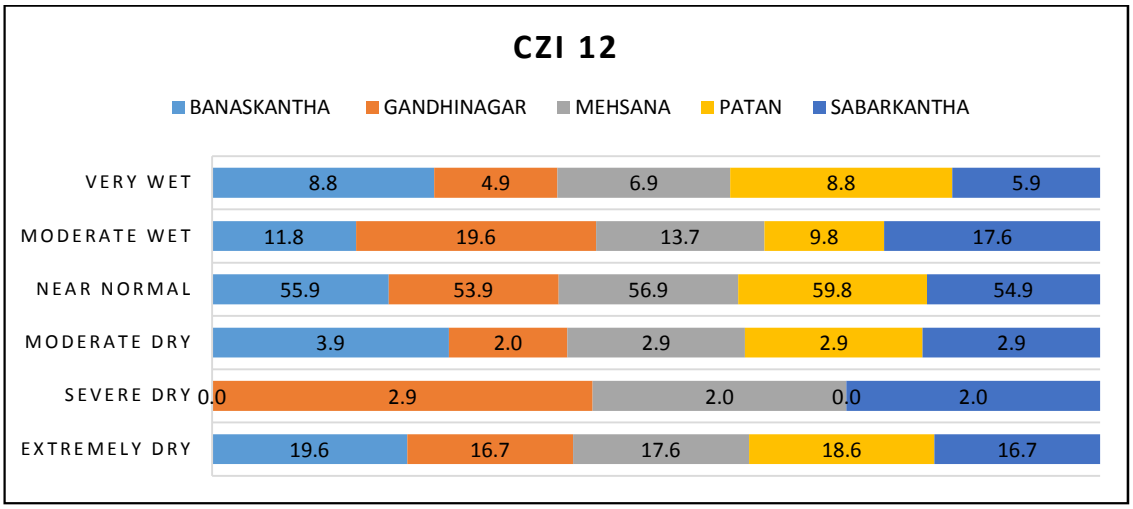


Figure 5.62: Frequency Analysis of CZI 12

The results of China Z index shows that Banaskantha district having more dry years compared to other districts with 20 years. From the above Table and Figure it was observed that in Sabarkantha and Gandhinagar district is less affected by drought condition and having less near normal conditions with 55 years. It is also observed that Banaskantha district having 19.6% years as extreme dry years and having 8.8% years as very wet conditions. The results also shows that Gandhinagar district having less dry conditions.

Modified China Z Index

The results of frequency analysis of Modified China Z Index is shown below Table 5.119 and the graphical represent and percentage distribution under each class is shown in Figure 5.63.

Table 5.119: Frequency Analysis of Modified China Z Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Extremely Dry	18	14	18	20	17
Severe Dry	2	2	2	1	2
Moderate Dry	0	5	3	3	3
Near Normal	59	52	55	59	55

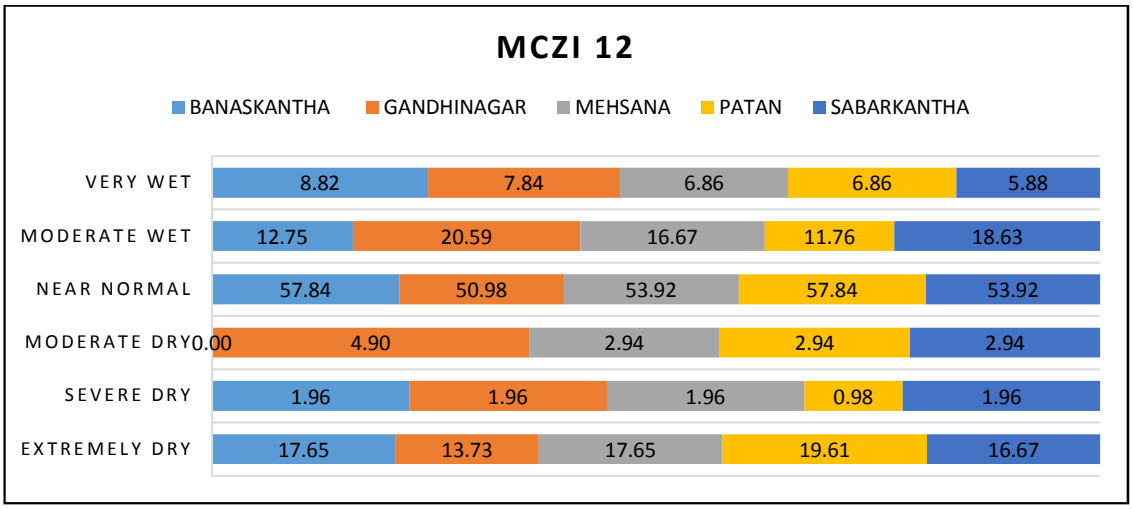


Figure 5.63: Frequency Analysis of MCZI 12

The results of Modified China Z index shows that Banaskantha district having more dry years compared to other districts with 18 years. From the above Table 5.119 and Figure 5.63 it was observed that in Sabarkantha and Gandhinagar district is less affected by drought condition and having less near normal conditions with 52 years. It is also observed that Banaskantha district having 19.6% years as extreme dry years and having 8.8% years as very wet conditions. The results also shows that Gandhinagar district having less dry conditions.

Z score Index

The results of frequency analysis of Z score Index is shown below Table 5.120 and the graphical represent and percentage distribution under each class is shown in Figure 5.64.

Table 5.120: Frequency Analysis of Z score Index

Classification	Banaskantha	Gandhinagar	Mehsana	Patan	Sabarkantha
Severe Dry	7	9	8	5	7
Moderate Dry	10	10	12	13	10
Near Normal	66	67	64	67	67

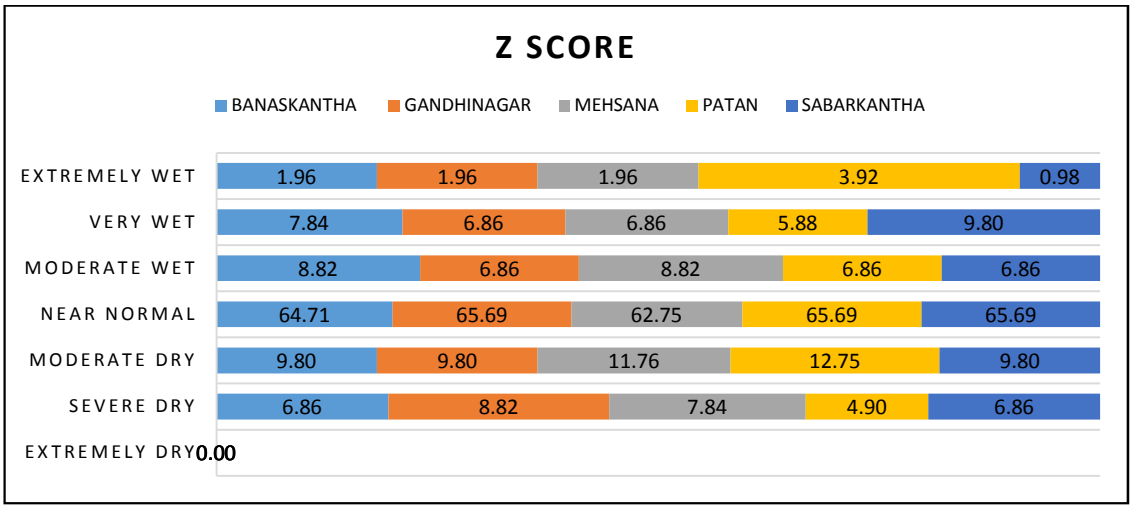


Figure 5.64: Frequency Analysis of Z score Index

The results shows that Gandhinagar and Mehsana had more severe drought events (9 and 8 events, respectively), while Patan had 5 events of severe drought during 102 years. Also, Sabarkantha district having 8% percentage years with very wet conditions and Patan districts having 3% percentage years with extreme wet conditions during study period.

5.4.1 Comparative Analysis of Frequency Analysis of Meteorological Drought Indices

Drought frequency was calculated for the different drought classes for various drought indices. Frequency of meteorological drought indices shows that the occurrence duration and percentage of drought events over a given time period.

The comparative results of meteorological drought indices shows that Banaskantha and Patan had more droughts events (28 and 30 events, respectively), while Gandhinagar and Mehsana had 23 and 25 events during 102 years. While Sabarkantha had 23 events of drought (7 and 16 years). The Sabarkantha district results shows that very dry years as 10 years (9.8%), Moderate dry years as 21 years (20.59%), Slight dry year as 8 years (7.8%), Extreme wet years as 4 years (3.9%), Very wet years as 8 number of years (7.84%). Also, Sabarkantha and Gandhinagar districts have less percentage of drought frequency which about 22% and 21% while Banaskantha and Patan have 27% and 29% more drought events. The percentage of drought years can provide valuable insights into the characteristics and trends of meteorological droughts and also rainfall variation in a North Gujarat region.

For 12 month SPI, RDI and SPEI it was observed that 18% to 20% years were classified as drought years. It is also observed that 50% to 60% years in north Gujarat district having near normal condition dry conditions, and 16% as wet

condition during study period. By analyzing the frequency distribution of drought indices, one can estimate the probability of experiencing drought events of different magnitudes. The results also used to compare drought characteristics between different regions, which is valuable for understanding regional disparities in drought risk and management.

The conclusions drawn from frequency analysis are essential for making informed decisions related to water resource management, agriculture, and disaster preparedness in drought-prone regions. It's important to note that the specific conclusions of a frequency analysis will vary depending on the dataset, the choice of drought indices, and the time period under consideration. Additionally, these conclusions should be interpreted in the context of local climate and environmental conditions to inform effective drought mitigation and adaptation strategies.

5.5 ESTIMATION OF VARIOUS HYDROLOGICAL DROUGHT INDICES OVER STUDY AREA

Hydrological drought analysis typically involves the assessment of water availability and the impact of drought on various water resources. The multiband rationing technique has been used to extract the water area from Landsat imageries. Surface water monitoring is a necessary component of researching ecological and hydrological processes. Three water indices, namely Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Water Ratio Index (WRI) used and these is based on the spectral index method using ArcGIS software. These are most popular remote sensing indices used to assess water bodies and changes in water content and can be valuable tools for hydrological drought assessment.

The Normalized Difference Salinity Index (NDSI) is also calculated using Landsat data to identify areas with varying levels of salinity in water bodies. Positive NDSI values may indicate areas with higher salinity. Negative NDSI values may indicate areas with lower salinity.

The Landsat data different years have been used for monitoring and mapping of water spread area in North Gujarat districts. Hydrological drought indices was formulated using the arc toolbox with a math calculator and procured an different raster images of different indices with pixel values ranging from - 1 to +1, and further, the developed images were reclassified in the ArcGIS environment.

5.5.1 Estimation of Hydrological drought indices over Banaskantha district

NDWI is a remote sensing index that uses the reflectance values of the near-infrared (NIR) and shortwave infrared (SWIR) bands. Similarly, MNDWI index that uses, green band (GREEN) band 3, and SWIR is a near Shortwave Infrared (SWIR) band 6.This index maximizes reflectance of water by using green light wavelengths and minimizes low reflectance of SWIR by water features. The key phases include (NDWI and MNDWI) monitoring changes in water bodies over time using satellite data. The high NDWI or MNDWI values indicate the presence of water bodies, low values indicate the reduction in water content and may be turn in to hydrological drought conditions. These indices particularly useful for monitoring changes in surface water content. Also useful in identifying the years and the areas which experiencing a reduction in water content, which may indicate hydrological drought conditions.

Analyze the NDWI and MNDWI values over different time periods to observe changes in water content. The results of the research from NDWI index reveal that the surface water bodies may vary from in Banaskantha district from 2001 to 2019 year. The results of NDWI index with percentage area having water spread area in district with annual rainfall for corresponding year is shown in below Figure 5.65.

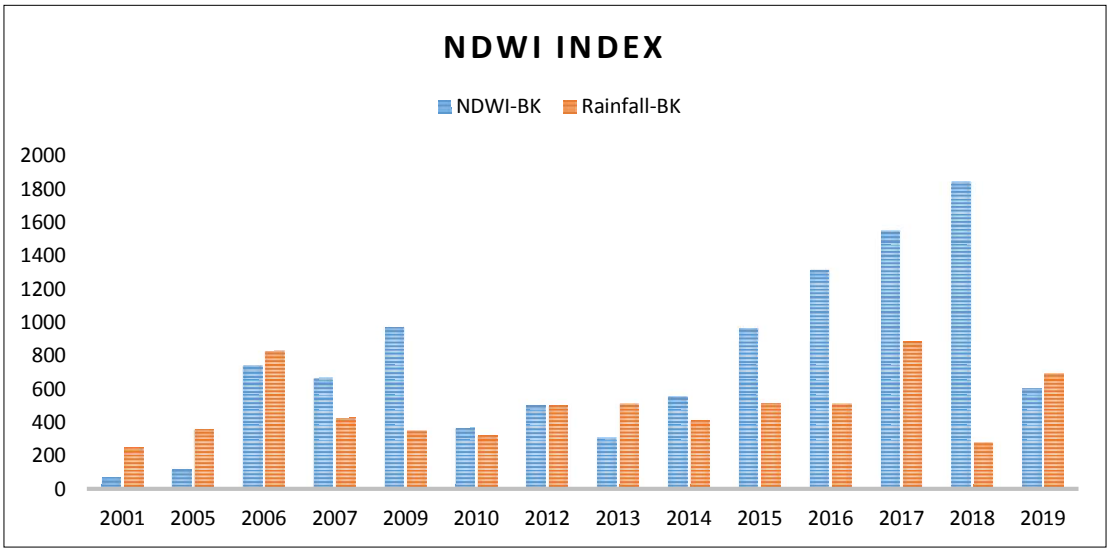


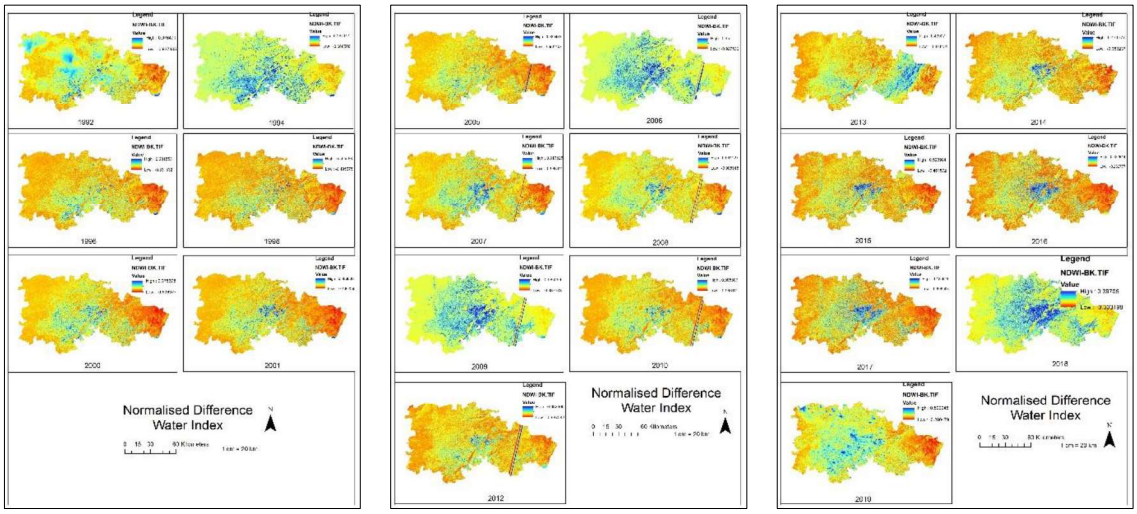
Figure 5.65: NDWI Index for Banaskantha district

From the above Figure 5.65, it was observed that the minimum area and maximum water spread area obtained by NDWI index was 67.40 Sq.km area in 2001 year and 1842.8 Sq.km area in 2018 year. The average water spread area for the studied period was 754.40 Sq.km with a standard deviation (SD) of 524.20 sq. km area. The percentage of water spread area in the district is varies from 5.5% to 15.5% in Banaskantha district during the period of study.

Similarly, the results of MNDWI index shows that minimum water spread area in 2001 year with 7.77 sq.km area and maximum water spread area 84.97 sq.km area in 2012, 91.59 sq.km area in 2019 observed. Also, the average water spread area in the district is 287.93 sq.km area in Banaskantha district during the period of study.

The effectiveness of these indices can also be influenced by the characteristics of the satellite sensor used for data acquisition, such as spatial and spectral resolution. Differences in atmospheric conditions, sun angle, and seasonal variations can affect the reflectance values in the bands used for these indices, leading to variations in results.

Below Map 5.1 shows the spatio-temporal changes of NDWI index over Banaskantha district. Very low values of NDWI (negative values) were recorded near river basin area. On a map, the higher values approaching +1 usually appear dark blue and correspond to either a high water content or a water surface, while the lower values all the way to -1 are the tell-tale signs of drought conditions or low amount of water area. The threshold value between -0.98 and +0.98 has been observed during 2005 to 2012. Threshold value between -0.22 and +0.50 has been observed during 2013 to 2019 which is used to estimate the water spread mapping.

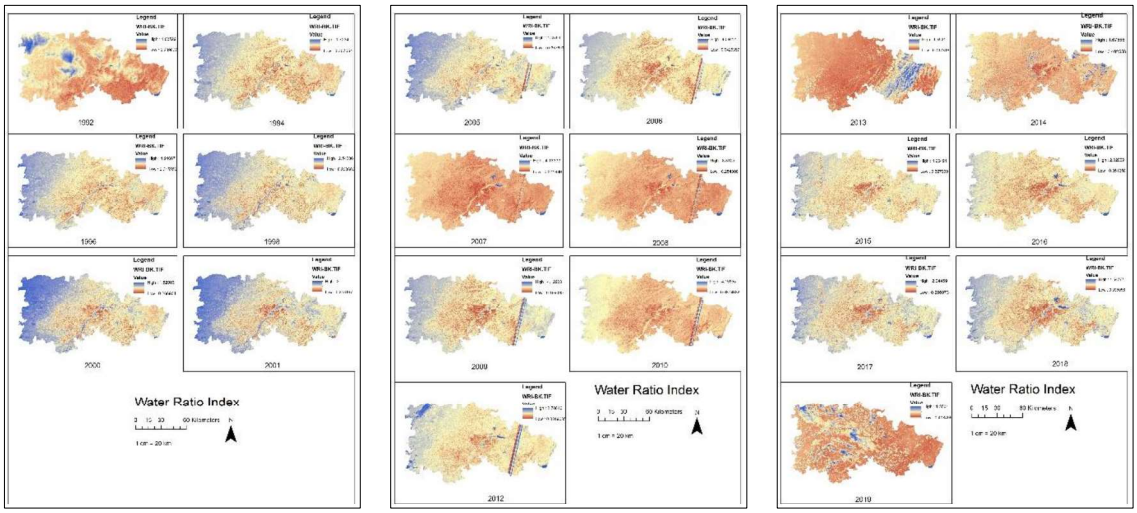


Map 5.1: Normalized Difference Water Index Map of Banaskantha district

The Water Ratio Index (WRI) is used to assess hydrological drought conditions using Landsat data. Water Ratio Index can help in identify the presence or absence of surface water in a given area. Monitoring of WRI values over time to track changes in hydrological conditions. Compare WRI values across different years to assess the severity and duration of hydrological drought events.

The results of WRI shows that in 1998 year least water speared area which is 1672.90 Sq.km area (15.70%). The average water spread area in Banaskantha district is 6122.0 Sq.km which is 57.60% with standard deviation of 2803.71 Sq.km

having 26.37% variation in water bodies during study period. It's important to note that the interpretation of WRI values may vary depending on regional characteristics and the specific hydrological context. The spatio temporal map of WRI index for Banaskantha district is shown in below Map 5.2.



Map 5.2: Water Ratio Index Map of Banaskantha district

The Normalized Difference Salinity Index (NDSI) can be calculated using Landsat data to identify areas with varying levels of salinity in water bodies. Positive NDSI values may indicate areas with higher salinity. Negative NDSI values may indicate areas with lower salinity. Normalized Difference Salinity Index (NDSI), the sand particles show higher reflectance in red band and lesser in near-infrared band. The differences between the red and near infrared bands have turned out to be useful for analyzing, monitoring and calculating the level of soil salinity.

The results of NDSI index shows that minimum 768.30 Sq.km area having very low saline characteristics which covers an area 7.2% of the district.

The moderate saline area in the district was 5795.70 Sq.km area (54.22%) which is maximum in 2006 year and for minimum moderate area observed in 1998 which covers 484.30 Sq.km area which is 4.6% of the district. From the analysis it was observed that average 3027.60 sqkm area which is around 28.5% area of Banaskantha districts having moderate saline characteristics during the study period.

The spatio temporal map of NDSI index for Banaskantha district is shown in below Map 5.3

Map 5.3: Normalized Difference Salinity Index Map of Banaskantha district

In summary, NDWI and NDSI serve different purposes, but combining integrate them in a complementary manner for a more comprehensive analysis of water bodies and salinity within those water bodies. The combination of these indices might be useful for studies in regions where salinity in water bodies is of particular interest. Water spread areas near vegetated regions may exhibit lower salinity.

5.5.2 Estimation of Hydrological drought indices over Gandhinagar district

Below Figure 5.66 shows the results of NDWI index of water spread area with percentage area and rainfall during particular year for Gandhinagar district.

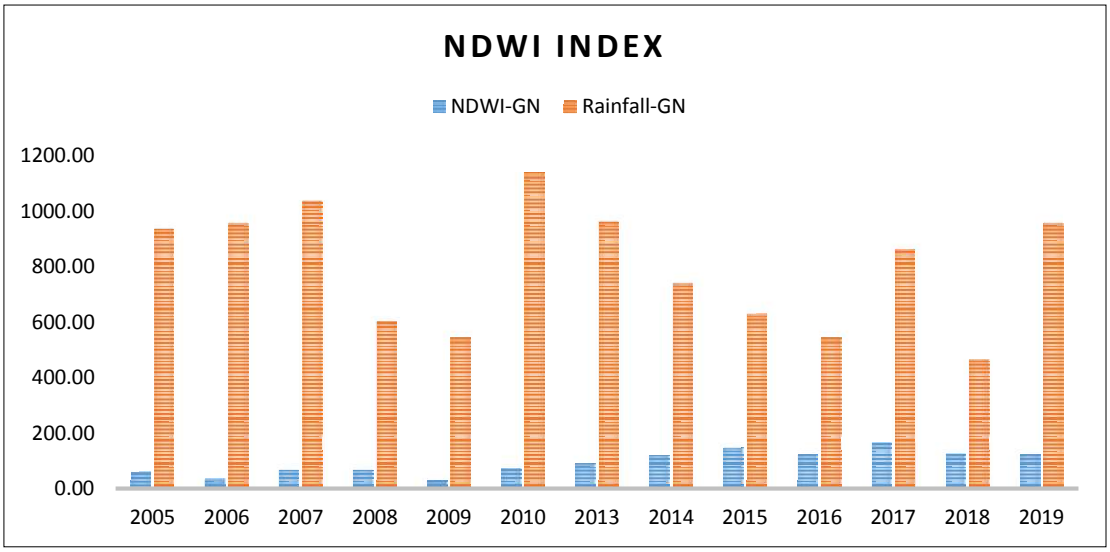
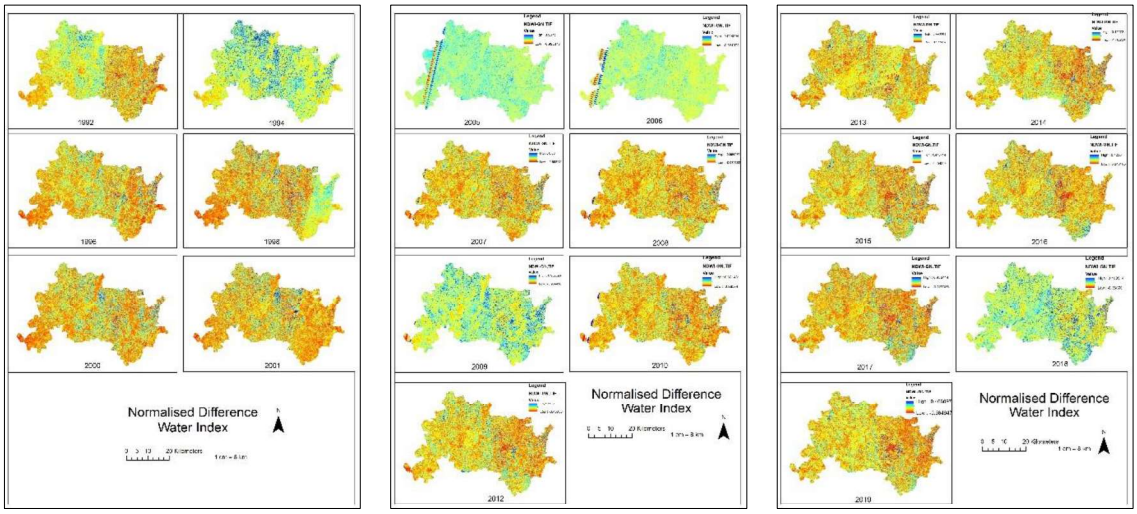


Figure 5.66: NDWI Index for Gandhinagar district

From the above Figure 5.66, it was observed that the minimum and maximum water spread area obtained by NDWI was 27.10 Sq.km area in 2009 year and 165.30 Sq.km area in 2017 year. The average rainfall during 2017 was 859.57 mm. The average water spread area for the studied period was 92.70 Sq.km with a standard deviation (SD) of 42.8 sq. km area. From the Figure 5.2 it is also revealed that as rainfall increases the water spread area is also increased. The percentage water spread area in the district varies from 1.5 % to 9.8% of the Gandhinagar district area.

Similarly, the results of MNDWI index shows that minimum water spread area in 2007 year as 5.92 Sq.km area and maximum water spread area as 15.22 Sq.km area in 2005, 14.37 Sq.km area in 2006 observed. Also, the average water spread area in the district is 64.27 Sq.km area during study period.

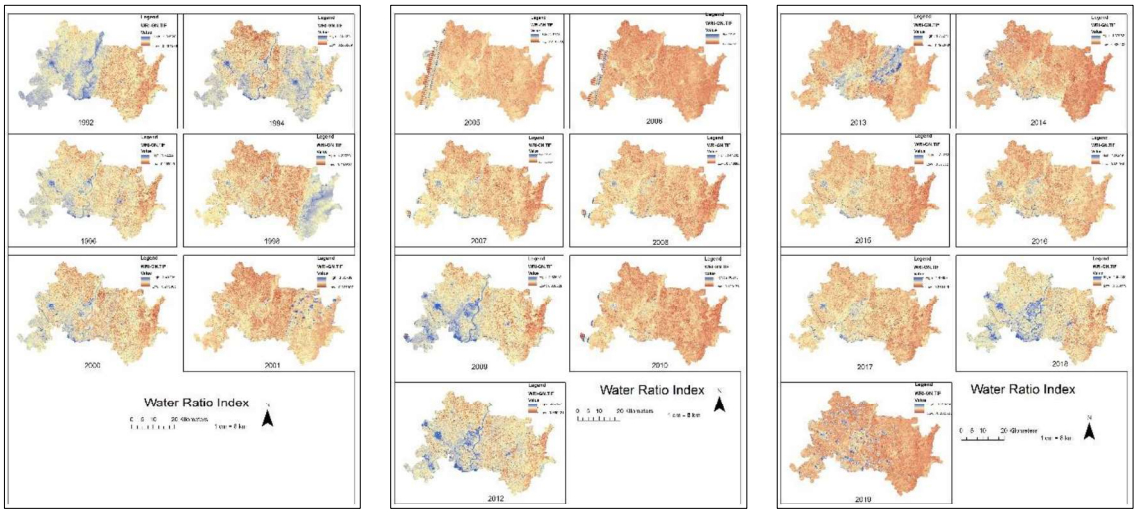
Below Map 5.4 shows the spatio-temporal changes of NDWI over Gandhinagar district.



Map 5.4: Normalized Difference Water Index Map of Gandhinagar district

The results of WRI shows that minimum water spread area as 67.10 Sq.km area (3.90%) in 1996 year. The average water spread area in Gandhinagar district is 614.70 sqkm which is 35.70% with standard deviation of 581.08 Sq.km having 33.70% variation during study period. It's important to note that the interpretation of WRI values may vary depending on regional characteristics and the specific hydrological context.

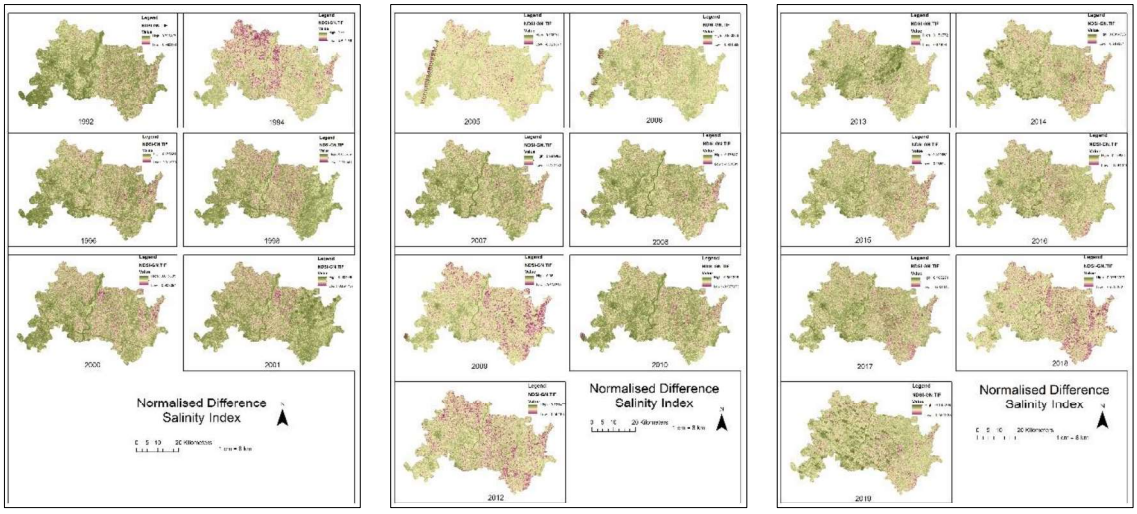
The spatio temporal map of WRI index for Gandhinagar district is shown in below Map 5.5.



Map 5.5: Water Ratio Index Map of Gandhinagar district

The results of NDSI index shows that minimum 1046.48 Sq.km area having very low saline characteristics which covers an area 3.48% of the district. The moderate saline area in the district was 529.88 Sq.km area (30.66%) which is maximum in 2006 year and for minimum moderate area observed in 1998 which covers 21.98 Sq.km area which is 1.30% of the district. From the analysis it was observed that average 203.18 sqkm area which is around 11.80% area of Gandhinagar districts having moderate saline characteristics during the study period.

The spatio temporal map of NDSI index for Gandhinagar district is shown in below Map 5.6



Map 5.6: Normalized Difference Salinity Index Map of Gandhinagar district

5.5.3 Estimation of Hydrological drought indices over Mehsana district

Below Figure 5.67 shows the results of NDWI index of water spread area with percentage area and rainfall during particular year for Mehsana district.

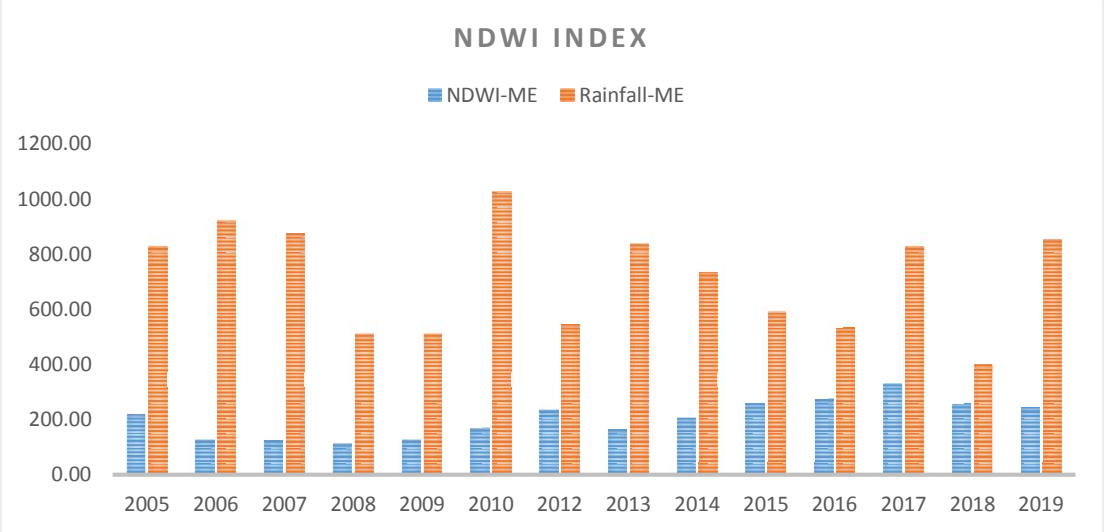
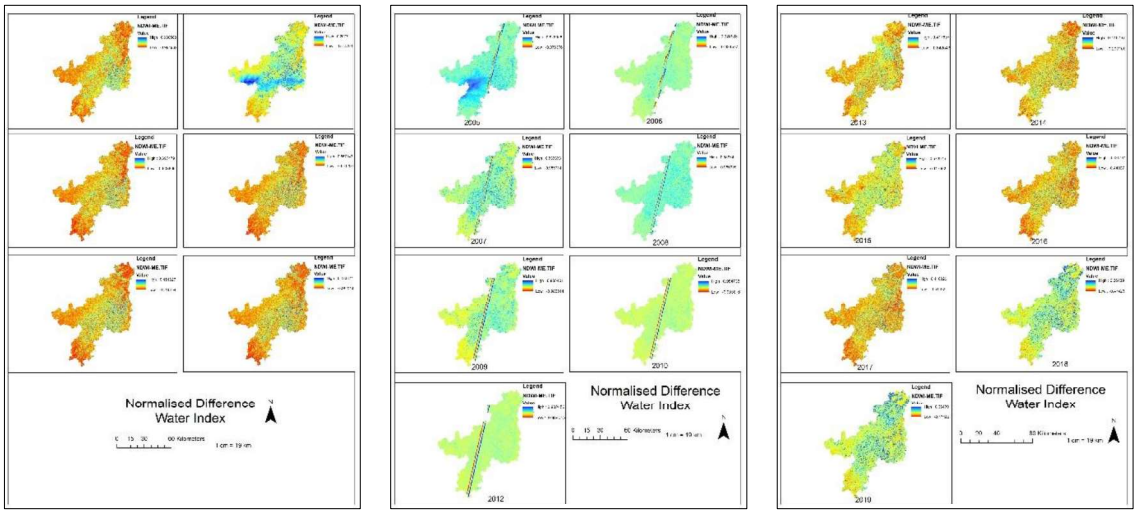


Figure 5.67: NDWI Index for Mehsana district

From the above Figure 5.67, it was observed that the minimum and maximum water spread area obtained by NDWI was 113.30 sq.km area in 2008 year and 329.80 sq.km area in 2017 year. The average rainfall during 2017 was 827.93 mm. The average water spread area for the studied period was 203.40 sq.km with a standard deviation (SD) of 67.10 sq. km area. From the Figure 5.3 it is also revealed that as rainfall increases the water spread area is also increased. The percentage water spread area in the district varies from 2.5% to 8.2%.

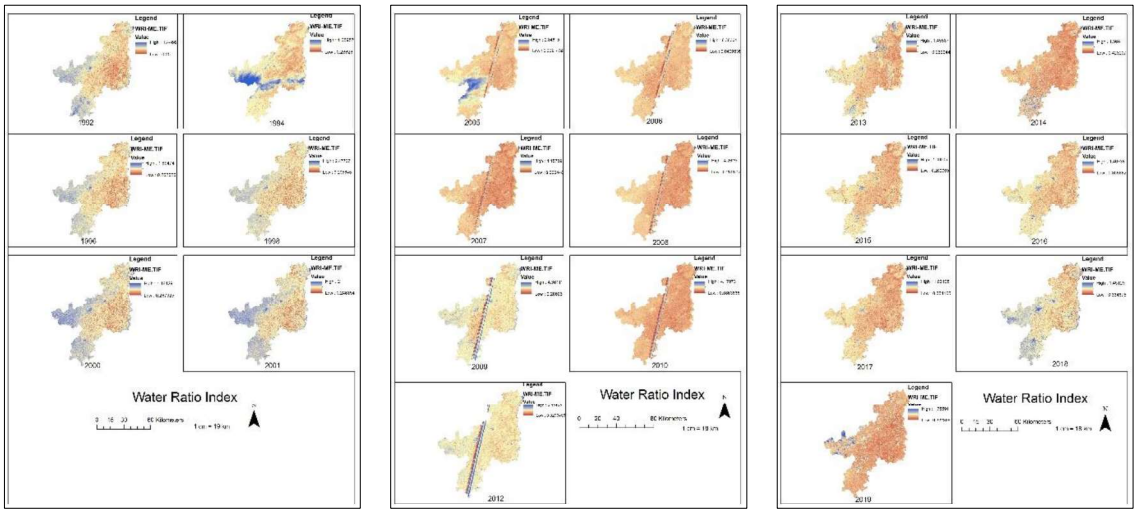
Similarly, the results of MNDWI index shows that minimum water spread area in 1996 year with 3.87 sq.km area and maximum water spread area 82.27 sq.km area in 2012, 61.14 sq.km area in 2010 observed. Also, the average water spread area in the district is 74.80 sq.km area (1.75%) in Mehsana district.

The spatio temporal map of NDWI index for Mehsana district is shown in below Map 5.7



Map 5.7: Normalized Difference Water Index Map of Mehsana district

The results of WRI shows that minimum water spread area as 134.5 sq.km area (3.00%) in 1998 year. The average water spread area in Mehsana district is 1825.40 sq.km which is 41.60% with standard deviation of 1357.58 sq.km having 30.90% variation during study period. It's important to note that the interpretation of WRI values may vary depending on regional characteristics and the specific hydrological context. The spatio temporal map of WRI index for Mehsana district is shown in below Map 5.8

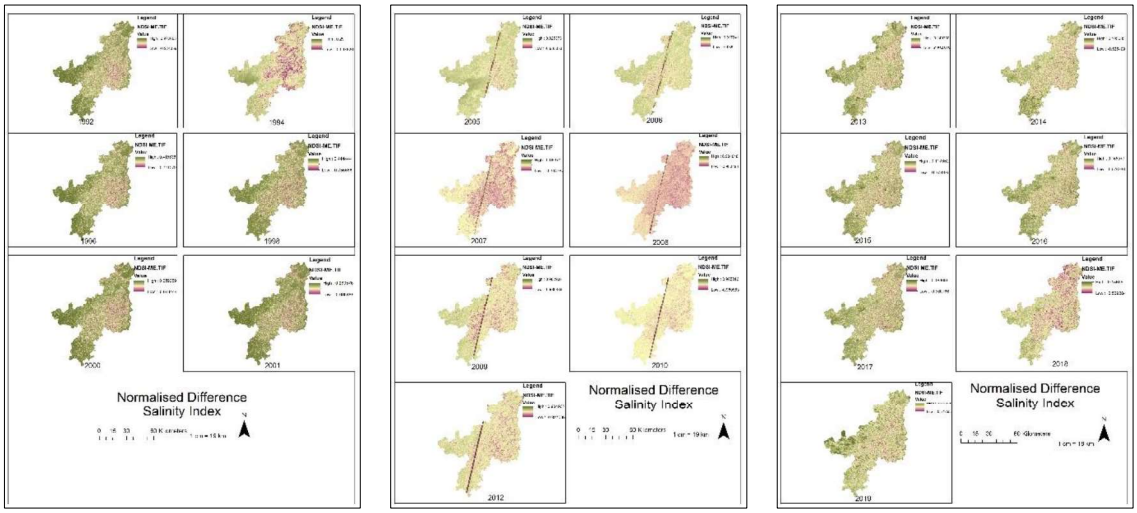


Map 5.8: Water Ratio Index Map of Mehsana district

The results of NDSI index shows that minimum 2437.80 sq.km area having very low saline characteristics which covers an area 55.52% of the district. The moderate saline area in the district was 2606.20 sq.km area (59.34%) which is maximum in 1996 year and for minimum moderate area observed in 1994 which covers 261.60 sq.km area which is 6% of the district. From the analysis it was observed that

average 973.50 sqkm area which is around 22.15% area of Mehsana districts having moderate saline characteristics during the study period.

The spatio temporal map of NDSI index for Mehsana district is shown in below Map 5.9



Map 5.9: Normalized Difference Salinity Index Map of Mehsana district

5.5.4 Estimation of Hydrological drought indices over Patan district

Below Figure 5.68 shows the results of NDWI index of water spread area with percentage area and rainfall during particular year for Patan district.

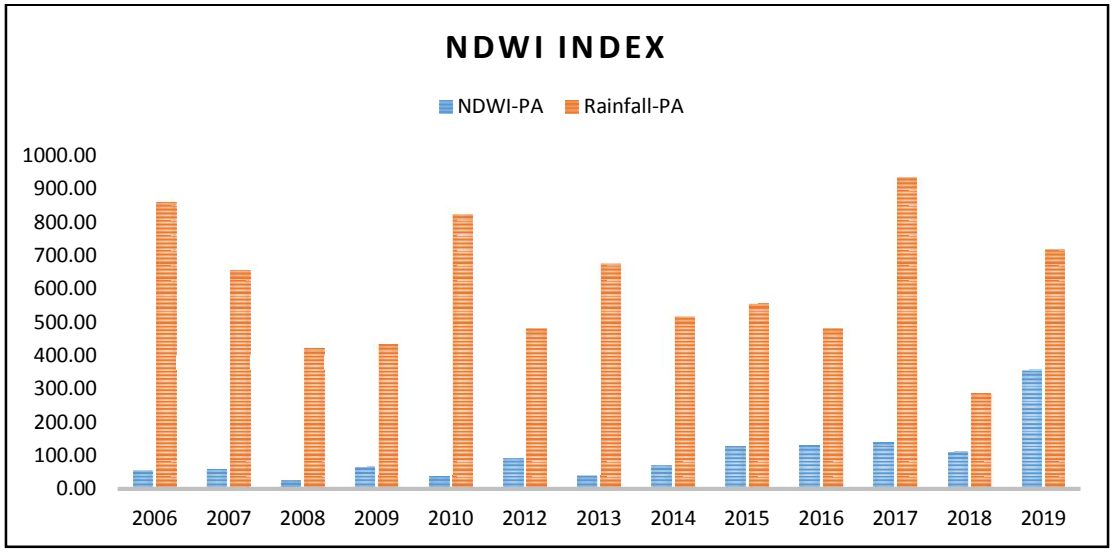


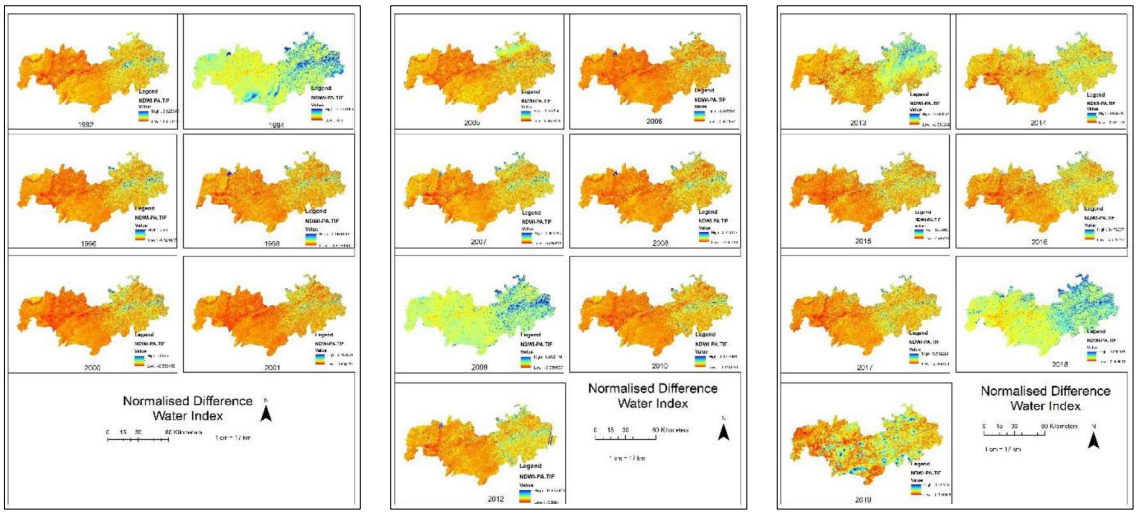
Figure 5.68: NDWI Index for Patan district

From the above Figure 5.68, it was observed that the minimum and maximum water spread area obtained by NDWI index was 24.20 sq.km area in 2008 year and 356.20

sq.km area in 2019 year. The average rainfall during 2019 was 717.20 mm. The average water spread area for the studied period was 99.9 sq.km with a standard deviation (SD) of 85.90 sq. km area. The percentage water spread area in the district varies from 1.5 % to 6.2% in the district.

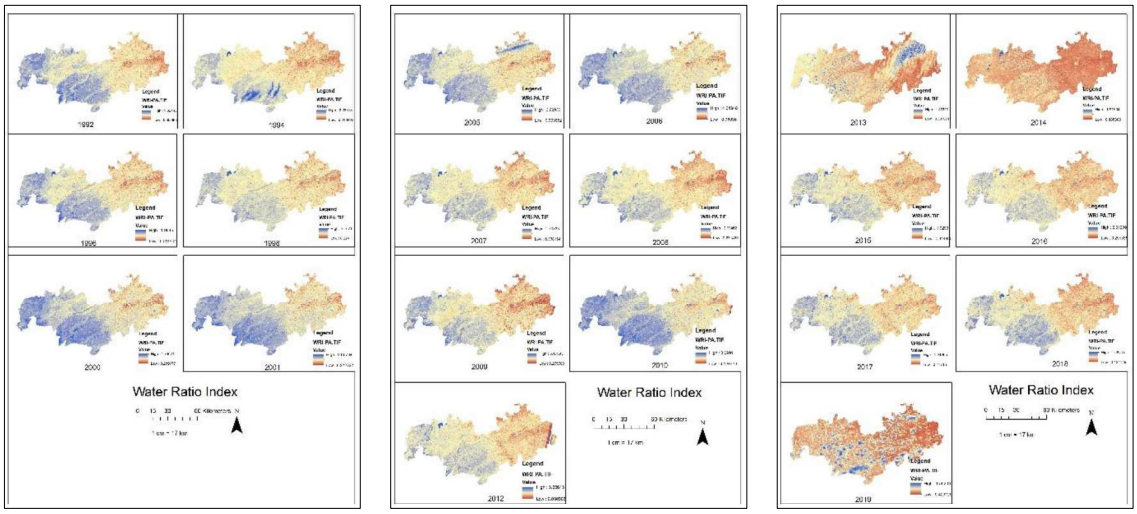
Similarly, the results of MNDWI index shows that minimum water spread area in 2009 year with 10.64 Sq.km area and maximum water spread area 47.23 sq.km area in 2014, 44.81 sq.km area in 2012 observed. Also, the average water spread area in the district is 33.70 sq.km area during study period.

The spatio temporal map of NDWI index for Patan district is shown in below Map 5.10



Map 5.10: Normalized Difference Water Index Map of Patan district

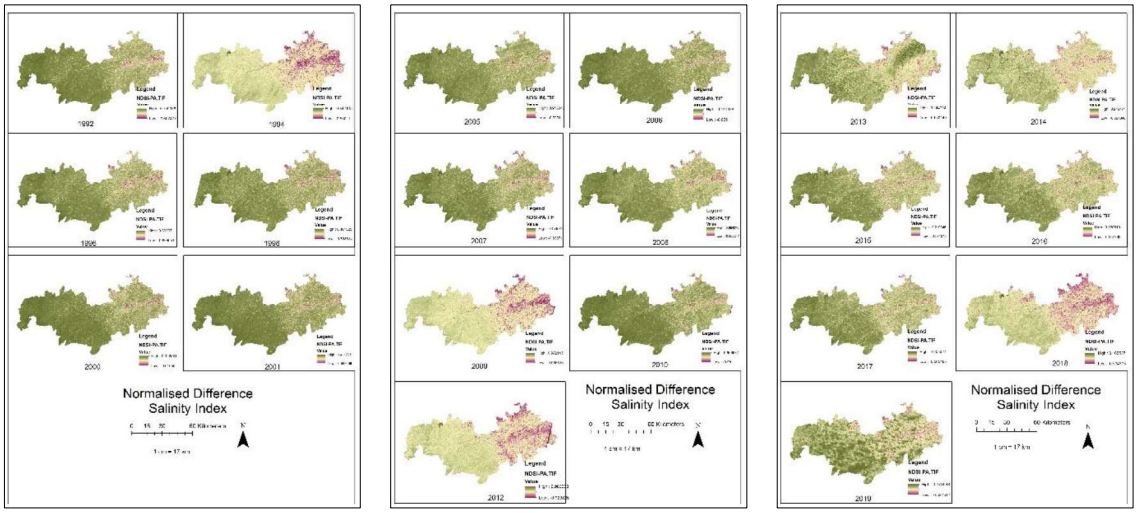
The results of WRI shows that minimum water spread area as 867.80 sq.km area (14.40%) in 2005 year. The average water spread area in Patan district is 3742.10 sq.km which is 62.10% with standard deviation of 1634.3 sq.km having 27.13% variation during study period. The spatio temporal map of WRI index for Patan district is shown in below Map 5.11.



Map 5.11: Water Ratio Index Map of Patan district

The results of NDSI index shows that minimum 1071.70 Sq.km area having very low saline characteristics which covers an area 17.80% of the district. The moderate saline area in the district was 4943 Sq.km area (82.10%) which is maximum in 2006 year and for minimum moderate area observed in 1998 which covers 848.1 sq.km area which is 14.10% of the district. From the analysis it was observed that average 2860 sq.km area which is around 47.15% area of Patan districts having moderate saline characteristics during the study period.

The spatio temporal map of NDSI index for Patan district is shown in below Map 5.12



Map 5.12: Normalized Difference Salinity Index Map of Patan district

5.5.5 Estimation of Hydrological drought indices over Sabarkantha district

Below Figure 5.69 shows the results of NDWI index of water spread area with percentage area and rainfall during particular year for Sabarkantha district.

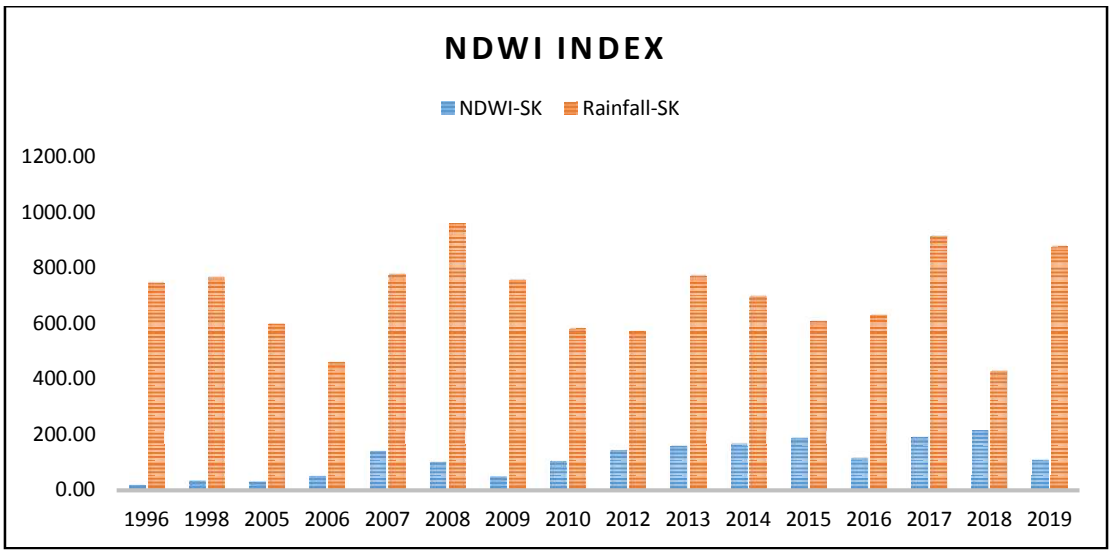
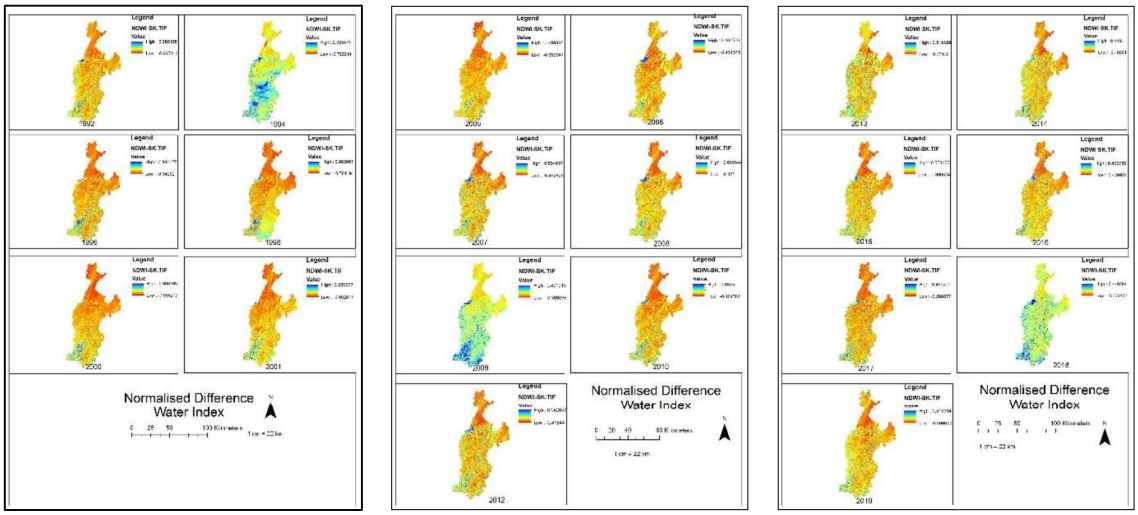


Figure 5.69: NDWI Index for Sabarkantha district

From the above Figure 5.69, it was observed that the minimum and maximum water spread area obtained by NDWI was 16.80 Sq.km area in 1996 year and 214.80 sq.km area in 2018 year. The average rainfall during 2018 was 912.30 mm. The average water spread area for the studied period was 99.9 sq.km with a standard deviation (SD) of 85.90 sq. km area. The percentage water spread area in the district varies from 2.5 % to 5.5% of the Sabarkantha district area.

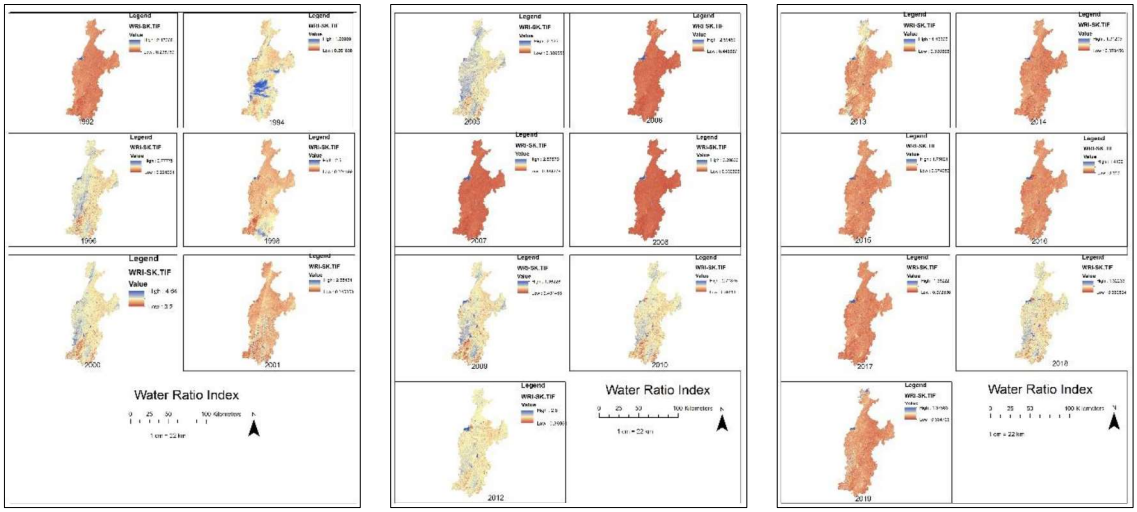
Similarly, the results of MNDWI index shows that minimum water spread area in 2009 year with 13.01 Sq.km area and maximum water spread area 40.51 sq.km area in 2006, 54.14 sq.km area in 2007 observed. Also, the average water spread area in the district is 26.12 sq.km area.

The spatio temporal map of NDWI index for Sabarkantha district is shown in below Map 5.13



Map 5.13: Normalized Difference Water Index Map of Sabarkantha district

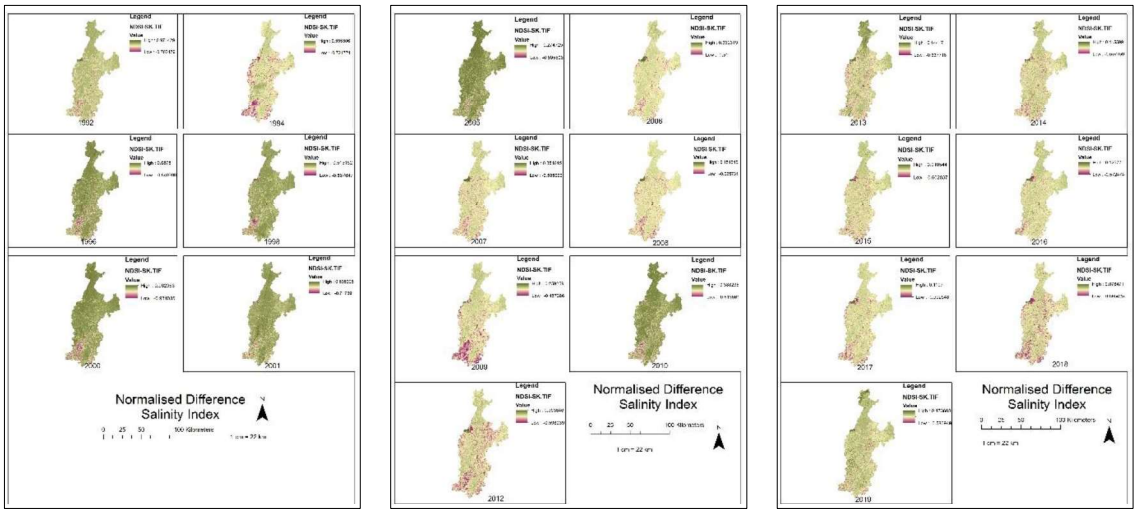
The results of WRI shows that minimum water spread area 108.60 Sq.km area (2.60%) in 2000 year. The average water spread area in Sabarkantha district is 1830.50 sqkm which is 43.70% with standard deviation of 581.08 Sq.km having 31.07% variation during study period. The spatio temporal map of WRI index for Sabarkantha district is shown in below Map 5.14.



Map 5.14: Water Ratio Index Map of Sabarkantha district

The results of NDSI index shows that minimum 1650.80 sq.km area having very low saline characteristics which covers an area 39.40% of the district. The moderate saline area in the district was 2509.60 sq.km area (59.90%) which is maximum in 2008 year and for minimum moderate area observed in 2001 which covers 329.90 sq.km area which is 7.9% of the district. From the analysis it was observed that average 2785.20 sq.km area which is around 66.49% area of Sabarkantha districts having moderate saline characteristics during the study period.

The spatio temporal map of NDSI index for Sabarkantha district is shown in below Map 5.15



Map 5.15: Normalized Difference Salinity Index Map of Sabarkantha district

5.5.6 Comparative analysis of Hydrological drought indices over North Gujarat district

This remote sensing and GIS application in hydrology is useful in many studies related to hydrology. The NDWI makes use of this property to successfully outline water bodies on the map and monitor water's surface area.

From the comparative analysis of above all indices it was observed that if annual rainfall increased this leads the increases in the surface water bodies in the study area and decrease salinity level. While if that if annual rainfall decreased this leads the decreases in the surface water bodies in the study area and increase salinity level in the North Gujarat districts.

NDWI is more sensitive to changes in the water content and turbidity, making it effective for detecting open water bodies. MNDWI, on the other hand, is designed to be sensitive to the presence of both water and built-up areas. It tends to highlight urban features in addition to water bodies.

The average water spread area for the studied period was 754.40 sq.km and percentage water spread area in the district varies from 5.5% to 15.5% in Banaskantha district. From the analysis of NDSI it was observed that average 3027.60 sq.km area which is around 28.5% area of **Banaskantha** districts having moderate saline characteristics.

The average water spread area for the studied period was 92.70 sq.km with a standard deviation (SD) of 42.8 sq. km area and the percentage water spread area

in the district varies from 1.5 % to 9.8% of the Gandhinagar district area. From the analysis of NDSI it was observed that average 321.97 sq.km area which is around 11.80% area of **Gandhinagar** districts having moderate saline characteristics.

The average water spread area for the studied period was 203.40 sq.km with a standard deviation (SD) of 67.10 sq. km area and the percentage water spread area in the district varies from 2.5% to 8.2% of the Mehsana district area. From the analysis of NDSI it was observed that average 973.50 Sq.km area which is around 23.80% area of **Mehsana** districts having moderate saline characteristics.

The average water spread area for the studied period was 99.9 Sq.km with a standard deviation (SD) of 85.90 sq. km area and the percentage water spread area in the district varies from 1.5 % to 6.2% of the Patan district area. From the analysis of NDSI it was observed that average 2860.0 Sq.km area which is around 46.20% area of **Patan** districts having moderate saline characteristics.

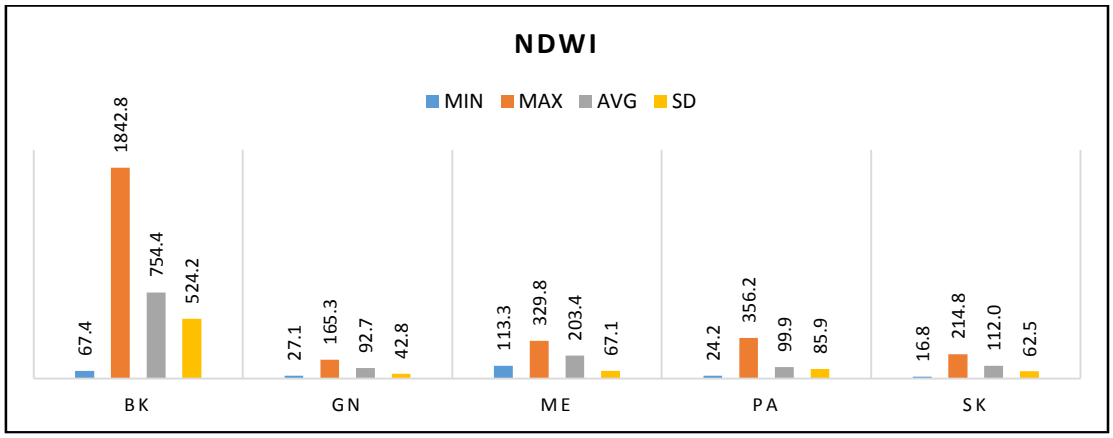
The average water spread area for the studied period was 73.5 sq.km with a standard deviation (SD) of 81.40 sq. km area and the percentage water spread area in the district varies from 2.5 % to 5.5% of the Sabarkantha district area. From the analysis of NDSI it was observed that average 2785.20 Sq.km area which is around 24.99% area of **Sabarkantha** districts having moderate saline characteristics.

5.6 FREQUENCY ANALYSIS OF HYDROLOGICAL DROUGHT INDICES OVER NORTH GUJARAT REGION

Frequency analysis of hydrological drought indices involves studying the occurrence and characteristics of hydrological drought events over time. This type of analysis is crucial for understanding the variability of hydrological droughts, identifying patterns, and making informed decisions for water resource management.

Statistical measures are a descriptive analysis techniques used to summarize the characteristics of dataset. Statistical measures include minimum, maximum, average, standard deviation and variance helpful in understanding the variation of obtain values in present study. For the accurate analysis the data range should be long as to covers a sufficiently extensive period to capture a range of hydrological conditions. In the present study of hydrological drought estimation the data range taken as long as long so as to obtain accurate results. This type of analysis is crucial for understanding the variability of hydrological droughts, identifying patterns, and making informed decisions for water resource management.

Analyzing the hydrological drought frequency for various indices with statistical distribution data is shown in below Figure 5.70 for North Gujarat region.



NDWI is primarily focused on detecting the presence of water, so an increase in values of NDWI generally correlates with an increase in water area. The results of NDWI of Banaskantha district shows that minimum water spread as 67.40 sq.km while maximum water spread area as 1842.80 sq.km which is maximum amongst North Gujarat districts. The minimum water spread area in Gandhinagar district of North Gujarat having 165.30 sq.km.

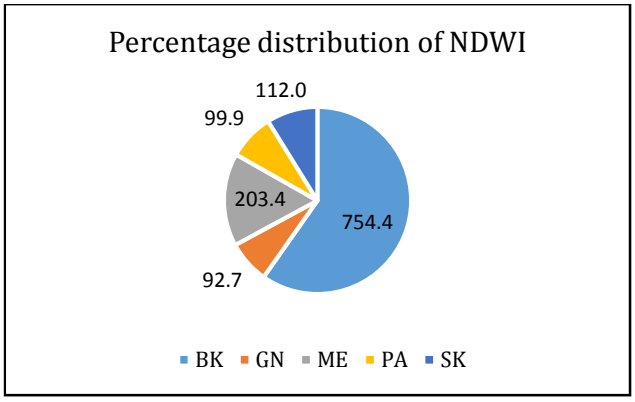
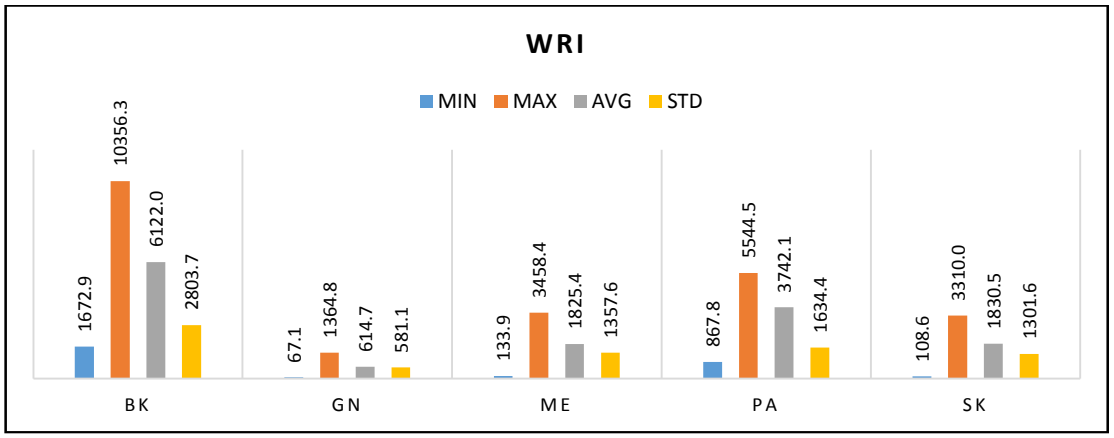


Figure 5.70: NDWI distribution for North Gujarat districts

Figure 5.70 shows the results of percentage of water spread in North Gujarat districts. From the analysis it can be concluded that Banaskantha districts having maximum water spread area which is 754.40 sq.km area while Gandhinagar district having very less water spread area. The Banas River is significant river in North Gujarat. It flows through the districts of Banaskantha and Sabarkantha which reflects in above results that Banaskantha district having 754.40 Sq.km area and 112.0 sq.km in Sabarkantha.



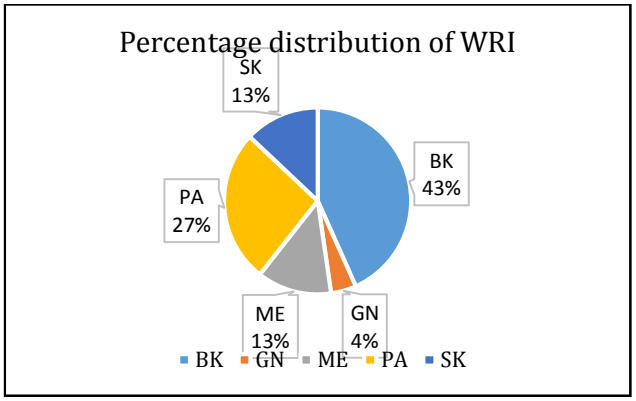


Figure 5.71: WRI distribution for North Gujarat region

The results of NDWI index and WRI index yields near about same results as NDWI is a remote sensing index that uses the reflectance values of the near-infrared (NIR) and shortwave infrared (SWIR) bands. Where WRI index calculated using (GREEN+RED) / (NIR+MIR) bands. The value of the WRI for water bodies is greater than 1.

The district wise figure shows that minimum, maximum, average and standard deviation values of water spread area. These data will helpful for providing information about the range of values in the dataset. This helps in understanding the spread of the data and identifying outliers. Monitoring the min and max values can be crucial, if a parameter exceeds certain min or max thresholds, it might indicate a problem. The problem related to hydrological drought condition will occurred.

Figure 5.71 shows the results of percentage of water spread in North Gujarat districts. From the analysis it can be concluded that Banaskantha districts having maximum water spread area which is 43% while Gandhinagar district having least water spread area as only about 4%. Mehsana districts having 13% water spread area and Patan district having again high water percentage area as 27%. The main reason behind these variation is due to the passing of river and having water holding structures in the districts.

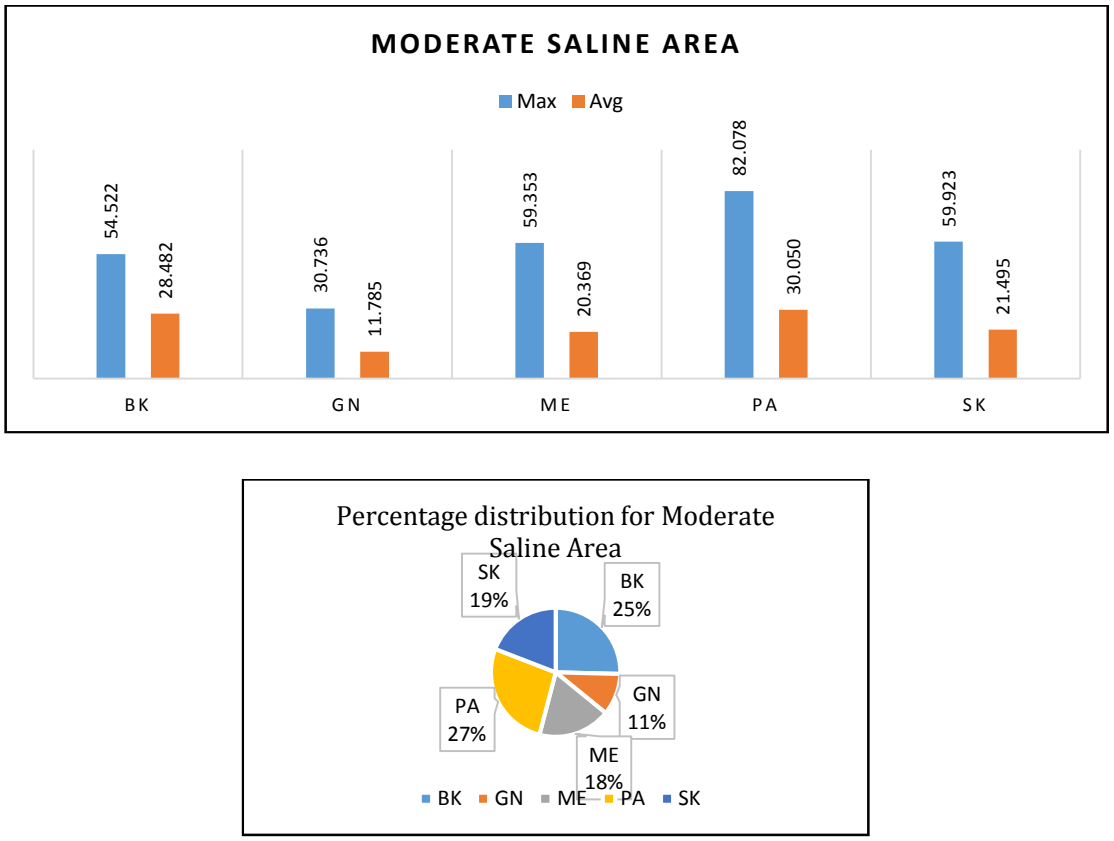


Figure 5.72: NDSI distribution for North Gujarat region

NDSI is designed to estimate salinity, and higher NDSI values might suggest lower salinity levels. However, the relationship between NDSI and actual salinity may not be straightforward and can depend on various factors, including the specific formula used, local conditions, and the characteristics of the water body.

Figure 5.72 shows percentage distribution of moderate saline area in North Gujarat region. The result shows that as NDWI value increases, NDSI value decreases. Gandhinagar district having very less salinity problem compared other North Gujarat districts.

It's important to note that while these indices can provide valuable information about water-related parameters, they are not direct measurements of salinity. To assess salinity accurately, field measurements and laboratory analyses are typically required. The findings of the current research emphasize the importance of the hydrological drought indices to envisage the adverse effects of salts accumulation in poorly drained soils similar to the study area under investigation.

5.7 ESTIMATION OF AGRICULTURAL DROUGHT INDICES OVER THE STUDY AREA

Remote sensing has been widely used and has delivered significant benefits in drought assessment and monitoring. Remote sensing techniques are crucial for timely decision making because they provide rapid geospatial data and a reasonably better spatial footprint of environmental phenomena characterizing entire area compared to point locations. In this work, a comparative study of different drought indices such as Normalized Difference Vegetation Index (NDVI), NDVI Deviation (NDVI-Deviation) is carried out.

The high NDVI values indicate wet conditions, and low NDVI values indicate dry conditions, it has become the primary tool for describing the phenology of dryness. The NDVI threshold value is between -1 and +1. NDVI values were often highest during wet seasons and lowest during dry seasons. The NDVI value decreases with increasing temperature, indicating a reduction in vegetation density.

NDVI deviation is employed to detect changes or deviations in vegetation conditions over time. Positive deviations may indicate periods of increased vegetation health or growth, while negative deviations could suggest stress, reduced vegetation cover, or other environmental changes.

Long term sequence of Landsat data were used in the present study to monitor the amount of drought area in North Gujarat districts. Landsat images of different years 1992 to 2019 at different intervals were studied and analyzed. NDVI images have been generated using the red and near infrared bands of Landsat sensors, and the minimum, maximum and mean values of NDVI for different years have been calculated separately.

5.7.1 Estimation of agricultural drought indices over Banaskantha district

NDVI analysis for Banaskantha district

In present study Landsat data used for NDVI analysis over multiple years which enables the identification of changes associated with drought classification and the area affected under each category is analyzed. Below Table 5.121 shows spatial distribution of drought-affected areas (in sq.km), categorized by the severity from NDVI values for Banaskantha district for 2013 to 2019 years. However, the same for the years 1992 to 2019 are showing in below Figure 5.73. Each classification corresponds to a specific square kilometres area, and the associated NDVI values provide a quantitative representation of drought affected areas during those intervals. The Classification done by NDVI drought severity classification. Then after

calculate the area of each severity class by counting the number of pixels classified into each category and converting it to square kilometres.

The classification of different areas into categories such as drought severity levels. NDVI values can be classified into different categories to represent varying levels of drought severity. For low NDVI: (less than 0) extreme drought stress or sparse vegetation. Moderate value of NDVI: (0.0 to 0.2) severe drought. Higher than Moderate value: (0.2 to 0.4) Moderate drought conditions. For high NDVI values (0.4 to 0.6), No drought or Moderate wet.

Table 5.121: Classification of NDVI for Banaskantha district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme dry	< 0	16.52	15.61	18.53	38.78	24.14	39.33	19.37
Severe dry	0.0 to 0.2	8280.0	6140.4	5554.1	5440.4	5489.7	4952.7	8264.3
Moderate dry	0..2 to 0.4	2316.7	4234.7	4331.7	4167.1	3999.6	4505.6	2293.2
Moderate wet	0.4 to 0.6	17.58	240.00	726.21	983.77	1117.3	1132.9	53.89
Extreme wet	> 0.6	0.00	0.00	0.33	0.63	0.01	0.00	0.00

(Area in square kilometres)

The results of the NDVI index for the 2019 year shows that 19.37 Sq.km area and 8264.30 Sq.km area fall under extreme dry and severe dry conditions, which are 0.20% and 77.70 %, of the total area of the Banaskantha district respectively. The study also, observed that moderately dry area is 2293.20 Sq.km area which is 21.60 % of the study area. The annual average rainfall was 690.82 mm during this year. But by considering all the years i.e., 1992 to 2019 of Landsat data the severe dry percentage in area ranges from 28.80% to 78.10%, extreme dry percentage ranges from 0.5% to 2.5% in Banaskantha district.

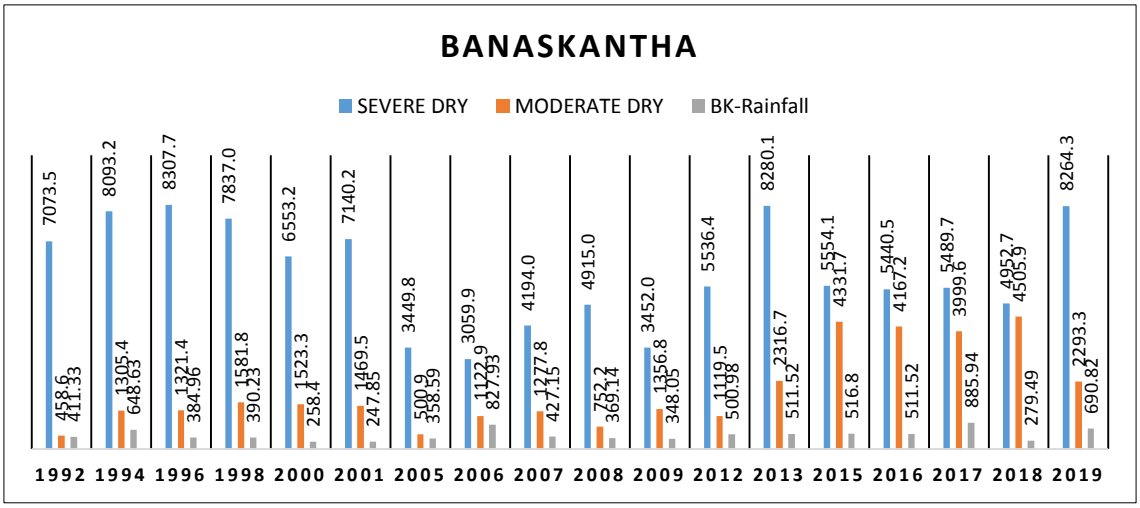


Figure 5.73: Comparisons of dry area and annual rainfall in Banaskantha district

Figure 5.73 shows comparisons of the amount of severe dry area and moderate dry area with corresponding annual rainfall. The analysis showed that as the rainfall in the area increases, the dryness decreases.

The results of the NDVI index shows that the maximum percentage of extreme dry area in the year 2018 with 38.39 Sq.km, which is 0.40% maximum percentage of severe dry areas in the year 1996 with 8307.70 sq. km, which is 78.10%, and during that year the rainfall was 384.96 mm in the study region. Also, moderate dry areas as 1321.40 Sq.km, which is 12.40% of the study area. Similarly, the minimum percentage of dry areas in the year 2006 with 3059.90 sq. km which is 28.80% of the area, and during that year the rainfall was 827.93 mm in the study region.

NDVI-Deviation analysis for Banaskantha district

The severity of drought situation is assessed by the extent of NDVI deviation from its long term mean. NDVI deviation is a measure of how the current NDVI value deviates. Analyzing NDVI deviation is a valuable approach to understanding changes in dryness in the area.

The results of the NDVI-deviation for Banaskantha district is shown in the below Table 5.122. NDVI deviation for the year 1994 shows that 2879.40 Sq.km as dry area and 708.70 Sq.km as normal dry. The maximum dry area was observed in 2019 year as 4921.30 Sq.km and normal dry area as 141.40Sq.km. Similarly, the minimum dry area was observed in 2006 year as 2269.80 Sq.km and normal dry area as 1012.40 Sq.km. The average deviation in dry area as 464.28 Sq.km and 208.66 Sq.km in normal dry area in Banaskantha district.

Table 5.122: Results of NDVI-Deviation for Banaskantha district

Year	Dry Area	Normal Dry Area
1992	4167.7	269.3
1994	2879.4	708.7
1996	3377.4	552.6
1998	2800.5	837.0
2000	2703.3	918.9
2001	3355.4	560.0
2005	3475.6	477.6
2006	2269.8	1012.4
2007	2895.7	980.0
2008	3863.4	563.4
2009	2542.9	1155.5
2010	2989.8	809.8
2012	3466.3	711.4
2014	4061.4	229.0

2015	3556.0	578.3
2016	3305.7	736.7
2017	3130.0	792.6
2018	3419.3	680.9
2019	4921.3	141.4

(Area in square kilometres)

The stacked bar chart will help to visualize how the percentage of dry and normal areas changes over the years which is shown in below Figure 5.74 for Banaskantha district. From this graphical representation it was observed that with an increase in the percentage of dry areas, it might indicates worsening drought conditions.

The percentage of dry area varies from 21.35% to 46.30% and percentage of Normal dry area varies from 1.5% to 10.87% respectively during study period. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation. It is observed that from 2013 to 2019 the dry percentage area has increased whereas in 2009 year the percentage of dry area in minimum.

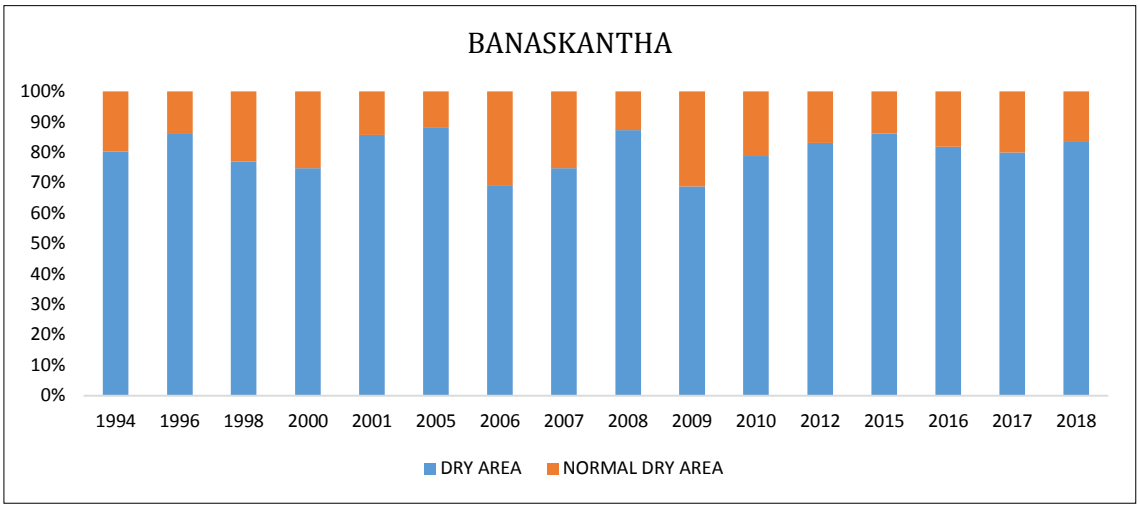


Figure 5.74: Percentage distribution of Dry area and Normal dry area in Banaskantha district

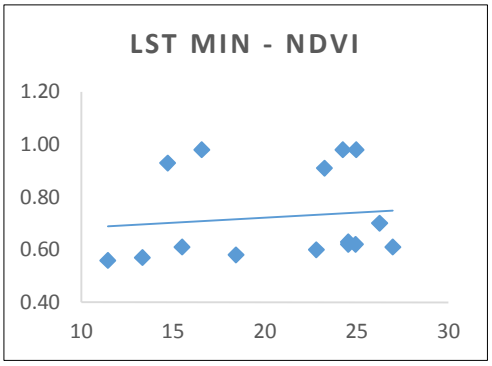
LST and NDVI analysis for Banaskantha district

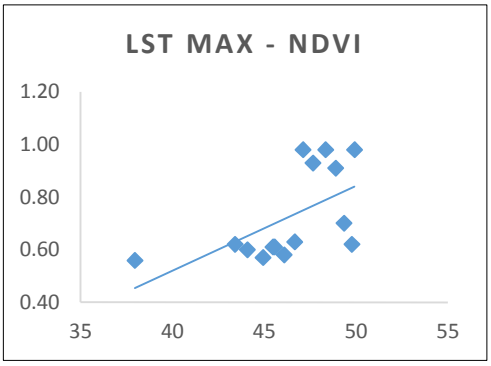
The relationship between NDVI and LST is valuable for understanding the complex interactions between dryness of land surface temperature. The combined analysis of NDVI and LST can enhance and help to monitor environmental changes over time. The NDVI index is very much sensitive to changes and variations of NDVI might cause changes in land surface temperature. The urban areas with sparse vegetation may have high LST even if NDVI is low, while forests with dense vegetation may have lower LST despite high NDVI.

The statistics of LST and NDVI values for different years (1992 to 2019) for Banaskantha district is shown in below Table 5.123. The outcome shows that the average max NDVI value was 0.62 and average lowest NDVI value -0.52. Further, the average LST min 25.13ºC and LST max 42.15 ºC. The results also shows that when there is high LST shows NDVI value is low, while low LST shows NDVI value is high.

Table 5.123: LST & NDVI values for different years for Banaskantha district

Year	LST-Min	LST-Max	NDVI-Min	NDVI-Max
1994	15.49	45.56	-0.54	0.61
1996	22.81	44.08	-0.28	0.60
2000	24.54	46.66	-0.29	0.63
2001	26.25	49.35	-0.32	0.70
2006	14.71	47.65	-0.93	0.93
2007	23.25	48.88	-0.98	0.91
2008	24.25	47.12	-0.99	0.98
2009	16.56	49.92	-0.99	0.98
2010	24.97	48.35	-0.98	0.98
2014	13.34	44.94	-0.13	0.57
2015	24.55	43.41	-0.29	0.62
2016	24.94	49.77	-0.28	0.62
2017	26.97	45.47	-0.34	0.61
2018	18.43	46.09	-0.17	0.58
2019	11.45	37.95	-0.09	0.56





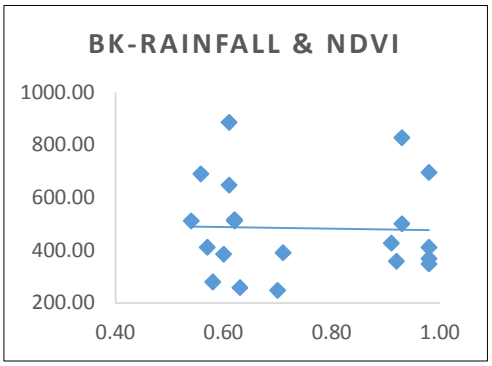


Figure 5.75: Relationship between LST and NDVI, Annual Rainfall & NDVI for Banaskantha district

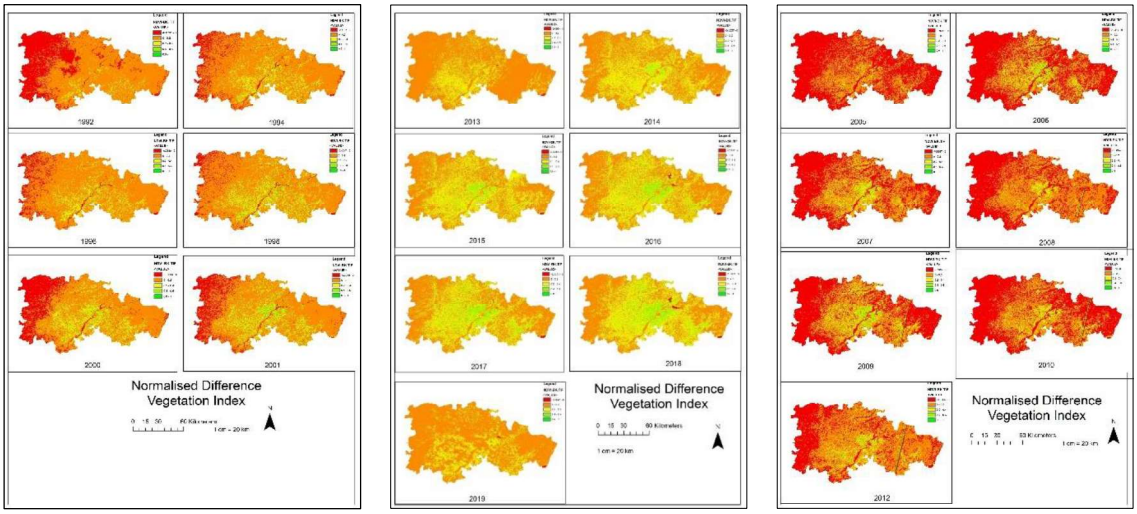
The Combination of NDVI and LST graph, provides very useful information for agricultural drought monitoring and early warning system for the farmers. Also, calculating the correlation between LST and NDVI, it can be clearly noticed that they show a high or less correlation. The correlation coefficient between NDVI and LST to quantify the strength and direction of their relationship.

- The relationship between LSTmin and NDVI shows a correlation coefficient as negative trend as -0.2075.
- Similarly, the relationship between LSTmax and NDVI shows a correlation coefficient as 0.5023

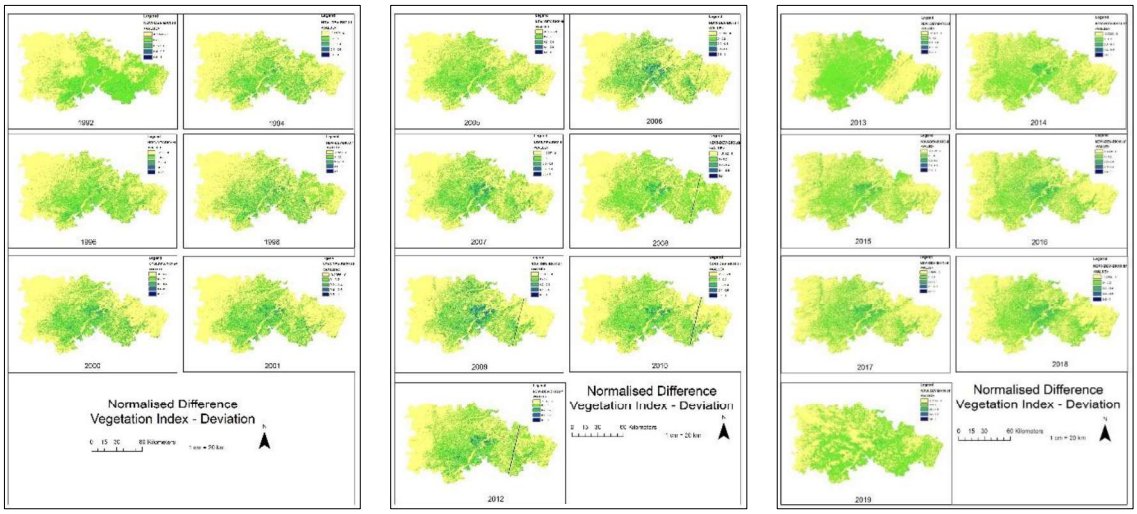
From the analysis, it was noticed that the maximum temperature in the district is increasing while the annual rainfall is decreasing and the dryness in the district is increasing. This relationship has also been found moderate for the area below mean LST.The linear trend was developed between the NDVI and LST relationship, which is shown in Figure 5.75. If NDVI shows a positive trend, it may indicate increasing vegetation health over time. If LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

Maps produced using relative greenness are quite useful to assess drought situation and hence this indicator is being used widely. NDVI can provide essential information for monitoring the onset and progression of drought. A sustained decrease in NDVI values over time is indicative of declining vegetation health, which is a common consequence of drought. NDVI allows for the quantification of drought severity. More severe drought conditions are typically associated with more significant decreases in NDVI values, indicating more extensive and severe impacts on vegetation.

Map Generation: An effort has been made to develop the spatial distribution of different drought severity classes. Below Maps 5.16 and 5.17 shows developed Maps using NDVI index and NDVI deviation for Banaskantha district.



Map 5.16: Normalized Difference Vegetation Index Map of Banaskantha District



Map 5.17: Normalized Difference Vegetation Index (Deviation) Map of Banaskantha District

5.7.2 Estimation of agricultural drought indices over Gandhinagar district

NDVI Analysis for Gandhinagar district

The spatial distribution drought classification and the area affected under each category is analyzed using NDVI index which is shown in below Table 5.124 for 2013 to 2019 years. However, the same for the years 1992 to 2019 are showing in below Figure 5.76. Each classification corresponds to a specific square kilometres area, and the associated NDVI values provide a quantitative representation of drought affected areas during those intervals.

Table 5.124: Classification of NDVI for Gandhinagar district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme dry	< 0	0.58	0.60	1.12	0.62	0.47	0.28	0.68
Severe dry	0.0 to 0.2	877.57	734.42	699.54	754.43	764.42	774.50	840.6
Moderate dry	0..2 to 0.4	810.04	956.98	944.84	907.30	864.90	893.69	821.4
Moderate wet	0.4 to 0.6	36.21	32.40	78.91	62.06	94.62	55.94	61.62
Extreme wet	> 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Area in square kilometres)

The results of the NDVI index for the 2019 year shows that 0.68 sq.km area and 840.60 sq.km area fall under extreme dry and severe dry conditions, which are 0.40% and 48.75 %, of the total area of the Gandhinagar district respectively. The study also, observed that moderately dry area is 821.40 sq.km area which is 47.64 % of the study area. The annual average rainfall was 954.49 mm during this year. But by considering all the years i.e. 1992 to 2019 of Landsat data the severe dry percentage in area ranges from 40.60 % to 74.0 %.

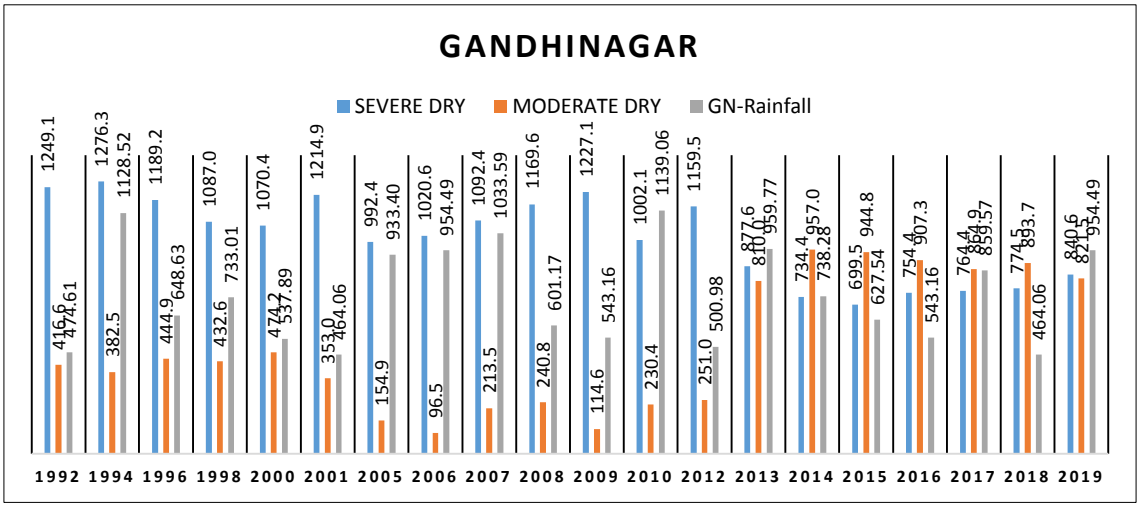


Figure 5.76: Comparisons between dry area and annual rainfall in Gandhinagar district

Figure 5.76 shows comparisons of the amount of severe dry area and moderate dry area with corresponding annual rainfall. The analysis showed that as the rainfall in the area increases, the dryness decreases.

From the results of NDVI it was observed that the maximum percentage of severe dry areas in the year 1994 with 1276.30 sq. km, which is 74.0%, and during that year the rainfall was 474.61 mm in the study region. Also, moderate dry areas as 382.60 sq.km which is 22.20% of the study area. Similarly, the minimum percentage of dry

areas in the year 2006 with 699.50 sq. km which is 40.06% of the area, and during that year the rainfall was 627.54 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.60% area with 96.50 sq.km during this year the annual rainfall is 954.49 mm.

NDVI-Deviation analysis for Gandhinagar district

The results of the NDVI-deviation for Gandhinagar district is shown in the below Table 5.125. The NDVI deviation for the year 1992 shows that 593.30 Sq.km as dry area and 90.93 Sq.km as normal dry. The maximum dry area was observed in 2015 year as 837.5 Sq.km and normal dry area as 41.31 sq.km. Similarly, the minimum dry area was observed in 1998 year as 466.13 sq.km and normal dry area as 173.07 sq.km. Also, average dry as area 616.6 Sq.km and normal dry area as 83.30 sq.km during study period. The average deviation in dry area as 62.31 sq.km and 37.36 sq.km in normal dry area in Gandhinagar district for data considered from 1992 to 2019.

Table 5.125: Results of NDVI-Deviation for Gandhinagar district

Year	Dry Area	Normal Dry Area
1992	593.30	90.93
1994	557.13	107.52
1996	550.72	121.24
1998	466.13	173.07
2000	505.38	177.07
2001	575.62	85.60
2005	573.28	91.47
2006	668.91	54.59
2007	593.41	102.03
2008	618.54	101.27
2010	571.57	118.74
2012	592.90	102.58
2013	695.74	29.06
2014	701.15	16.14
2015	837.46	41.31
2016	663.16	37.02
2017	611.62	52.83
2018	663.02	33.62
2019	677.03	47.10

(Area in square kilometres)

The stacked bar chart will help to visualize how the percentage of dry and normal areas changes over the years which is shown in below Figure 5.77 for Gandhinagar

district. From this graphical representation it was observed that with an increase in the percentage of dry areas might indicate worsening drought conditions.

The percentage of dry area varies from 27.04% to 48.58% and percentage of normal dry area varies from 0.94 % to 10.27 % during study period of 1992 to 2019. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation. It is observed that from 2013 to 2019 the dry percentage area has increased.

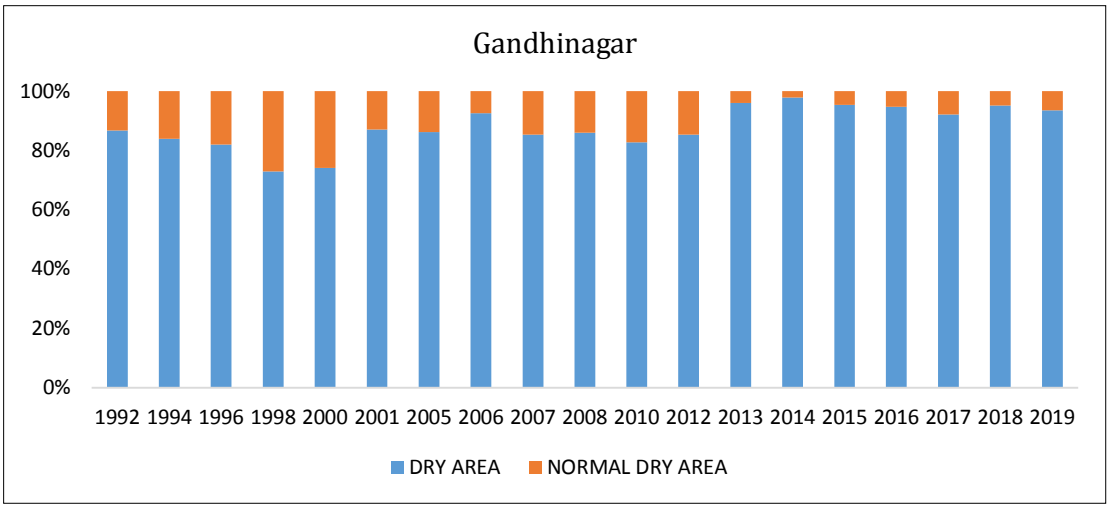


Figure 5.77: Percentage distribution of Dry area and Normal dry area in Gandhinagar district

LST and NDVI analysis for Gandhinagar district

The statistics of LST and NDVI values for different years (1992 to 2019) for Gandhinagar district is shown in below Table 5.126. The outcome shows that the average max NDVI value was 0.98 and average lowest NDVI value -0.98. Further, the average LST min 23.45ºC and LST max 46.14 ºC.

Table 5.126: LST &NDVI values for different years for Gandhinagar district

Year	LST-Min	LST-Max	NDVI-Min	NDVI-Max
2006	17.02	45.56	-0.90	0.92
2007	24.97	44.45	-0.98	0.72
2008	26.25	48.78	-0.98	0.90
2009	25.12	49.22	-0.98	0.98
2012	25.41	44.45	-0.32	0.59
2014	14.77	49.62	-0.09	0.51
2015	24.82	47.99	-0.23	0.58
2016	28.26	47.27	-0.20	0.58
2017	30.43	40.62	-0.11	0.53

2018	28.03	41.47	-0.08	0.57
2019	12.83	48.12	-0.17	0.58

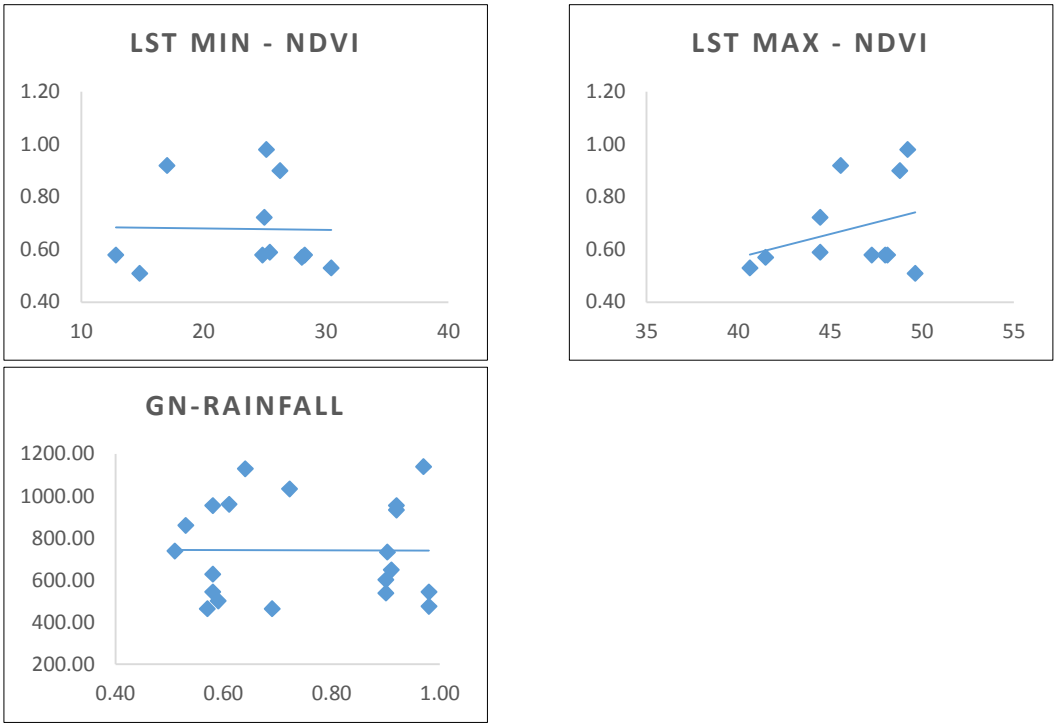


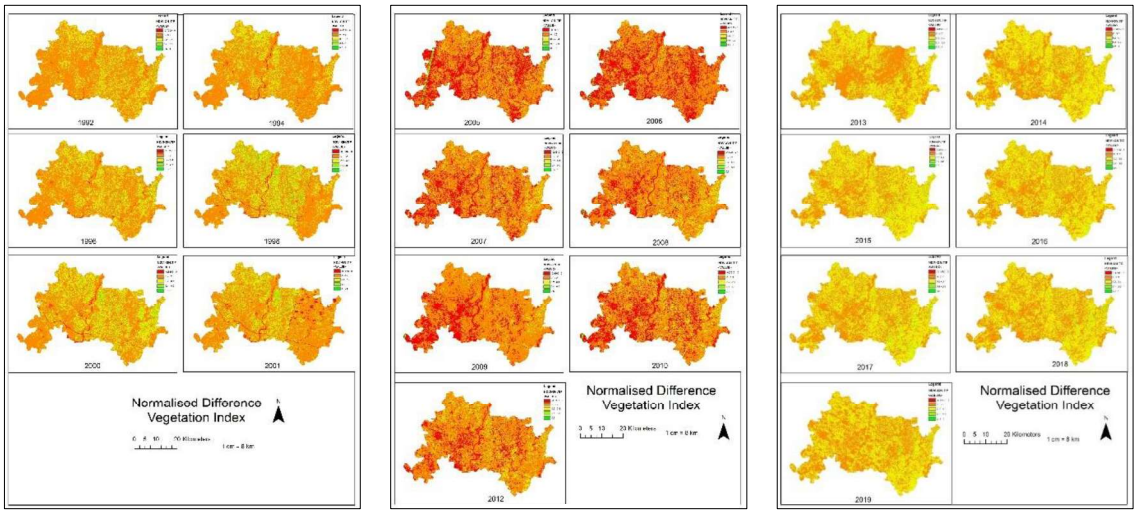
Figure 5.78: Relationship between LST and NDVI, Annual Rainfall and NDVI for Gandhinagar district

The correlation coefficient between NDVI and LST to quantify the strength and direction of their relationship.

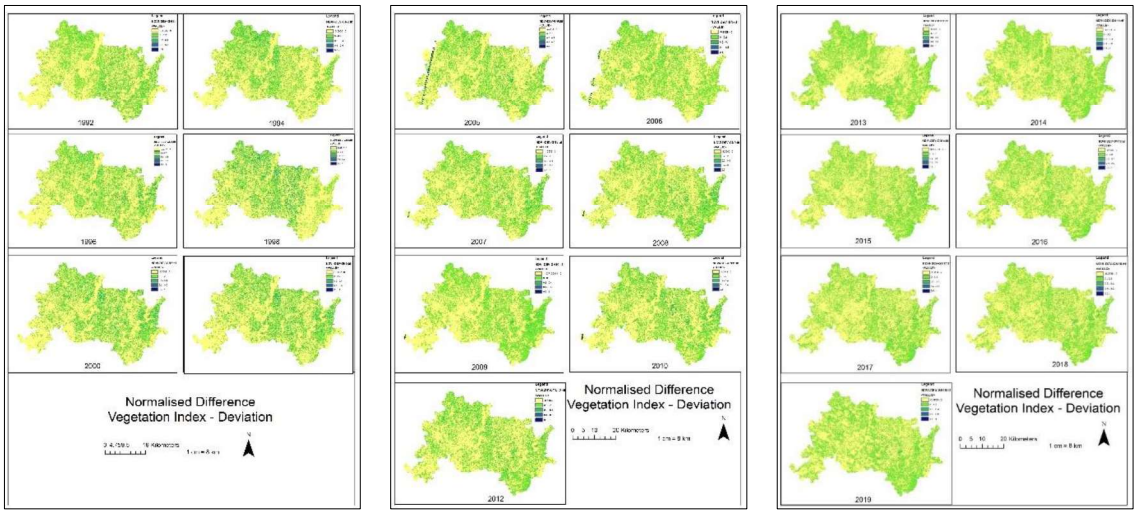
- The relationship between LSTmin and NDVI shows a correlation coefficient as negative trend as -0.016.
- Similarly, the relationship between LSTmax and NDVI shows a correlation coefficient as -0.1172

From the analysis, it was noticed that the maximum temperature in the district is increasing while the annual rainfall is decreasing and the dryness in the district is increasing. This relationship has also been found moderate for the area below mean LST. The linear trend was developed between the NDVI and LST relationship, which is shown in Figure 5.78. If NDVI shows a positive trend, it may indicate increasing vegetation health over time and LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

Below Map 5.18 and 5.19 shows developed Maps using NDVI index and NDVI deviation for Gandhinagar district.



Map 5.18: Normalized Difference Vegetation Index Map of Gandhinagar District



Map 5.19: Normalized Difference Vegetation Index (Deviation) Map of Gandhinagar District

5.7.3 Estimation of agricultural drought indices over Mehsana district

NDVI Index for Mehsana district

The spatial distribution drought classification and the area affected under each category is analyzed using NDVI index is shown in below Table 5.127 for 2013 to 2019 years for Mehsana district. . However, the same for the years 1992 to 2019 are showing in below Figure 5.79. Each classification corresponds to a specific square kilometres area, and the associated NDVI values provide a quantitative representation of drought affected areas during those intervals.

Table 5.127: Classification of NDVI for Mehsana district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme dry	< 0	6.61	7.29	7.81	8.94	10.50	4.03	5.85
Severe dry	0.0 to 0.2	2251	2026.4	2051.9	2029.2	2139.4	2167.0	2487.8
Moderate dry	0..2 to 0.4	2054	2279.6	2178.3	2167.3	2024.1	2111.5	1792.2
Moderate wet	0.4 to 0.6	78.9	78.48	153.78	186.42	217.85	109.34	106.00
Extreme wet	> 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Area in Sq.km)

The results of the NDVI index for the 2019 year shows that 5.85 sq.km area and 2487.80 sq.km area fall under extreme dry and severe dry conditions, which are 0.13% and 56.65 %, of the total area of the Mehsana district respectively. The study also, observed that moderately dry area is 1792.20 Sq.km area which is 40.81 % of the study area. The annual average rainfall was 854.30 mm during this year.

But by considering all the years i.e. from 1992 to 2019 the severe dry percentage in area ranges from 37.70 % to 80.40 %.

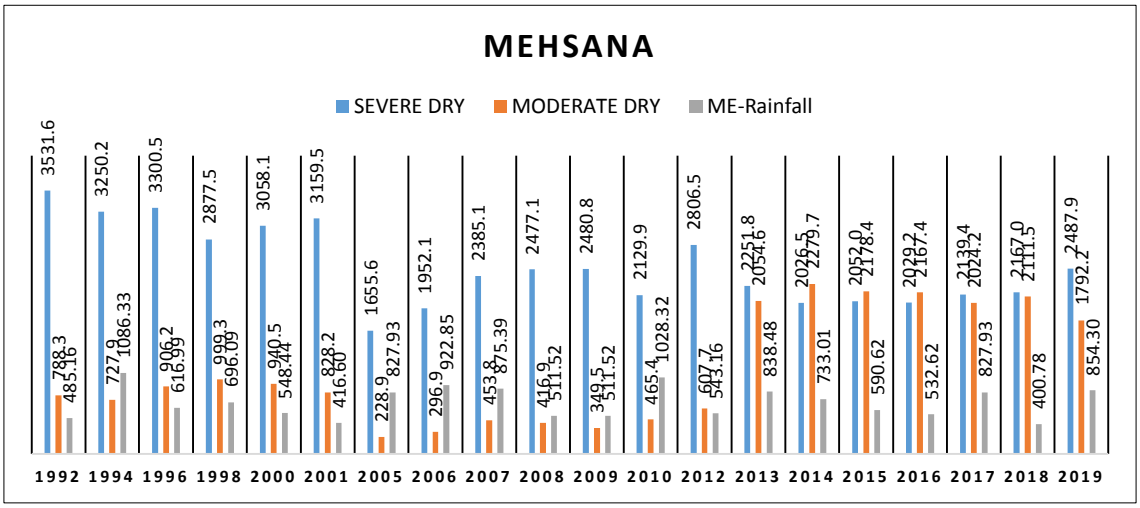


Figure 5.79: Comparisons between dry area and annual rainfall in Mehsana district

Figure 5.79 shows comparisons of the amount of severe dry area and moderate dry area with corresponding annual rainfall. The analysis showed that as the rainfall in the area increases, the dryness decreases.

The results of the NDVI index that it was observed that the maximum percentage of severe dry areas in the year 1992 with 3531.60 sq. km, which is 80.40%, and during that year the rainfall was 485.16 mm in the study region. Also, moderate dry areas as 788.30 sq.km, which is 17.90% of the study area. Similarly, the minimum

percentage of dry areas in the year 2005 with 1655.60 sq. km which is 37.70% of the area, and during that year the rainfall was 827.90 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.20% area with 228.90 Sq.km during this year the annual rainfall is 827.93 mm.

NDVI-Deviation analysis for Mehsana district

The results of the NDVI-deviation for Mehsana district is shown in the below Table 5.128. NDVI deviation for the year 1992 shows that 1461.80 Sq.km as dry area and 469.30 Sq.km as normal dry. The maximum dry area was observed in 2019 year as 1865.05 Sq.km and normal dry area as 110.75 sq.km. Similarly, the minimum dry area was observed in 1998 year as 1118.7 sq.km and normal dry area as 464.50 sq.km. Also, average dry as area 1496.20 sq.km and normal dry area as 260.60 sq.km during study period.

The average deviation in dry area as 135.26 sq.km and 82.51 sq.km in normal dry area in Mehsana district during 1992 to 2019 years.

Table 5.128: Results of NDVI-Deviation for Mehsana district

Year	Dry Area	Normal Dry Area
1992	1461.80	469.30
1994	1432.80	277.60
1996	1423.70	284.70
1998	1118.70	464.50
2000	1217.20	426.30
2001	1423.70	284.70
2005	1429.14	197.59
2006	1457.62	215.70
2007	1600.65	259.72
2008	1678.69	226.44
2009	1423.70	284.70
2010	1423.83	294.58
2012	1605.85	259.69
2013	1775.12	63.14
2014	1824.41	53.02
2015	1694.13	100.00
2016	1636.79	126.40
2017	1541.92	148.08
2018	1693.31	72.00
2019	1865.00	110.75

(Area in square kilometres)

The stacked bar chart will help to visualize how the percentage of dry and normal areas changes over the years which is shown in below Figure 5.80 for Mehsana district. From this graphical representation it was observed that with an increase in the percentage of dry areas might indicate worsening drought conditions.

The percentage of dry area varies from 25.48 % to 42.47 % and percentage of Normal dry area varies from 2.28 % to 10.69 % respectively during study period. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation.

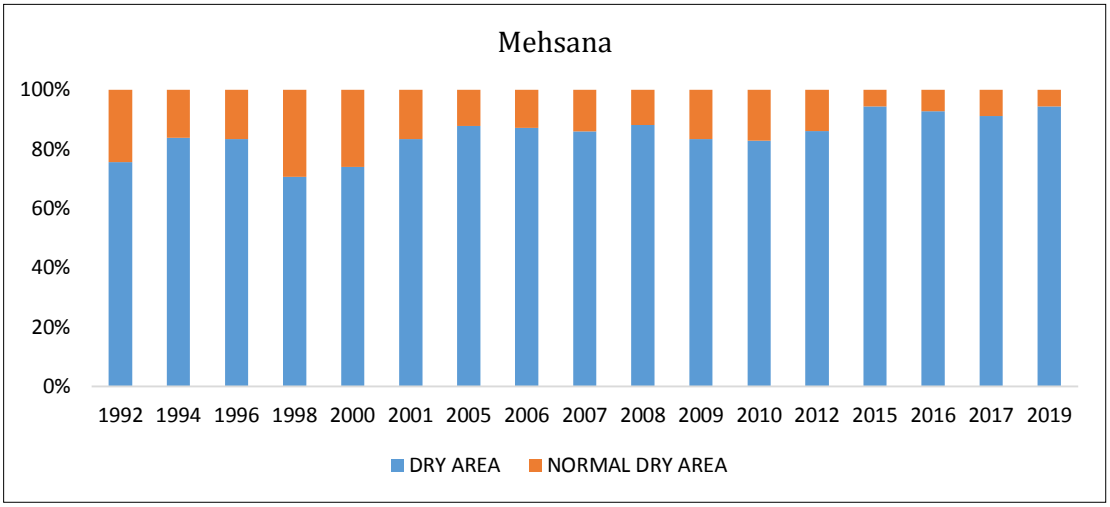


Figure 5.80: Percentage distribution of Dry area and Normal dry area in Mehsana district

LST and NDVI analysis for Mehsana district

The statistics of LST and NDVI values for different years (1992 to 2019) for Mehsana district is shown in below Table 5.129. Further, the average LST min 22.36ºC and LST max 45.96 ºC.

Table 5.129: LST & NDVI values for different years for Mehsana district

Year	LST-Min	LST-Max	NDVI-Min	NDVI-Max
1992	19.28	38.01	-0.97	0.97
1994	26.67	50.28	-0.25	0.59
1996	22.81	42.58	-0.41	0.74
1998	24.11	44.45	-0.44	0.75
2000	24.54	43.71	-0.25	0.64
2001	26.25	50.28	-0.28	0.68
2006	16.56	47.03	-0.91	0.93
2007	22.81	48.12	-0.98	0.90
2008	22.8	47.15	-0.98	0.98

2009	18.38	50.28	-0.98	0.98
2010	24.54	47.39	-0.99	0.98
2014	16.51	41.48	-0.11	0.53
2015	25.12	48.68	-0.12	0.57
2016	25.07	46.8	-0.17	0.58
2017	26.82	51.39	-0.18	0.58
2018	25.26	44.38	-0.16	0.54
2019	12.6	39.38	-0.21	0.57

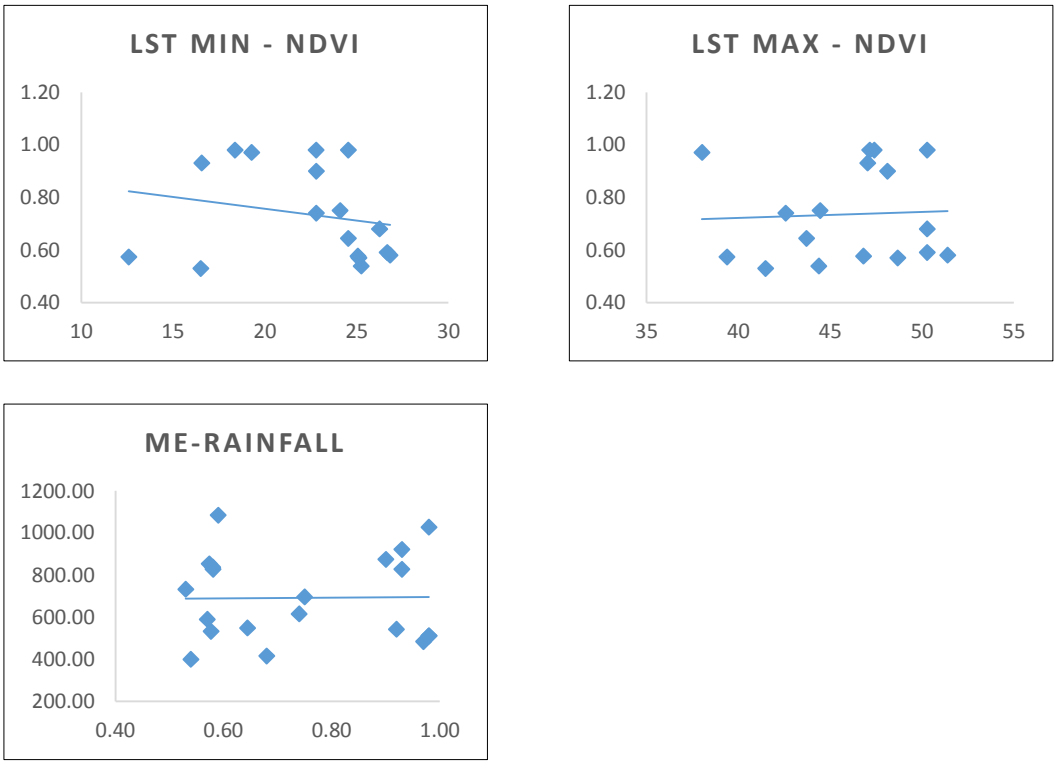


Figure 5.81: Relationship between LST and NDVI, Annual Rainfall and NDVI for Mehsana district

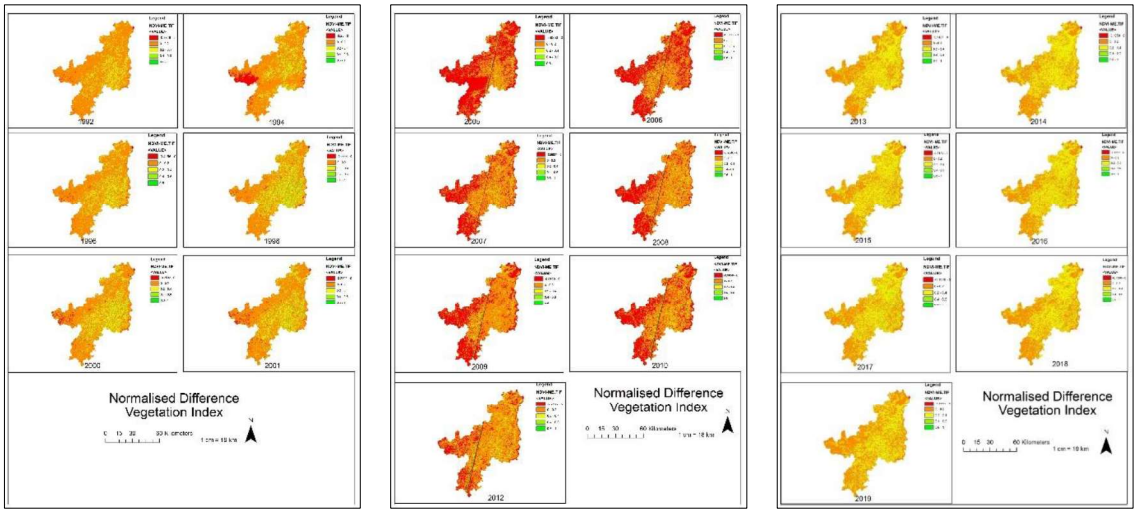
The correlation coefficient between NDVI and LST to quantify the strength and direction of their relationship.

- The relationship between LSTmin and NDVI shows a correlation coefficient as negative trend as -0.2075.
- Similarly, the relationship between LSTmax and NDVI shows a correlation coefficient as 0.0500.

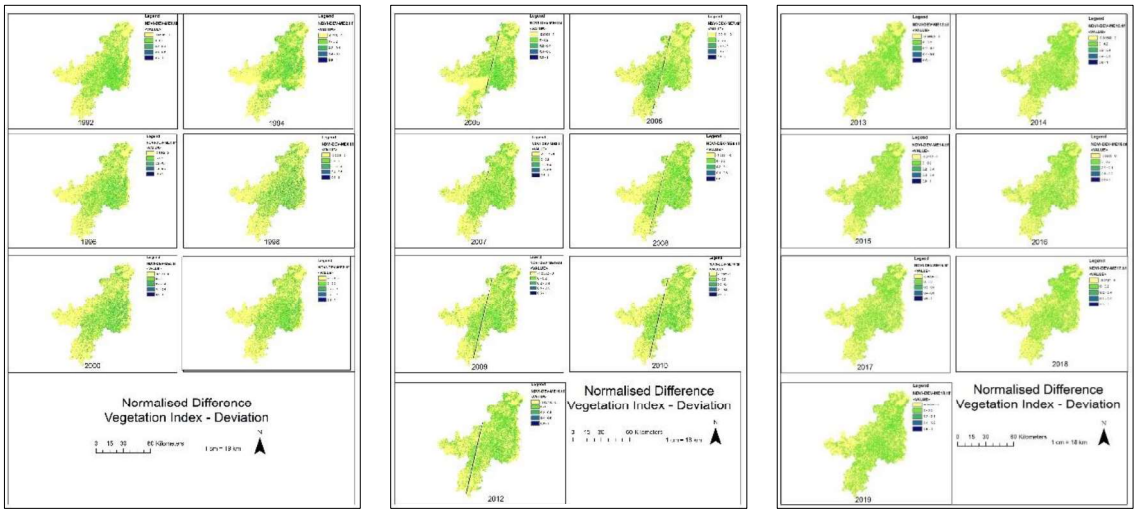
The linear trend was developed between the NDVI and LST relationship, which is shown in Figure 5.81. If NDVI shows a positive trend, it may indicate increasing

vegetation health over time and LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

Below Map 5.20 and 5.21 shows developed Maps using NDVI index and NDVI deviation for Mehsana district.



Map 5.20: Normalized Difference Vegetation Index Map of Mehsana District



Map 5.21: Normalized Difference Vegetation Index (Deviation) Map of Mehsana District.

5.7.4 Estimation of agricultural drought indices over Patan district

The spatial distribution drought classification and the area affected under each category is analyzed using NDVI index is shown in below Table 5.130 from 2013 to 2019 years for Patan district. However, the same for the years 1992 to 2019 are showing in below Figure 5.82. Each classification corresponds to a specific square kilometres area, and the associated NDVI values provide a quantitative representation of drought affected areas during those intervals.

Table 5.130: Classification of NDVI for Patan district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme dry	< 0	1.55	22.29	5.39	16.30	6.12	13.05	4.24
Severe dry	0.0 to 0.2	5926.9	5835.6	5707.8	5686.5	5733.8	5784.9	5933.9
Moderate dry	0..2 to 0.4	52.53	165.49	310.49	320.86	283.62	225.71	85.18
Moderate wet	0.4 to 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Area in Sq.km)

The results of the NDVI index for the 2019 year shows that 4.24 sq.km area and 5933.90 sq.km area fall under extreme dry and severe dry conditions, which are 0.07% and 98.50 %, of the total area of the Patan district respectively. The study also, observed that moderately dry area is 85.18 Sq.km area which is 1.45 % of the study area. The annual average rainfall was 717.19 mm during this year. But by considering all the years i.e. from 1992 to 2019the severe dry percentage in area ranges from 17.80 % to 98.5 %, and extreme dry percentage in area ranges from 2% to 5%.

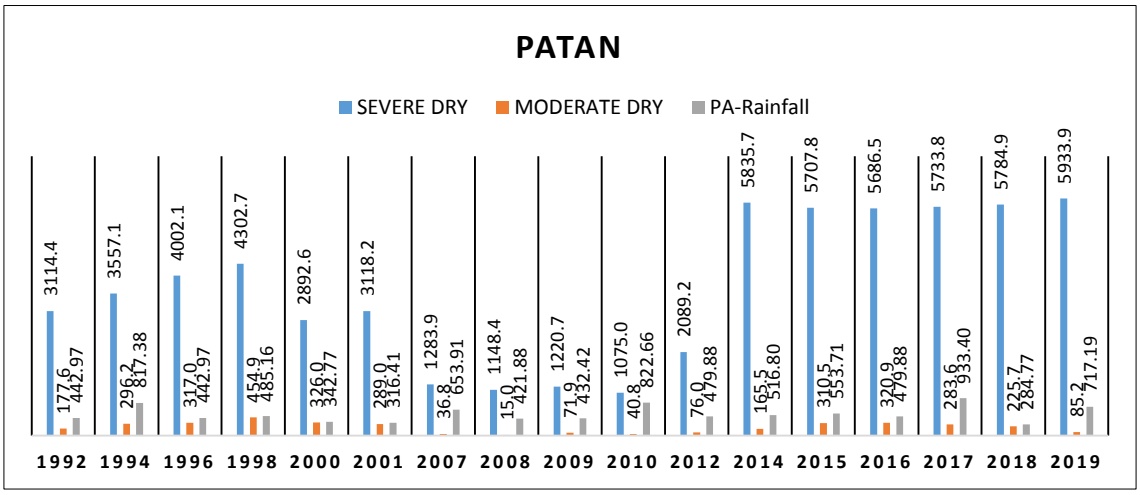


Figure 5.82: Comparisons between dry area and annual rainfall in Patan district

Figure 5.82 shows comparisons of the amount of severe dry area and moderate dry area with corresponding annual rainfall.

The results of the NDVI index that it was observed that the maximum percentage of severe dry areas in the year 2018 with 5784.90 sq. km, which is 96.0%, and during that year the rainfall was 284.77 mm in the study region. Also, moderate dry areas as 1075.0 Sq.km, which is 17.8% of the study area. Similarly, the minimum percentage of dry areas in the year 2008 with 15.0 sq. km which is 0.20% of the area, and during that year the rainfall was 421.8 mm in the study region.

NDVI-Deviation analysis for Patan district

The results of the NDVI-deviation for Patan district is shown in the below Table 5.131. NDVI deviation for the year 1992 shows that 2221.30 sq.km as dry area and 239.50 sq.km as normal dry. The maximum dry area was observed in 2019 year as 2564.5 sq.km and normal dry area as 65.60 sq.km. Similarly, the minimum dry area was observed in 2000 year as 1831.9 sq.km and normal dry area as 243.8 sq.km. Also, average dry as area 2147.90 sq.km and normal dry area as 173.90 sq.km during study period. The average deviation in dry area as 178.07 Sq.km and 49.85 sq.km in normal dry area in Patan district.

Table 5.131: Results of NDVI-Deviation for Patan district

Year	Dry Area	Normal Dry Area
1992	2221.3	239.5
1994	1940.8	212.2
1996	2033.5	192.0
1998	1852.6	263.7
2000	1831.9	243.8
2001	2233.5	192.0
2005	2224.9	117.2
2006	1959.7	170.4
2007	2009.8	205.7
2008	2177.4	140.0
2009	1923.8	201.7
2010	2028.5	191.6
2012	2173.6	245.0
2015	2290.6	122.9
2016	2383.2	120.5
2017	2333.1	119.7
2018	2479.4	85.9
2019	2564.5	65.6

(Area in square kilometres)

The stacked bar chart will help to visualize how the percentage of dry and normal areas changes over the years which is shown in below Figure 5.83 for Patan district. From this graphical representation it was observed that with an increase in the percentage of dry areas might indicate worsening drought conditions.

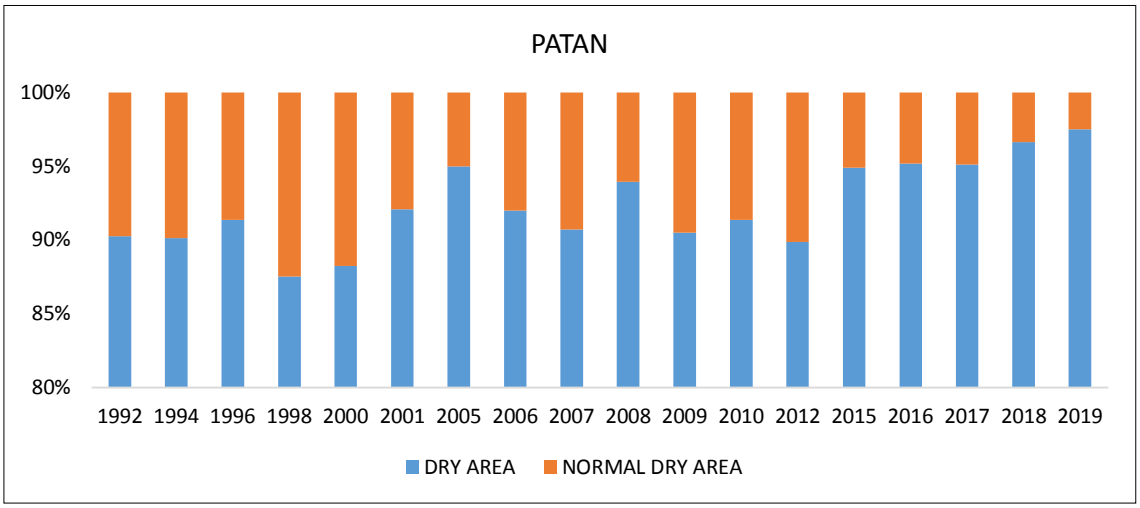


Figure 5.83: Percentage distribution of Dry area and Normal dry area in Patan district

The percentage of dry area varies from 30.41% to 42.58% and percentage of normal dry area varies from 1.09% to 4.38% during study period. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation.

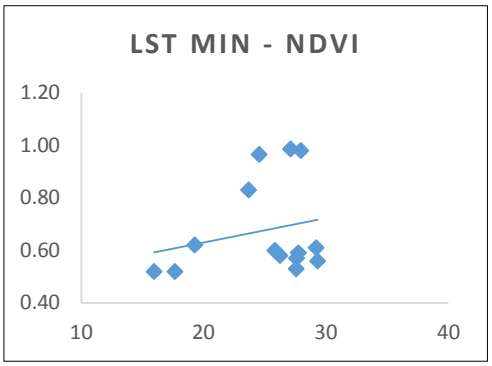
LST and NDVI analysis for Patan district

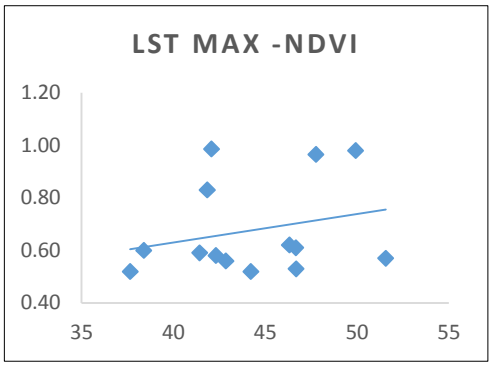
The relationship between NDVI and LST is valuable for understanding the complex interactions between dryness of land and surface temperature. The statistics of LST and NDVI values for different years (1992 to 2019) for Patan district is shown in below Table 5.132. Further, the average LST min 24.97ºC and LST max 44.26ºC. The results also shows that when there is high LST shows NDVI value is low, while low LST shows NDVI value is high.

Table 5.132: LST & NDVI values for different years for Patan district

Year	LST-Min	LST-Max	NDVI-Min	NDVI-Max
1992	25.82	38.38	-0.75	0.60
1994	26.25	42.31	-0.34	0.58
2000	29.18	46.66	-0.32	0.61
2006	19.28	46.32	-0.44	0.62
2007	23.68	41.83	-0.37	0.83
2008	24.54	47.76	-0.98	0.97
2009	27.09	42.06	-0.98	0.99
2010	27.93	49.92	-0.90	0.98
2014	17.66	44.22	-0.22	0.52
2015	27.59	51.56	-0.22	0.57
2016	27.75	41.43	-0.26	0.59
2017	29.31	42.85	-0.21	0.56
2018	27.56	46.68	-0.17	0.53

2019	15.95	37.64	-0.17	0.52





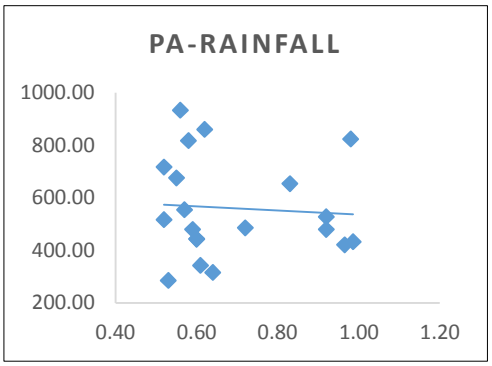


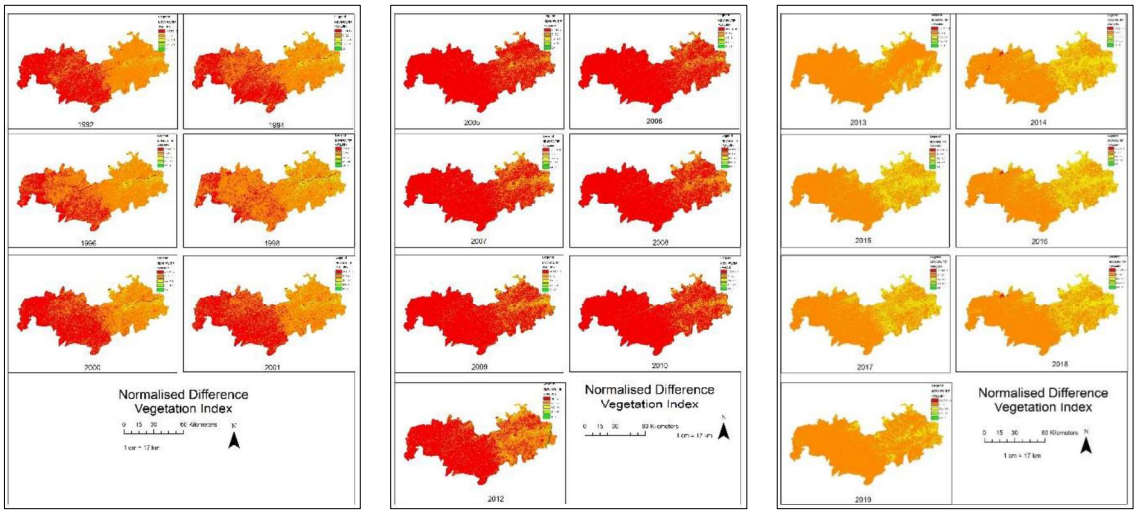
Figure 5.84: Relationship between LST and NDVI, Annual Rainfall and NDVI for Patan district

The correlation coefficient between NDVI and LST to quantify the strength and direction of their relationship.

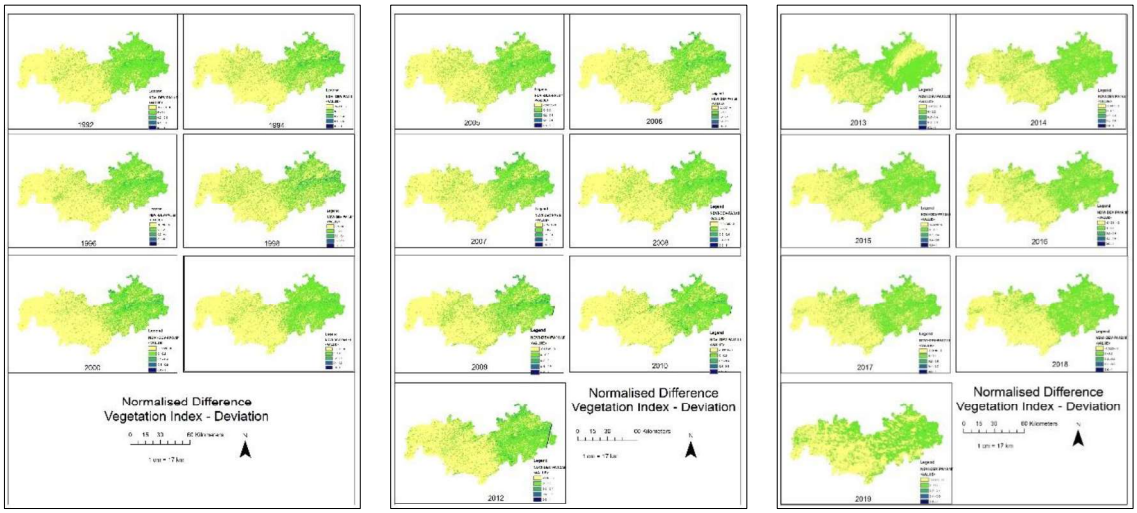
- The relationship between LST min and NDVI shows a correlation coefficient as negative trend as 0.2215.
- Similarly, the relationship between LST max and NDVI shows a correlation coefficient as 0.2471.

The linear trend was developed between the NDVI and LST relationship, which is shown in Figure 5.84. If NDVI shows a positive trend, it may indicate increasing vegetation health over time and LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

Below Map 5.22 and 5.23 shows developed Maps using NDVI index and NDVI deviation for Patan district.



Map 5.22: Normalized Difference Vegetation Index Map of Patan District



Map 5.23: Normalized Difference Vegetation Index (Deviation) Map of Patan District

5.7.5 Estimation of agricultural drought indices over Sabarkantha district

The spatial distribution drought classification and the area affected under each category is analyzed using NDVI index is shown in below Table 5.133 from 2013 to 2019 years for Sabarkantha district. However, the same for the years 1992 to 2019 are showing in below Figure 5.85. Each classification corresponds to a specific square kilometres area, and the associated NDVI values provide a quantitative representation of drought affected areas during those intervals.

Table 5.133: Classification of NDVI for Sabarkantha district

Classification	Range	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Extreme dry	< 0	13.87	18.52	23.83	21.43	25.52	20.63	15.10

Severe dry	0.0 to 0.2	2518.0	2358.7	2297.1	2648.8	2652.5	2486.7	2890.5
Moderate dry	0..2 to 0.4	1597.5	1726.1	1726.9	1457.5	1381.7	1545.0	1217.1
Moderate wet	0.4 to 0.6	59.03	85.13	140.62	60.74	128.71	136.15	65.74
Extreme wet	> 0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Area in Sq.km)

The results of the NDVI index for the 2019 year shows that 15.10 Sq.km area and 2890.50 Sq.km area fall under extreme dry and severe dry conditions, which are 0.40% and 69.01 %, of the total area of the Sabarkantha district respectively. The study also, observed that moderately dry area is 1217.10 Sq.km area which is 29.05 % of the study area. The annual average rainfall was 875.39 mm during this year. But by considering all the years i.e. from 1992 to 2019 the severe dry percentage in area ranges from 28.30 % to 87.40 %, and the wet percentage in area ranges from 1.49 % to 3.35 %.

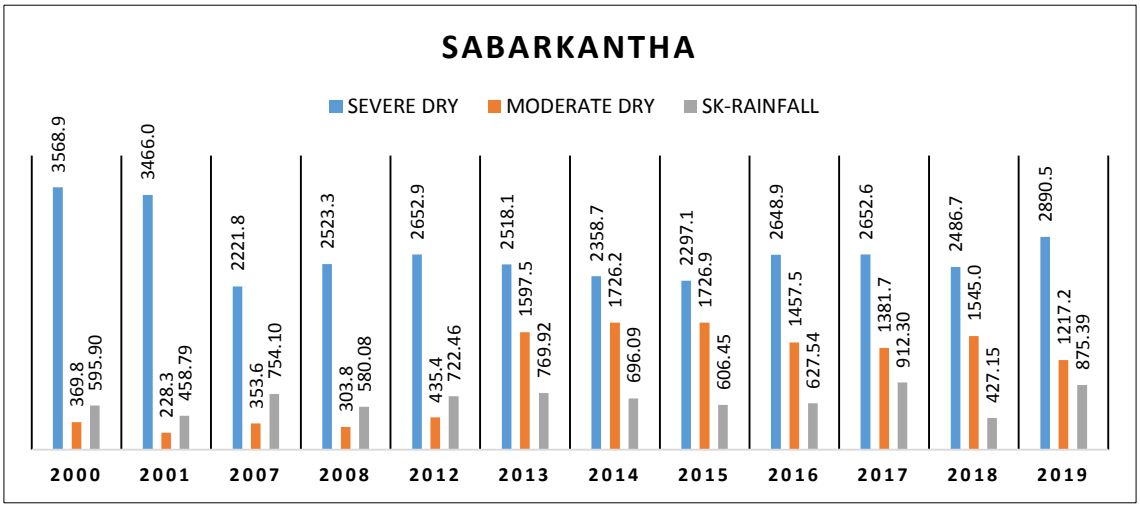


Figure 5.85: Comparisons between dry area and annual rainfall in Sabarkantha district

Figure 5.85 for shows comparisons of the amount of severe dry area and moderate dry area with corresponding annual rainfall. The analysis showed that as the rainfall in the area increases, the dryness decreases.

The results of the NDVI index that it was observed that the maximum percentage of severe dry areas in the year 1992 with 3660.10 sq. km, which is 87.40%, and during that year the rainfall was 585.35 mm in the study region. Also, moderate dry areas as 403.7 Sq.km, which is 9.6% of the study area. Similarly, the minimum percentage of dry areas in the year 2005 with 1186.60 sq. km which is 28.30% of the area, and during that year the rainfall was 775.20 mm in the study region. Also, the minimum

moderate dry percentage in 2005 year with 2.70% area with 114.30 Sq.km during this year the annual rainfall is 775.20 mm.

NDVI-Deviation analysis for Sabarkantha district

The results of the NDVI-deviation for Sabarkantha district is shown in the below Table 5.134. NDVI deviation for the year 1992 shows that 1256.05 sq.km as dry area and 184.62 sq.km as normal dry. The maximum dry area was observed in 2019 year as 1597.21 sq.km and normal dry area as 81.24 sq.km.

Similarly, the minimum dry area was observed in 2000 year as 974.74 sq.km and normal dry area as 240.42 sq.km. Also, average dry as area 1308.17 sq.km and normal dry area as 185.47 sq.km during study period. The average deviation in dry area as 130.85 sq.km and 47.97 sq.km in normal dry area in Sabarkantha district.

Table 5.134: Results of NDVI-Deviation for Sabarkantha district

Year	Dry Area	Normal Dry Area
1992	1256.05	184.62
1994	1401.67	138.84
1996	1042.96	260.14
1998	1106.65	173.09
2000	974.74	240.42
2001	1401.67	138.84
2005	1315.95	228.50
2006	1358.50	230.15
2007	1308.59	242.81
2008	1445.81	188.72
2009	1312.75	138.56
2010	1113.57	240.36
2012	1392.72	236.44
2014	1540.42	72.37
2015	1493.00	122.43
2017	1580.63	64.92
2018	1408.85	122.38
2019	1597.21	81.24

(Area in square kilometres)

The stacked bar chart will help to visualize how the percentage of dry and normal areas changes over the years which is shown in below Figure 5.86 for Sabarkantha district. From this graphical representation it was observed that with an increase in the percentage of dry areas might indicate worsening drought conditions.

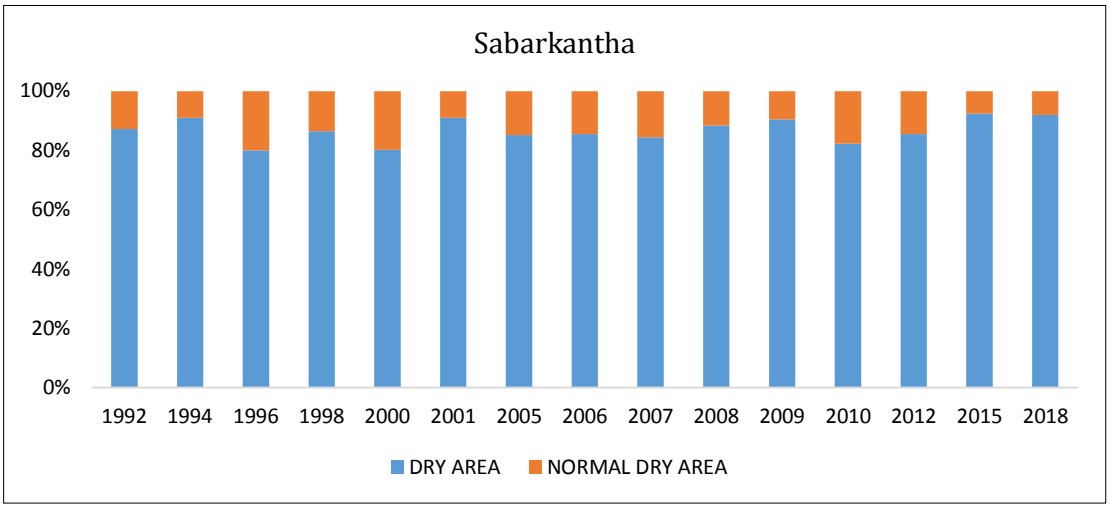


Figure 5.86: Percentage distribution of Dry area and Normal dry area in Sabarkantha district

The percentage of dry area varies from 23.27 % to 38.14 % and percentage of Normal dry area varies from 1.94 % to 6.21 % respectively during study period. Also, in decrease in the percentage of normal areas could signify prolonged stress on vegetation.

LST and NDVI analysis for Sabarkantha district

The relationship between NDVI and LST is valuable for understanding the complex interactions between dryness of land and surface temperature. The statistics of LST and NDVI values for different years (1992 to 2019) for Sabarkantha district is shown in below Table 5.135. Further, the average LST min 21.46ºC and LST max 46.04 ºC. The results also shows that when there is high LST shows NDVI value is low, while low LST shows NDVI value is high.

Table 5.135: LST & NDVI values for different years for Sabarkantha district

Year	LST-Min	LST-Max	NDVI-Min	NDVI-Max
1992	22.52	48.56	-0.97	0.70
1994	23.68	42.23	-0.59	0.72
1996	24.97	46.67	-0.68	0.84
2001	16.13	37.61	-0.69	0.71
2005	22.37	43.71	-0.27	0.59
2006	17.93	38.77	-0.36	0.51
2007	23.25	46.35	-0.38	0.59
2008	23.68	48.84	-0.45	0.63
2009	23.75	44.45	-0.26	0.46
2010	23.25	46.15	-0.39	0.61
2012	22.81	44.08	-0.35	0.60

2014	11.75	51.23	-0.12	0.56
2015	13.62	47.53	-0.21	0.60
2016	24.49	47.65	-0.13	0.57
2017	27.03	50.38	-0.11	0.59
2018	25.36	48.77	-0.08	0.60
2019	18.15	49.65	-0.17	0.58

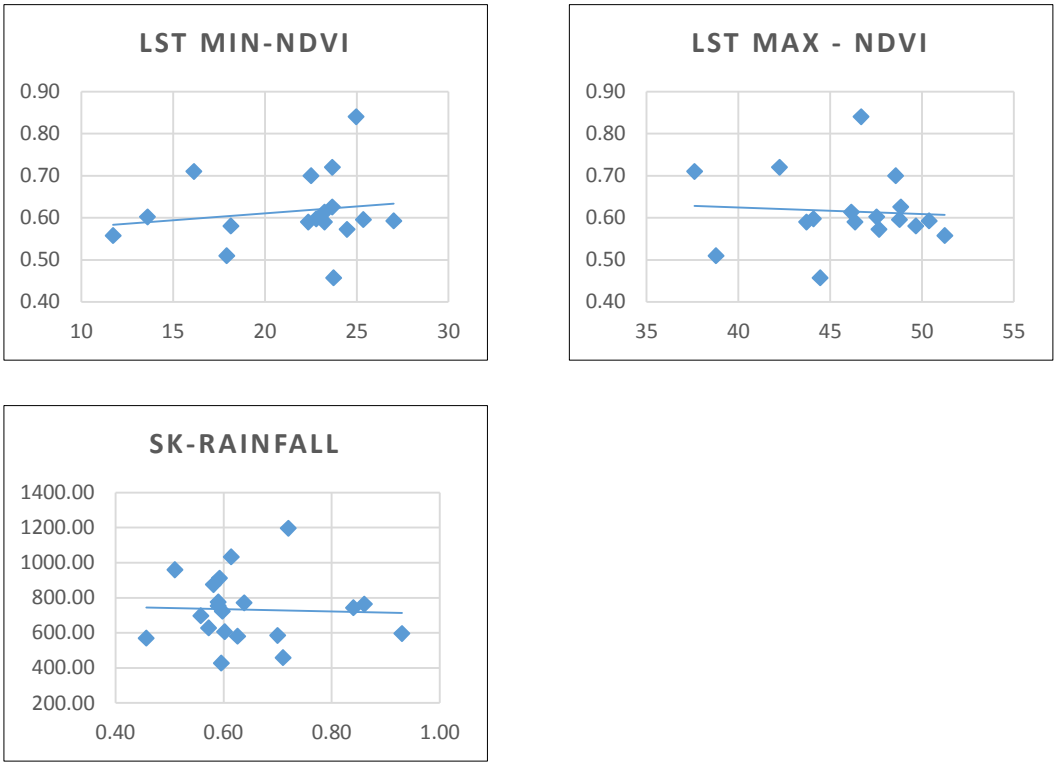


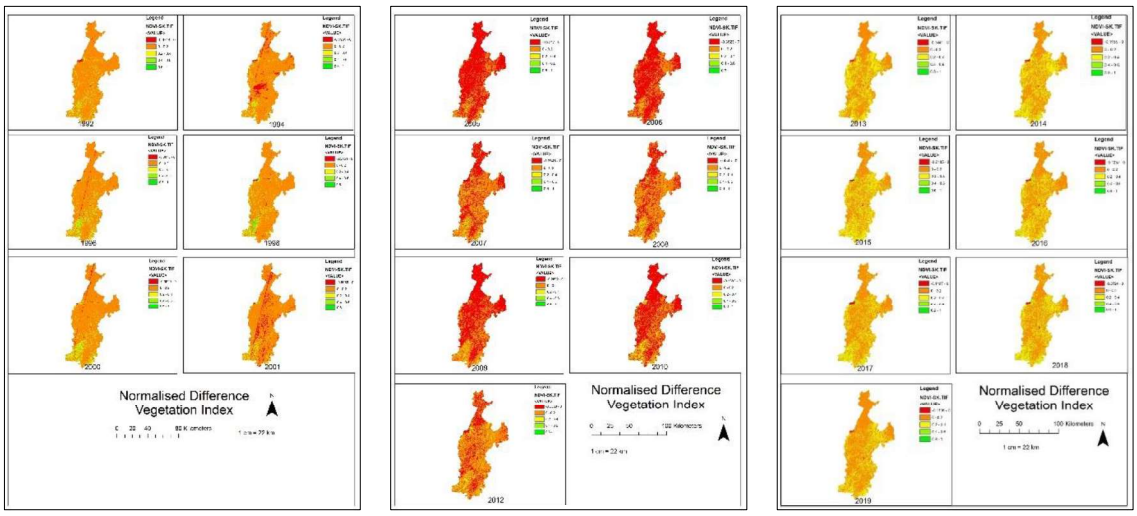
Figure 5.87: Relationship between LST and NDVI, Annual Rainfall and NDVI for Sabarkantha district

The correlation coefficient between NDVI and LST to quantify the strength and direction of their relationship.

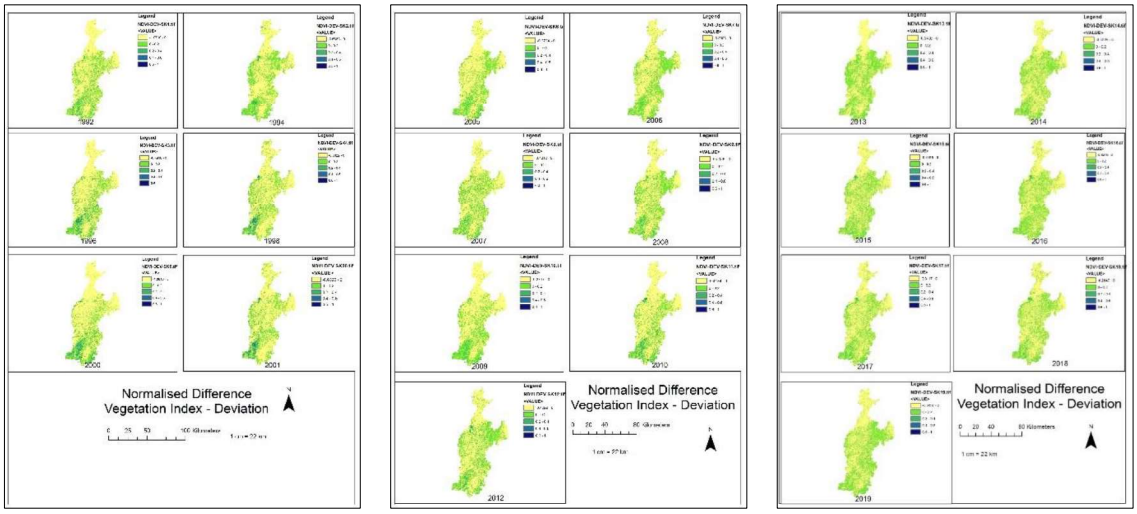
- The relationship between LSTmin and NDVI shows a correlation coefficient as negative trend as 0.1625.
- Similarly, the relationship between LSTmin and NDVI shows a correlation coefficient as -0.070.

The linear trend was developed between the NDVI and LST relationship, which is shown in Figure 5.87. If NDVI shows a positive trend, it may indicate increasing vegetation health over time and LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

Below Map 5.24 and 5.25 shows developed Maps using NDVI index and NDVI deviation for Sabarkantha district.



Map 5.24: Normalized Difference Vegetation Index Map of Sabarkantha District



Map 5.25: Normalized Difference Vegetation Index (Deviation) Map of Sabarkantha District

5.7.6 Comparative analysis of agricultural drought Indices over North Gujarat region

Landsat images of different years 1992 to 2019 with different year's interval were analyzed using NDVI and NDVI deviation. The high NDVI values indicate wet conditions, and low NDVI values indicate dry conditions, it has become the primary tool for describing the phenology of dryness. The NDVI threshold value is between -1 and +1. NDVI values were often highest during wet seasons and lowest during dry seasons. Also, the severity of drought situation is assessed by the extent of NDVI deviation from its long term mean. NDVI deviation is a measure of how the current

NDVI value deviates. Analyzing NDVI deviation is a valuable approach to understanding changes in dryness in the area.

- The results of **Banaskantha** district for NDVI index shows that the maximum percentage of severe dry areas in the year 1996 with 8307.70 sq. km, which is 78.10%, and during that year the rainfall was 384.96 mm in the study region. Also, moderate dry areas as 1321.40 Sq.km which is 12.40% of the study area. The minimum percentage of dry areas in the year 2006 with 3059.90 sq. km which is 28.80% of the area, and during that year the rainfall was 827.93 mm in the study region. The percentage of dry area varies from 21.35% to 46.30% and percentage of Normal dry area varies from 1.5% to 10.87% respectively during study period.

- The results of **Gandhinagar** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 1994 with 1276.30 sq. km, which is 74.0%, and during that year the rainfall was 474.61 mm in the study region. Moderate dry areas as 382.60 sq.km which is 22.20% of the study area. The minimum percentage of dry areas in the year 2006 with 699.50 sq. km which is 40.06% of the area, and during that year the rainfall was 627.54 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.60% area with 96.50 sq.km during this year the annual rainfall is 954.49mm. The percentage of dry area varies from 27.04% to 48.58% and percentage of Normal dry area varies from 0.94 % to 10.27 % respectively during study period.

- The results of **Mehsana** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3531.60 sq. km, which is 80.40%, and during that year the rainfall was 485.16 mm in the study region. Moderate dry areas as 788.30 sq.km, which is 17.90% of the study area. The minimum percentage of dry areas in the year 2005 with 1655.60 sq. km which is 37.70% of the area, and during that year the rainfall was 827.90 mm in the study region. Also, the minimum moderate dry percentage in 2006 year with 5.20% area with 228.90 sq.km during this year the annual rainfall is 827.93 mm. The percentage of dry area varies from 25.48 % to 42.47 % and percentage of Normal dry area varies from 2.28 % to 10.69 % respectively during study period.

- The results of **Patan** district for the NDVI index shows that the maximum percentage of severe dry areas in the year 2018 with 5784.90 sq. km, which is 96.0%, and during that year the rainfall was 284.77 mm in the study region. Also, moderate dry areas as 1075.0 sq.km, which is 17.8% of the study area. Similarly, the minimum percentage of dry areas in the year 2008 with 15.0 sq. km which is 0.20% of the area, and during that year the rainfall was 421.8 mm

in the study region. The percentage of dry area varies from 30.41 % to 42.58 % and percentage of Normal dry area varies from 1.09 % to 4.38 % respectively during study period.

- The results of **Sabarkantha** district the NDVI index shows that the maximum percentage of severe dry areas in the year 1992 with 3660.10 sq. km, which is 87.40%, and during that year the rainfall was 585.35 mm in the study region. Also, moderate dry areas as 403.7 Sq.km, which is 9.6% of the study area. Similarly, the minimum percentage of dry areas in the year 2005 with 1186.60 sq.km which is 28.30% of the area, and during that year the rainfall was 775.20 mm in the study region. Also, the minimum moderate dry percentage in 2005 year with 2.70% area with 114.30 Sq.km during this year the annual rainfall is 775.20 mm. The percentage of dry area varies from 23.27 % to 38.14 % and percentage of Normal dry area varies from 1.94 % to 6.21 % respectively during study period.

NDVI index used for the quantification of drought severity over the study area. More severe drought conditions are typically associated with more significant decreases in NDVI values, which indicating more extensive and severe impacts on vegetation. The linear trend was also developed between the NDVI and LST data. From the analysis it was observed that If NDVI shows a positive trend, it may indicate increasing vegetation health over time and LST shows a negative trend, it suggests decreasing land surface temperatures, possibly due to factors like increased vegetation cover.

This will provides valuable information for understanding how vegetation health is changing over time and can be crucial for making informed decisions related to agriculture, forestry, land management, and environmental conservation.

5.8 COMPUTATION OF VEGETATION STRESS USING VARIOUS INDICES OVER STUDY REGION

Monitoring vegetation health is critical for understanding the effects of environmental conditions, especially drought, on ecosystems, agriculture, and natural resources. The Vegetation Condition Index (VCI) is a valuable tool for assessing and interpreting these changes over time period. In this analysis, VCI values over different years were analyzed using Landsat images over North Gujarat districts.

The VCI is a commonly used remote sensing index for drought analysis and monitoring amount of area under each severity class. The VCI is calculated from remote sensing data, typically using the Normalized Difference Vegetation Index (NDVI), which quantifies the greenness and health of vegetation. It provides a quantitative measure of the condition of vegetation, especially in agricultural and

natural ecosystems, and is widely used to assess the impact of drought on vegetation.

The VCI scale typically ranges from 0 to 100, where: Values close to 100 indicate healthy and normal vegetation conditions. Values significantly below 100 suggest vegetation stress, which can be caused by factors like drought, water scarcity. The lower the VCI, the more severe the vegetation stress. Drought severity is often categorized based on VCI values, with thresholds defined to classify drought as mild, moderate, severe, or extreme.

VCI <10: Extremely stressed vegetation (Extremely drought-affected).
VCI 11-20: Highly stressed vegetation (Severe drought-affected).
VCI 21-30: Moderately stressed vegetation (Moderate drought-affected).
VCI 31-40: Healthy vegetation (Light drought conditions).
VCI >40: Vigorous vegetation (No drought conditions).

Also, the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (SAVI) are another remote sensing indices used to assess vegetation health and vigor. While they share the same general purpose, which is to quantify and to monitor vegetation conditions, they have distinct characteristics that make them suitable for different applications.

The high NDVI values indicate healthy, thick and healthy vegetation, and it has become the primary tool for describing the phenology of vegetation. Because of yearly variations in vegetation responses, the obtained NDVI data was analyzed for each year. Similarly, The SAVI is a vegetation index used in remote sensing to assess and monitor vegetation health and condition while compensating for variations in soil brightness. It was specifically developed to minimize the influence of soil reflectance on vegetation indices, making it especially useful in regions where soil background can significantly affect the accuracy of standard vegetation indices like the NDVI.

- NDVI can sometimes provide false positives in stress detection due to its sensitivity to soil conditions.
- SAVI is more accurate in detecting vegetation stress because it accounts for soil brightness.

For classifying NDVI and SAVI values into categories such as "slight dense," "moderate dense," and "high dense" is a common way to interpret and communicate the level of vegetation density and health in a study area.

Below section shows the results of different indices over North Gujarat districts.

5.8.1 Computation of vegetation stress using various indices over Banaskantha district

Results of VCI for Banaskantha district

The Vegetation Condition Index (VCI) is a valuable tool for assessing and interpreting changes over time period. The VCI values over 2013 to 2019 years using Landsat data for Banaskantha district is analyzed and results shown in below Table 5.136.

Table 5.136: Classification of VCI for Banaskantha district

Classification	Range	2013	2014	2015	2016	2017	2018
Extreme Drought	< 10	6.3	0.9	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	170.3	19.9	0.1	1.5	0.0	25.7
Moderate Drought	20 to 30	1610.1	220.2	15.4	36.3	9.8	30.2
Light Drought	30 to 40	4251.3	2141.9	72.4	80.8	18.8	930.8
No Drought	> 40	4592.9	8247.9	10543	10512	10602	9644

(Area in Sq.km)

From the above Table 5.136 it was observed that in the year 2018 the severe drought covers an area of 25.7 sq.km which is 0.24% the total district. Moderate drought conditions, and Light drought conditions covers area of 30.2 sq.km and 930.80 sq.km respectively. The average drought percentage 9 % in the Banaskantha district. The results of VCI index shows that moderate drought having 20.8 percent and light drought having 55.10 percent during study period of 1992 to 2019 in the district.

Results of NDVI and SAVI for Banaskantha district

The temporal and spatial analysis of vegetation stress in Banaskantha district is calculated using Landsat data of 30 m resolution considering 1992 to 2019 years using SAVI and NDVI. Below Table 5.137 shows the results of detail classification during 2013 to 2019 of category in which containing particular sq.km area of vegetation using SAVI and NDVI. However, the same for the years 1992 to 2019 are showing in below Figure 5.88.The monitoring of these indices over time helps in identifying the percentage of area and total area which is prone to vegetation stress.

Table 5.137: Classification of SAVI for Banaskantha district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	< 0.00	16.5	15.6	18.5	38.8	2.4	39.3	19.4
Slight Dense	0.00 to 0.30	8280.6	6141.3	5554.8	5441.0	5490.3	4953.3	8264.8
Moderate Dense	0.30 to 0.60	2316.2	4233.9	4331.1	4166.7	3999.1	4505.4	2292.8

Highly Dense	> 0.60	17.6	240.0	726.5	984.3	1117.3	1132.9	53.9

(Area in Sq.km)

Table 5.138: Classification of NDVI for Banaskantha district

Classification	**Range**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
No Vegetation	-1 to 0	16.5	15.6	18.5	38.8	24.1	39.3	19.4
Slight Vegetation	0.01 to 0.30	10337	9550.5	8648.5	8301.8	8165.4	7973.4	10201
Moderate Vegetation	0.31 to 0.60	277.1	1064.7	1963.5	2289.6	2441.2	2618.1	410.5

(Area in Sq.km)

SAVI results of 2019 year shows that the non-vegetation class falls in the range of less than 0.00 which covers 19.4 sq. km area of the district which is 0.18% of the total area of the district. The Slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 77.74% of the total district area which comprises 8264.80 sq.km. Also, Moderate dense vegetation in the districts covers 21.56% of the total area which is 2292.80 sq. km of the district. The highly dense area in the district is 53.9 sq.km. The annual average rainfall was 690.82 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 46.59% to 78.48% during study period of 1992 to 2019.

NDVI results of 2019 year shows that the non-vegetation threshold value less than 0.00 which covers 19.40 sq. km area of the district which is 0.18% of the total area of the district. The Slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 92% of the total area which covers 10201 sq. km of the district. Also, Moderate dense vegetation in the districts comprise 3.85 % of the total vegetation area which is 410.5 sq. km of the district. The study also observed a change in vegetation from 70.02 % to 95.12 % during study period of 1992 to 2019.

The results of NDVI and SAVI yield similar results, their performance can differ based on environmental conditions. The choice between NDVI and SAVI depends on the specific characteristics of the study area with SAVI being preferred in situations where soil background influences need to be minimized. It's advisable to carefully evaluate the characteristics of the study area and select the vegetation index that best suits the objectives of the analysis.

This graphical reprsentation for the study period for year 1992 to 2019 is shown in below Figure 5.88, which shows that comparisons of dense percentage area between SAVI index and NDVI index for Banaskantha district.

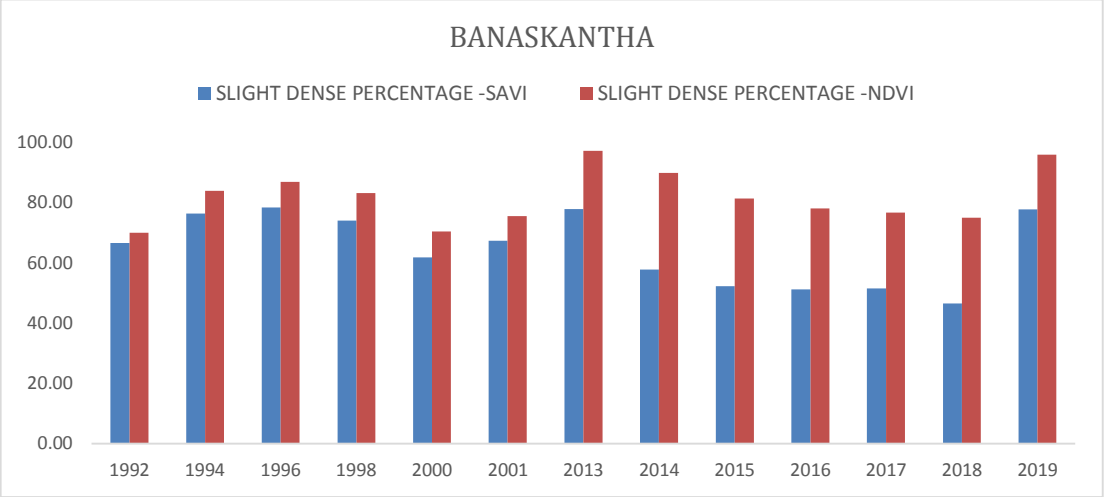


Figure 5.88: Dense percentage area between SAVI and NDVI for Banaskantha district

From the above Figure 5.88 it the result of SAVI shows that minimum vegetation was observed in 2018 year as 46.59% and maximum vegetation was observed in 1996 year as 78.48%. Similarly, NDVI shows that minimum vegetation was observed in 2000 year as 70.47% and maximum vegetation was observed in 2013 year as 97.24%. The average vegetation in Banaskantha district was 64.61% during study period.

The declining trends in NDVI and SAVI for certain points may warrant further investigation into the causes, such as land-use changes, climate fluctuations, or human activities. This analysis it will provides valuable information for understanding how vegetation is changing over time and can be crucial for making informed decisions related to agriculture, forestry, land management, and environmental conservation.

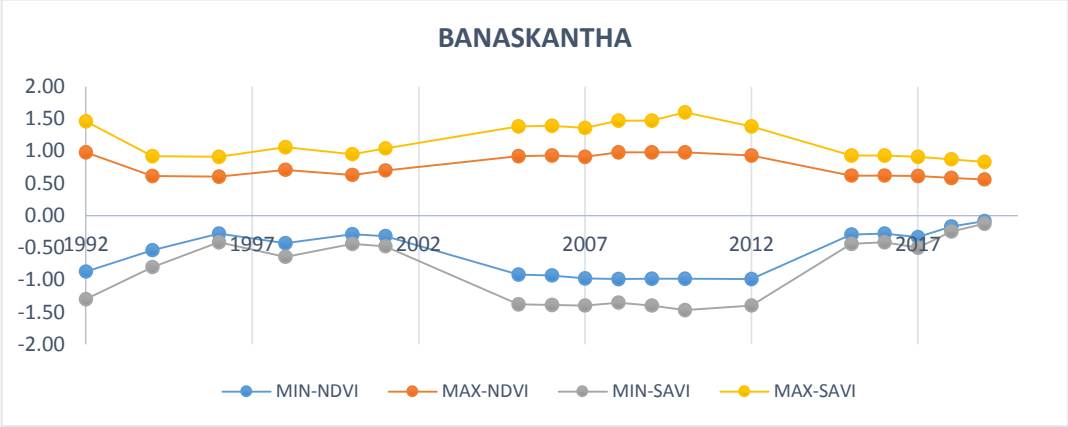


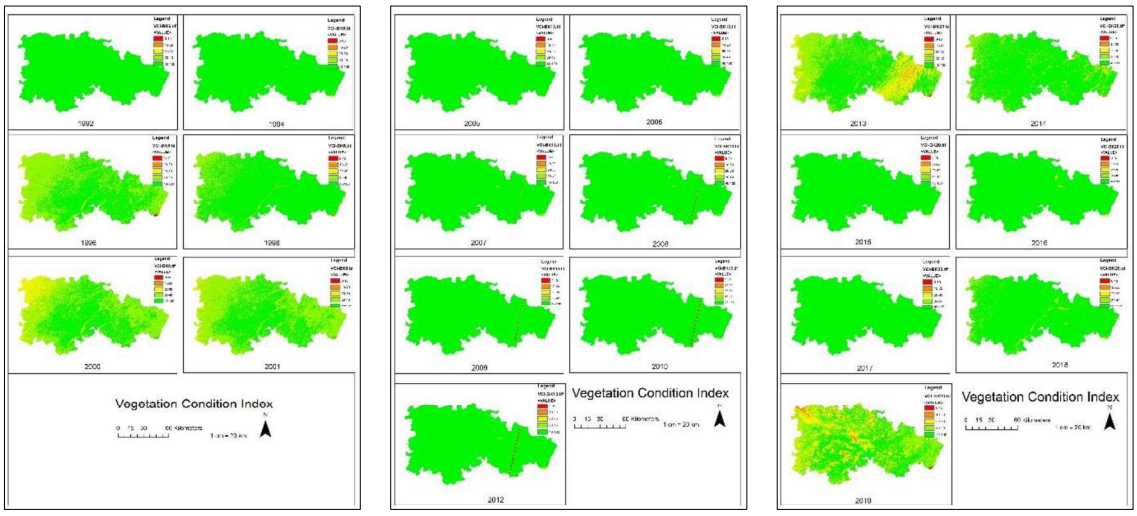
Figure 5.89: Max and Min values of NDVI and SAVI over Banaskantha district

The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI to determine which index was shown in above Figure 5.89. The minimum NDVI value is -0.99 and maximum NDVI value is 0.98 and the minimum SAVI value is -1.47 and maximum SAVI value is 1.60.From the analysis it was observed that NDVI tends to be more sensitive to changes in vegetation density and less affected by soil brightness variations. Therefore, it often provides higher values when vegetation is at its peak.

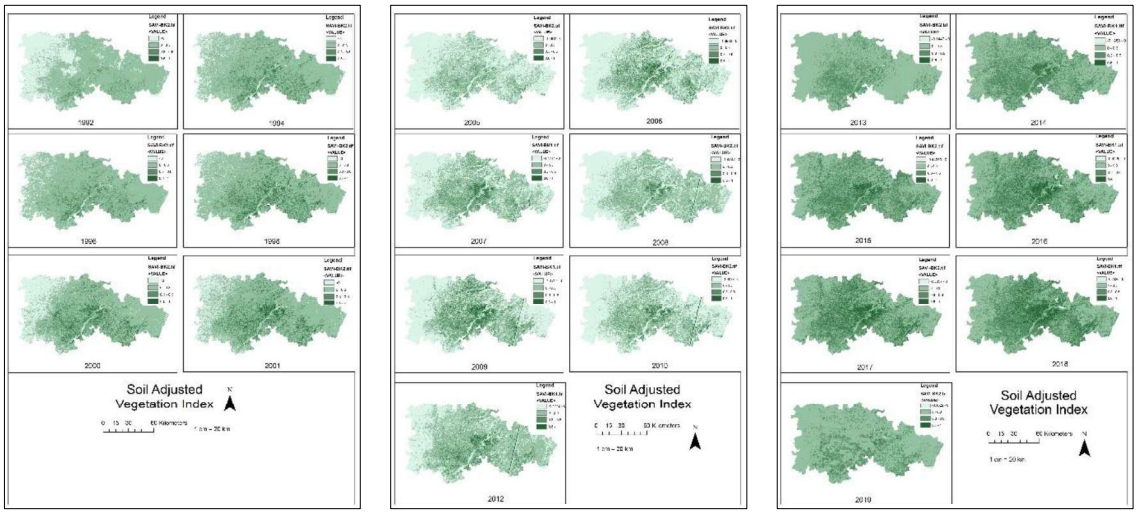
This decline in vegetation is a matter of significant ecological importance and warrants careful consideration and proactive measures.

The findings underscore the importance of addressing potential factors contributing to this decline, such as land use changes, climate variations, or human activities. Moving forward, it is imperative to implement conservation strategies and sustainable land management practices to reverse this trend and ensure the long-term health and resilience of the ecosystem. The study's results serve as a call to action for policymakers, conservationists, and the community to collaborate on preserving and restoring the vital green infrastructure essential for environmental balance and human well-being.

The Vegetation Condition Index Map and Soil Adjusted Vegetation Index Map is shown in below Map 5.26 and 5.27 respectively for Banaskantha district.



Map 5.26: Vegetation Condition Index Map of Banaskantha District



Map 5.27: Soil Adjusted Vegetation Index Map of Banaskantha District

5.8.2 Computation of vegetation stress using various indices over Gandhinagar district

The VCI values over 2013 to 2019 years using Landsat data for Gandhinagar district is analyzed and results shown in below Table 5.139.

Table 5.139: Classification of VCI for Gandhinagar district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme Drought	< 10	0.1	0.3	0.0	0.0	0.2	0.2	0.0
Severe Drought	10 to 20	0.8	1.3	0.0	0.2	3.3	7.6	0.4
Moderate Drought	20 to 30	24.4	20.7	1.5	3.9	32.8	53.9	29.4
Light Drought	30 to 40	340.2	188.8	21.9	52.2	355.8	551.2	186.7
No Drought	> 40	1358.9	1513.4	1700.9	1668.1	1332.2	1111.6	1507.9

(Area in Sq.km)

From the above Table 5.139 it was observed that in the year 2018 the severe drought covers an area of 7.6 sq.km which is 0.44% the total district. Moderate drought conditions, and Light drought conditions covers area of 29.4 sq.km and 186.7 sq.km respectively. The average drought percentage 12.15 % in the Gandhinagar district.

Results of NDVI and SAVI for Gandhinagar district

Below Table 5.140 and 5.141 shows the results of classification of category in which containing particular sq.km area of vegetation using SAVI and NDVI respectively for

2013 to 2019 year. However, the same for the years 1992 to 2019 are showing in below Figure 5.90.

Table 5.140: Classification of SAVI for Gandhinagar district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	< 0.00	0.6	0.6	1.1	0.6	0.5	0.3	0.7
Slight Dense	0.00 to 0.30	877.7	734.6	699.7	754.6	764.6	774.6	840.8
Moderate Dense	0.30 to 0.60	809.9	956.8	944.7	907.1	864.8	893.5	821.3
Highly Dense	> 0.60	36.2	32.4	78.9	62.1	94.6	55.9	61.6

(Area in Sq.km)

Table 5.141: Classification of NDVI for Gandhinagar district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	-1 to 0	0.6	0.6	1.1	0.6	0.5	0.3	0.7
Slight Vegetation	0.01 to 0.30	1517.4	1490.8	1402.1	1453.7	1392.1	1452.5	1473.5
Moderate Vegetation	0.31 to 0.60	206.4	233.0	321.2	270.1	331.8	271.7	250.2

(Area in Sq.km)

SAVI results of 2019 year shows that the non-vegetation class falls in the range of less than 0.00 which covers 0.70 sq. km area of the district which is 0.18% of the total area of the district. The Slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 48.72 % of the total district area which comprises 840.8 Sq.km. Also, Moderate dense vegetation in the districts covers 47.63% of the total area which is 821.30 sq. km of the district. The highly dense area in the district is 61.60 Sq.km. The annual average rainfall was 954.48 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 40.58 % to 74.55 % during study period of 1992 to 2019 years.

NDVI results of 2019 year shows that slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 85% of the total area which covers 1473.2 sq.km of the district. Also, Moderate dense vegetation in the districts comprise 14.51 % of the total vegetation area which is 250.2 sq.km of the district. The study also observed a change in vegetation from 63.71% to 89.45% during study period of 1992 to 2019 years.

This graphical representation for the year 1992 to 2019 is shown in below Figure 5.90 which shows that comparisons of dense percentage area between SAVI index and NDVI index for Gandhinagar district.

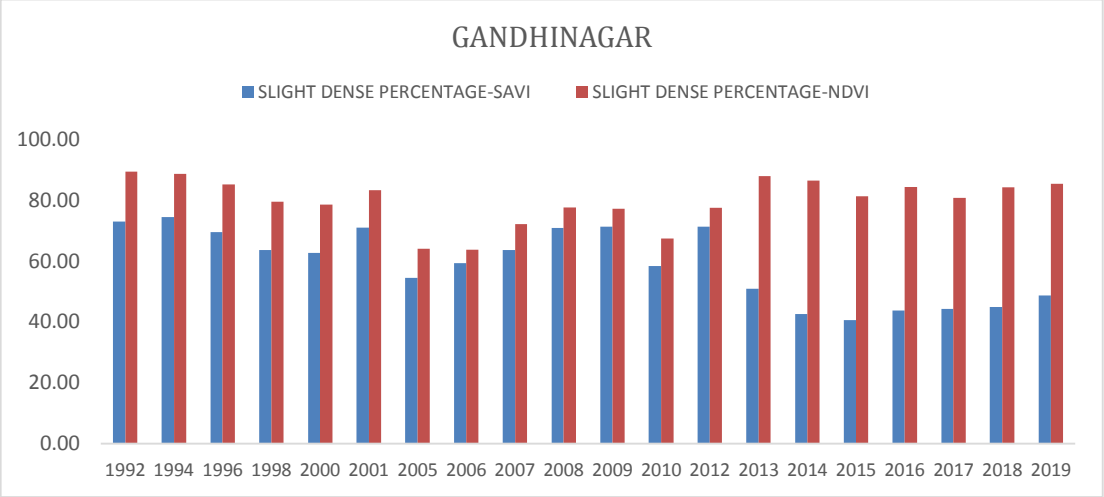


Figure 5.90: Dense percentage area between SAVI and NDVI for Gandhinagar district

From the above Figure 5.90, result of SAVI shows that minimum vegetation was observed in 2015 year as 40.58% and maximum vegetation was observed in 1994 year as 74.55%. Similarly, NDVI shows that minimum vegetation was observed in 2006 year as 63.71% and maximum vegetation was observed in 1992 year as 89.45%. The average vegetation in Gandhinagar district was 59.12% during study period.

The declining trends in NDVI and SAVI for certain points may warrant further investigation into the causes, such as land-use changes, climate fluctuations, or human activities.

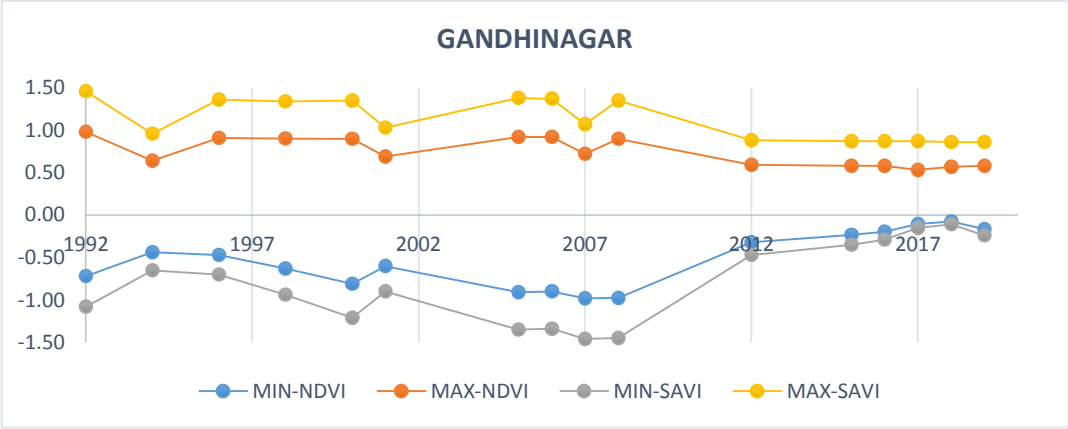
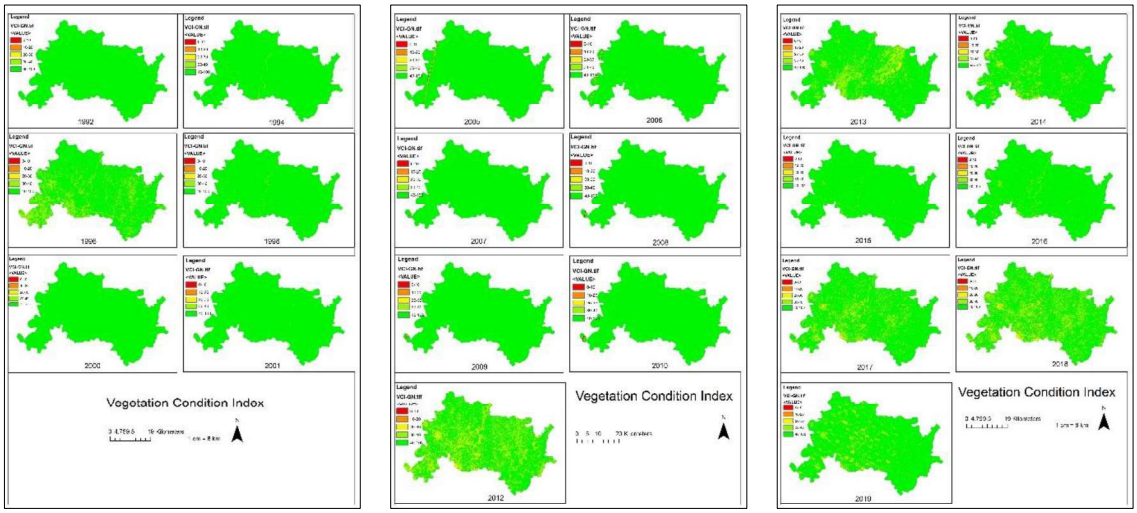


Figure 5.91: Max and Min values of NDVI and SAVI over Gandhinagar district

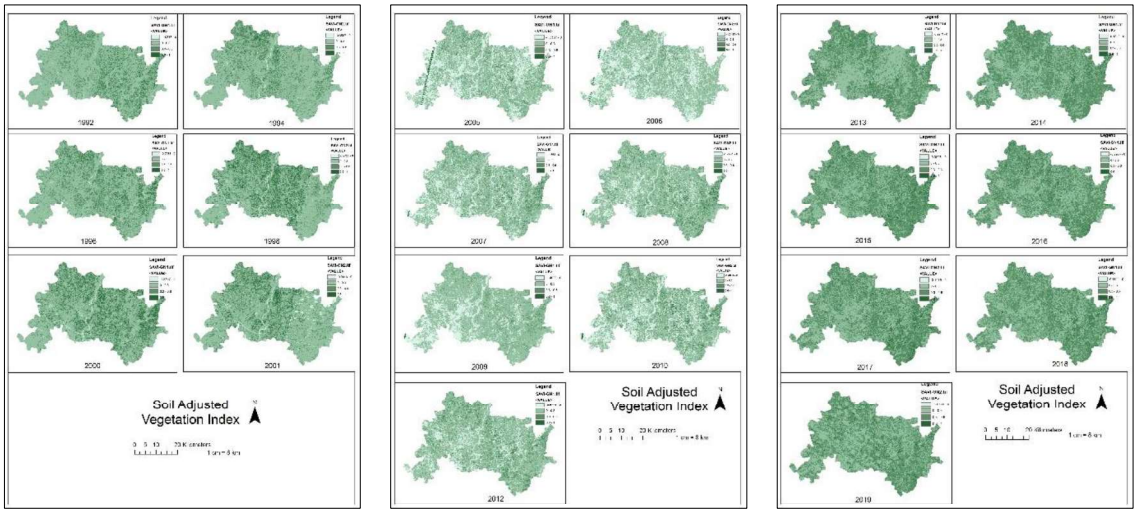
The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI index is shown in above Figure 5.91. The minimum NDVI value is -0.98 and maximum NDVI value is 0.98 and the minimum SAVI value is -1.46 and maximum SAVI value is 1.46. From the analysis it was observed that NDVI tends to be more

sensitive to changes in vegetation density and less affected by soil brightness variations. Therefore, it often provides higher values when vegetation is at its peak.

The Vegetation Condition Index Map and Soil Adjusted Vegetation Index Map is shown in Below Map 5.28 and 5.29 respectively for Gandhinagar district.



Map 5.28: Vegetation Condition Index Map of Gandhinagar District



Map 5.29: Soil Adjusted Vegetation Index Map of Gandhinagar District

5.8.3 Computation of vegetation stress using various indices over Mehsana district

The VCI values over 2013 to 2019 years using Landsat data for Mehsana district is analyzed and results shown in below Table 5.142.

Table 5.142: Classification of VCI for Mehsana district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme Drought	< 10	0.1	1.2	0.4	0.1	0.0	0.0	0.0
Severe Drought	10 to 20	6.6	9.3	10.1	6.7	6.0	0.5	0.1
Moderate Drought	20 to 30	19.6	67.8	27.7	11.2	12.5	16.0	26.8
Light Drought	30 to 40	586.3	505.0	842.3	270.8	174.1	143.7	497.1
No Drought	> 40	3779.4	3808.7	3511.4	4103.1	4199.3	4231.6	3867.9

(Area in Sq.km)

From the above Table 5.142 it was observed that in the year 2019 the Moderate drought conditions, and Light drought conditions covers area of 26.8 Sq.km and 497.10 Sq.km area respectively. The average drought percentage 11% in the Mehsana district. The results of VCI index shows that moderate drought having 23.6 percent and light drought having 53.25 percent during study period in the district.

Results of NDVI and SAVI for Mehsana district

The temporal and spatial analysis of vegetation stress in Mehsana district is calculated using SAVI and NDVI index. Below Table 5.143 and 5.144 shows the results of classification of category in which containing particular Sq.km area of vegetation. However, the same for the years 1992 to 2019 are showing in below Figure 5.92.

Table 5.143: Classification of SAVI for Mehsana district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	< 0.00	6.6	7.3	7.8	8.9	10.5	4.0	5.8
Slight Dense	0.00 to 0.30	2252.2	2026.9	2052.3	2029.6	2139.7	2167.4	2488.2
Moderate Dense	0.30 to 0.60	2054.2	2279.2	2178.0	2167.0	2023.9	2111.2	1791.9
Highly Dense	> 0.60	78.9	78.5	153.8	186.4	217.8	109.3	106.0

(Area in Sq.km)

Table 5.144: Classification of NDVI for Mehsana district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	-1 to 0	6.6	7.3	7.8	8.9	10.5	4.0	5.8
Slight Vegetation	0.01 to 0.30	3882	3892.0	3711.2	3681.2	3642.9	3801.1	3924.3
Moderate Vegetation	0.31 to 0.60	502.9	492.6	672.9	701.8	738.5	586.9	461.8

(Area in Sq.km)

SAVI results of 2019 year shows that the non-vegetation having 5.8 sq.km area of the district. The slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 56.66 % of the total district area which comprises 2488.2 sq.km. Also, Moderate dense vegetation in the districts covers 40.78 % of the total area which is 1791.9 sq. km of the district. The highly dense area in the district is 106 sq.km. with annual average rainfall was 854.30 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 46.15 % to 80.86 % during study period of 1992 to 2019 years.

NDVI results of 2019 year shows that slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 89.36% of the total area which covers 3924.3 sq. km of the district. Also, Moderate dense vegetation in the districts comprise 10.51 % of the total vegetation area which is 461.80 sq. km of the district. The study also observed a change in vegetation from 55.99 % to 93.55 % during study period of 1992 to 2019 years.

This graphical representation for the year 1992 to 2019 is shown in below Figure 5.92 that comparisons of dense percentage area between SAVI index and NDVI index for Mehsana district.

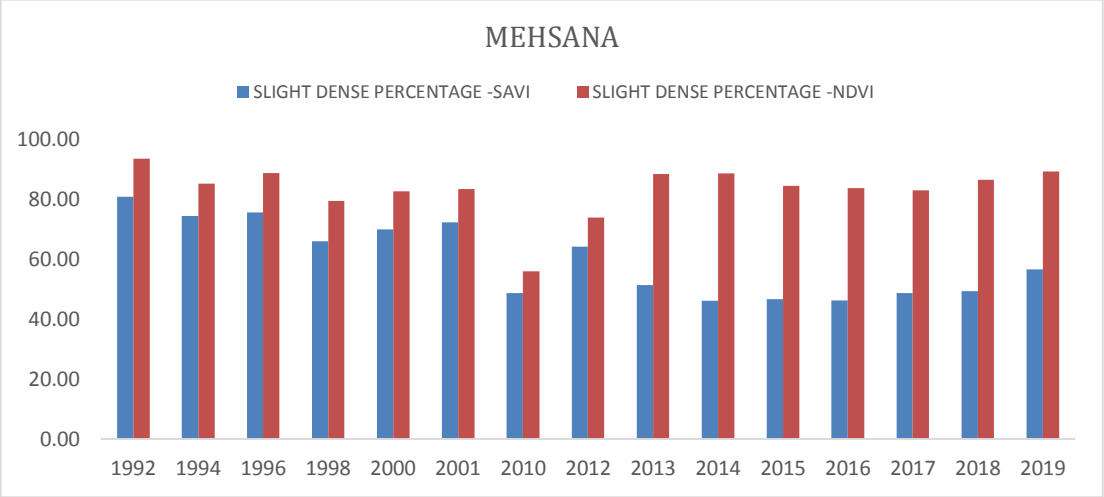


Figure 5.92: Dense percentage area between SAVI and NDVI for Mehsana district

From the above Figure 5.92 the result of SAVI shows that minimum vegetation was observed in 2014 year as 46.15% and maximum vegetation was observed in 1992 year as 80.86%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 55.99% and maximum vegetation was observed in 1992 year as 93.55%. The average vegetation in Mehsana district was 59.83% during study period.

The declining trends in NDVI and SAVI for certain points may warrant further investigation into the causes, such as land-use changes, climate fluctuations, or human activities.

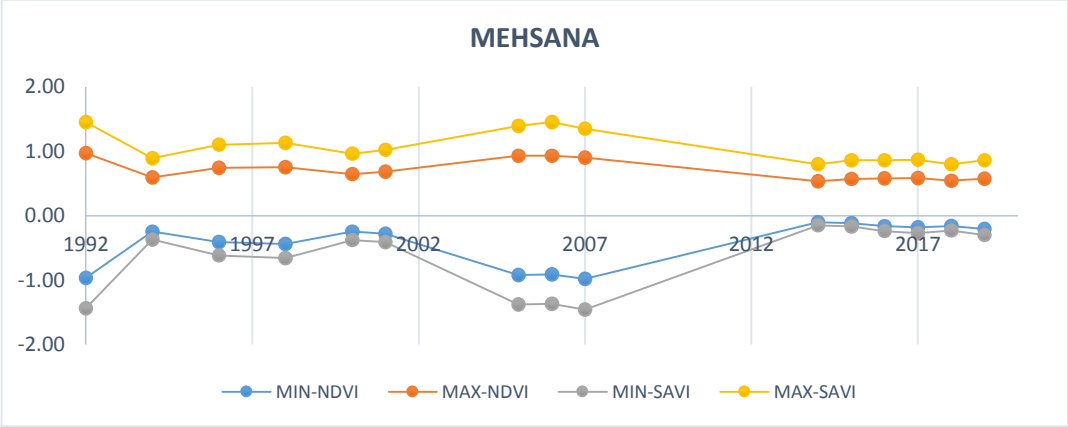
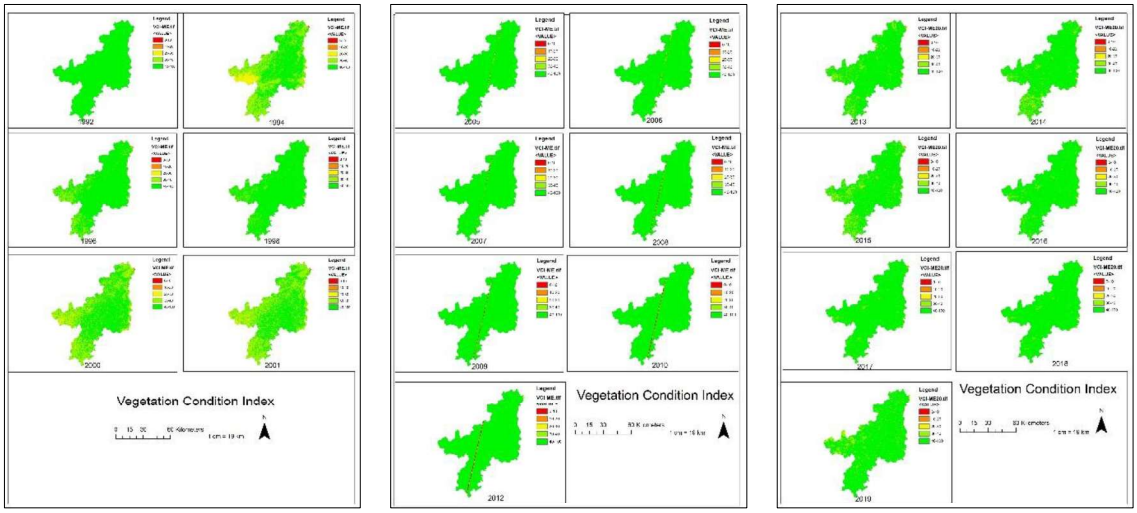


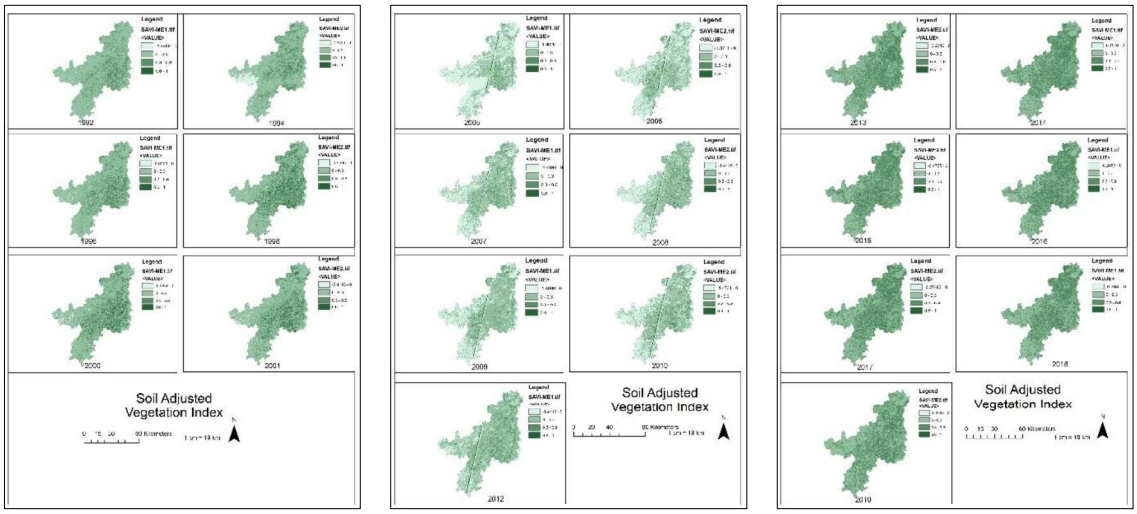
Figure 5.93: Max and Min values of NDVI and SAVI over Mehsana district

The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI is shown in above Figure 5.93. The minimum NDVI value is -0.96 and maximum NDVI value is 0.97 and the minimum SAVI value is -1.46 and maximum SAVI value is 1.45. From the analysis it was observed that NDVI tends to be more sensitive to changes in vegetation density and less affected by soil brightness variations. Therefore, it often provides higher values when vegetation is at its peak.

The Vegetation Condition Index Map and Soil Adjusted Vegetation Index Map is shown in Below Map 5.30 and 5.31 respectively for Mehsana district.



Map 5.30: Vegetation Condition Index Map of Mehsana District



Map 5.31: Soil Adjusted Vegetation Index Map of Mehsana District

5.8.4 Computation of vegetation stress using various indices over Patan district

The VCI values over 2013 to 2019 years using Landsat data for Patan district is analyzed and results shown in below Table 5.145.

Table 5.145: Classification of VCI for Patan district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme Drought	< 10	0.1	0.1	0.1	0.2	0.5	2.4	0.0
Severe Drought	10 to 20	1.3	9.3	1.3	8.8	2.0	8.8	1.0
Moderate Drought	20 to 30	439.0	14.5	8.4	7.5	9.5	10.1	670.6
Light Drought	30 to 40	3306.9	138.0	924.9	297.1	1058.5	1864.8	2654.3
No Drought	> 40	2233.7	5861.6	5089.1	5710.2	4953.1	4137.5	2697.5

(Area in Sq.km)

From the above Table 5.145 it was observed that in the year 2019 the Moderate drought conditions, and Light drought conditions covers area of 670.6 Sq.km and 2654.30 Sq.km area respectively. Also, from the analysis it was observed that 10.5 Sq.km area under extreme dry conditions 46.6 sqkm area as severe dry and 4439.70 Sq.km area as moderate dry conditions during the study period. The average drought percentage is 34% in the Patan district.

Results of NDVI and SAVI for Patan district

Below Table 5.146 and 5.147 shows the results of classification of category in which containing particular Sq.km area of vegetation using SAVI and NDVI index

respectively. The monitoring of these indices over time helps in identifying the percentage of area and total area which is prone to vegetation stress. However, the same for the years 1992 to 2019 are showing in below Figure 5.94

Table 5.146: Classification of SAVI for Patan district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	< 0.00	1.5	22.3	5.4	0.0	6.1	13.0	4.2
Slight Dense	0.00 to 0.30	5439.9	4554.5	4624.4	0.0	4743.3	4741.7	5372.3
Moderate Dense	0.30 to 0.60	536.9	1432.9	1331.3	0.0	1213.5	1234.5	638.8
Highly Dense	> 0.60	2.7	13.8	62.6	0.0	60.7	34.4	8.0

(Area in Sq.km)

Table 5.147: Classification of NDVI for Patan district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
No Vegetation	-1 to 0	1.6	22.3	5.4	16.3	6.1	13.0	4.2
Slight Vegetation	0.01 to 0.30	5927.0	5835.7	5707.8	5686.5	5733.8	5784.9	5933.9
Moderate Vegetation	0.31 to 0.60	52.5	165.5	310.5	320.9	283.6	225.7	85.2

(Area in Sq.km)

SAVI results of 2019 year shows that slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 89.19 % of the total district area which comprises 5372.3 sq.km. Also, Moderate dense vegetation in the districts covers 10.59 % of the total area which is 638.8 sq. km of the district. The highly dense area in the district is 8 sq.km. The annual average rainfall was 717.19 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 16.35 % to 89.19 % during study period.

NDVI results of 2019 year shows that slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 98.50% of the total area which covers 5933.9 sq. km of the district. Also, Moderate dense vegetation in the districts comprise 14.14 % of the total vegetation area which is 85.2 sq. km of the district. The study also observed a change in vegetation from 15.74 % to 98.51 % during study period.

This graphical representation for the year 1992 to 2019 shows is shown in below Figure 5.94 between SAVI index and NDVI index for Patan district.

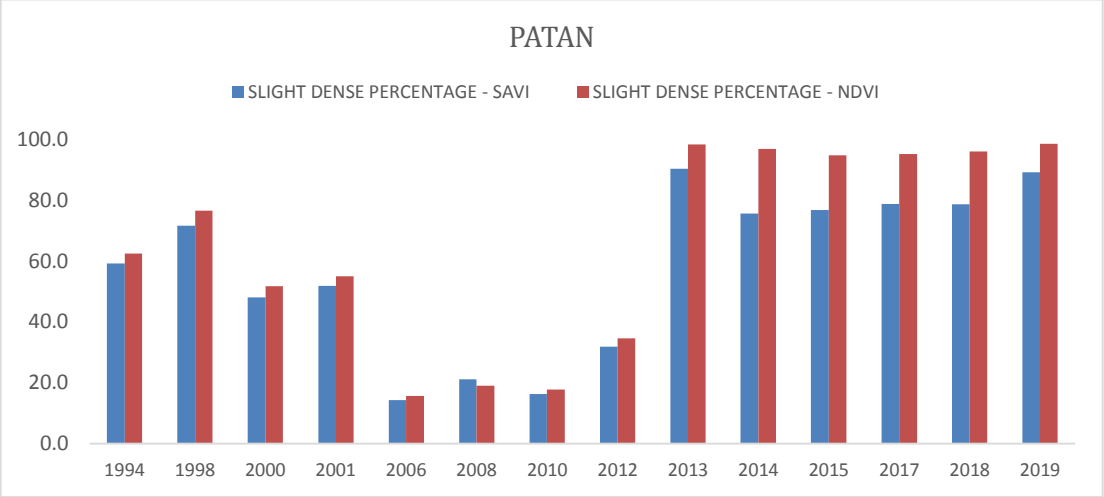


Figure 5.94: Dense percentage area between SAVI and NDVI for Patan district

Figure 5.94 shows the result of SAVI that minimum vegetation was observed in 2010 year as 16.35% and maximum vegetation was observed in 2019 year as 89.19%. Similarly, NDVI shows that minimum vegetation was observed in 2005 year as 15.75% and maximum vegetation was observed in 2019 year as 98.55%. The average vegetation in Patan district was 57.80% during study period.

The declining trends in NDVI and SAVI for certain points may warrant further investigation into the causes, such as land-use changes, climate fluctuations, or human activities.

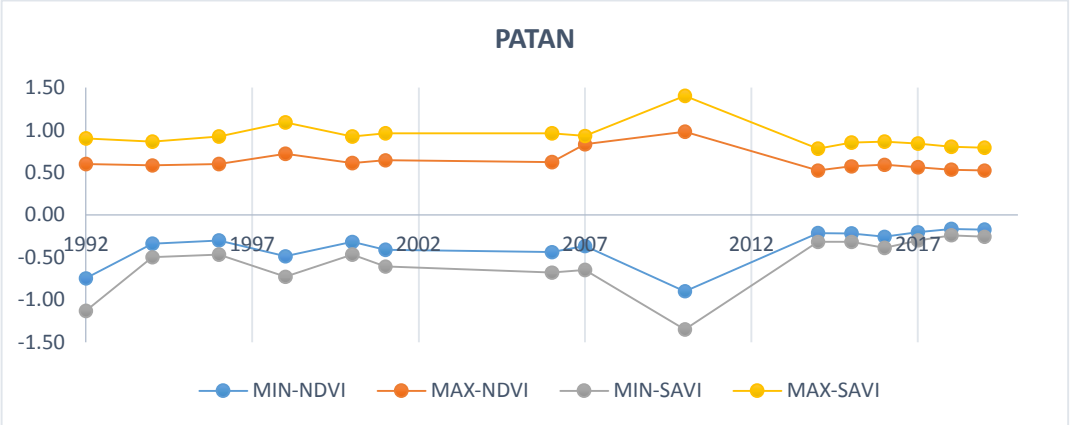
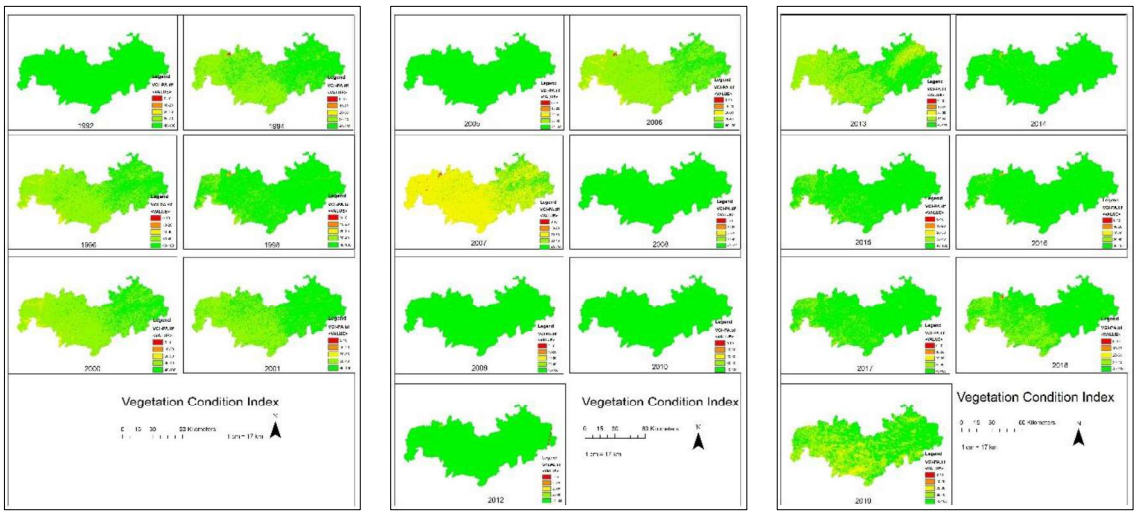


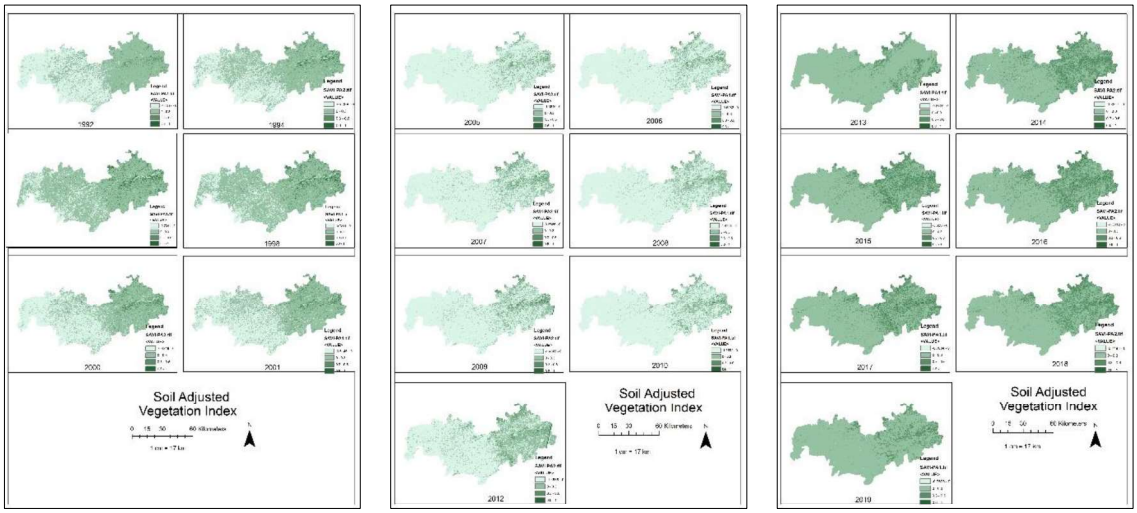
Figure 5.95: Max and Min values of NDVI and SAVI over Patan district

The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI index was shown in above Figure 5.95. The minimum NDVI value is -0.90 and maximum NDVI value is 0.98 and the minimum SAVI value is -1.35 and maximum SAVI value is 1.40.

The Vegetation Condition Index Map and Soil Adjusted Vegetation Index Map is shown in Below Map 5.32 and 5.33 respectively for Patan district.



Map 5.32: Vegetation Condition Index Map of Patan District



Map 5.33: Soil Adjusted Vegetation Index Map of Patan District

5.8.5 Computation of vegetation stress using various indices over Sabarkantha district

The VCI values over 2013 to 2019 years using Landsat data for Sabarkantha district is analyzed and results shown in below Table 5.148.

Table 5.148: Classification of VCI for Sabarkantha district

Classification	Range	2013	2014	2015	2016	2017	2018	2019
Extreme Drought	< 10	0.2	4.0	0.0	0.5	19.4	18.3	0.0
Severe	10 to 20	17.2	17.9	8.5	24.0	8.9	11.7	11.1

Drought								
Moderate Drought	20 to 30	147.6	21.7	24.2	18.8	35.1	111.1	49.8
Light Drought	30 to 40	1468.6	632.0	72.6	857.9	1686.2	2215.0	338.9
No Drought	> 40	2554.8	3513.0	4083.2	3287.3	2438.9	1832.5	3788.7

(Area in Sq.km)

From the above Table 5.148 it was observed that in the year 2019 the severe drought condition covers an area of 11.10 sqkm, Moderate drought conditions, and Light drought conditions covers area of 49.8 sq.km and 338.90 sq.km area respectively. The maximum extreme dry area was 24.5 Sq.km severe dry area as 24.00 sq.km and moderate dry area as 779.0 sq.km during the study period. The average drought percentage 28 % in the Sabarkantha district.

Results of NDVI and SAVI for Sabarkantha district

Below Table 5.149 and 5.150 shows the results of classification of category in which containing particular sq.km area of vegetation using SAVI and NDVI respectively. The monitoring of these indices over time helps in identifying the percentage of area and total area which is prone to vegetation stress. However, the same for the years 1992 to 2019 are showing in below Figure 5.96

Table 5.149: Classification of SAVI for Sabarkantha district

Classification	**Range**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
No Vegetation	< 0.00	13.9	18.5	23.8	21.4	25.5	20.6	15.1
Slight Dense	0.00 to 0.30	2518.4	2359.1	2297.5	2649.3	2652.9	2487.0	2890.8
Moderate Dense	0.30 to 0.60	1597.2	1725.8	1726.5	1457.1	1381.4	1544.7	1216.9
Highly Dense	> 0.60	59.0	85.1	140.6	60.7	128.7	136.1	65.7

(Area in Sq.km)

Table 5.150: Classification NDVI for Sabarkantha district

Classification	**Range**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
No Vegetation	-1 to 0	13.9	18.5	23.8	11.8	21.4	20.6	15.1
Slight Vegetation	0.01 to 0.30	3784	3756.5	3682.2	2057.9	3878.3	3688.3	3911.7
Moderate Vegetation	0.31 to 0.60	389.7	413.5	482.5	65.6	288.8	479.6	261.7

(Area in Sq.km)

SAVI results of 2019 year shows that slightly dense vegetation threshold value ranges from 0.00 to 0.30, it covers 69.10 % of the total district area which comprises 2890.8 Sq.km. Also, Moderate dense vegetation in the districts covers 29.03 % of

the total area which is 1216.9 sq. km of the district. The highly dense area in the district is 65.7 Sq.km. The annual average rainfall was 875.40 mm during this year. The drought conditions can stress vegetation, so monitoring rainfall and precipitation patterns is crucial in assessing vegetation stress. The study also observed a change in vegetation from 37.41 % to 87.64 % during study period.

NDVI results of 2019 year shows that slightly dense vegetation class, which falls in the range of 0.00 to 0.30, it covers 93.38% of the total area which covers 3911.7 sq. km of the district. Also, Moderate dense vegetation in the districts comprise 6.24 % of the total vegetation area which is 261.70 sq. km of the district. The study also observed a change in vegetation from 40.90 % to 93.95 % during study period.

This graphical representation for the year 1992 to 2019 is shown in below Figure 5.96 between SAVI index and NDVI index for Sabarkantha district.

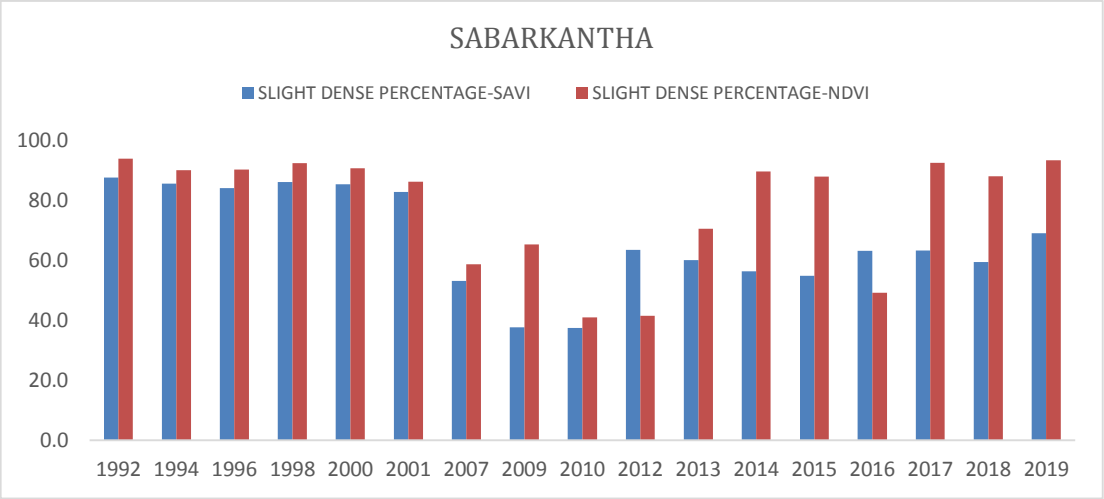


Figure 5.96: Dense percentage area between SAVI and NDVI for Sabarkantha district

From the above Figure 5.96 it was observed that SAVI shows that minimum vegetation was observed in 2009 year as 37.41% and maximum vegetation was observed in 1992 year as 87.60%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 40.90% and maximum vegetation was observed in 2019 year as 93.40%. The average vegetation in Sabarkantha district was 66.47% during study period.

The declining trends in NDVI and SAVI for certain points may warrant further investigation into the causes, such as land-use changes, climate fluctuations, or human activities.

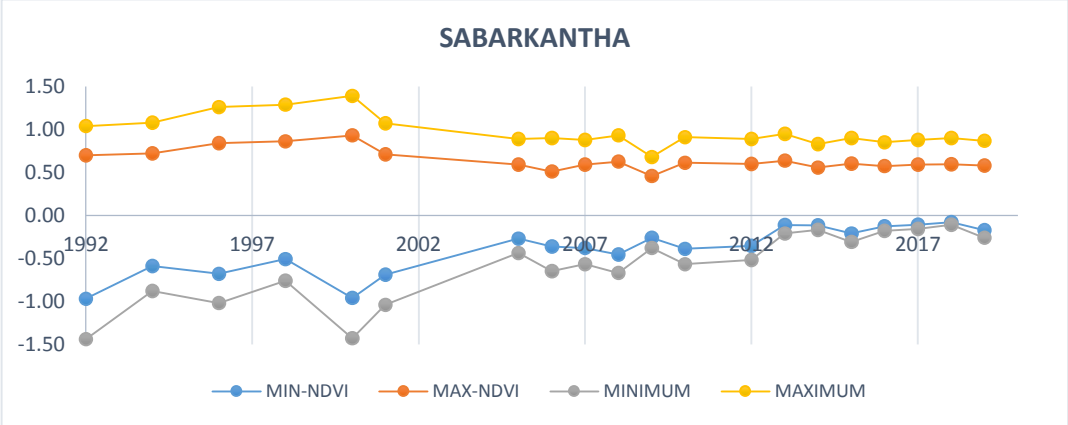
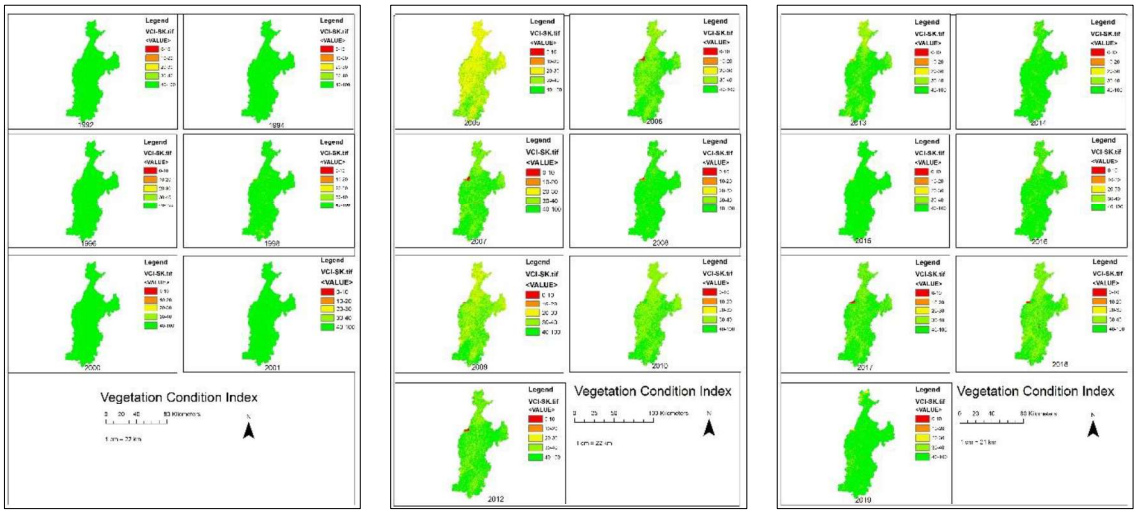


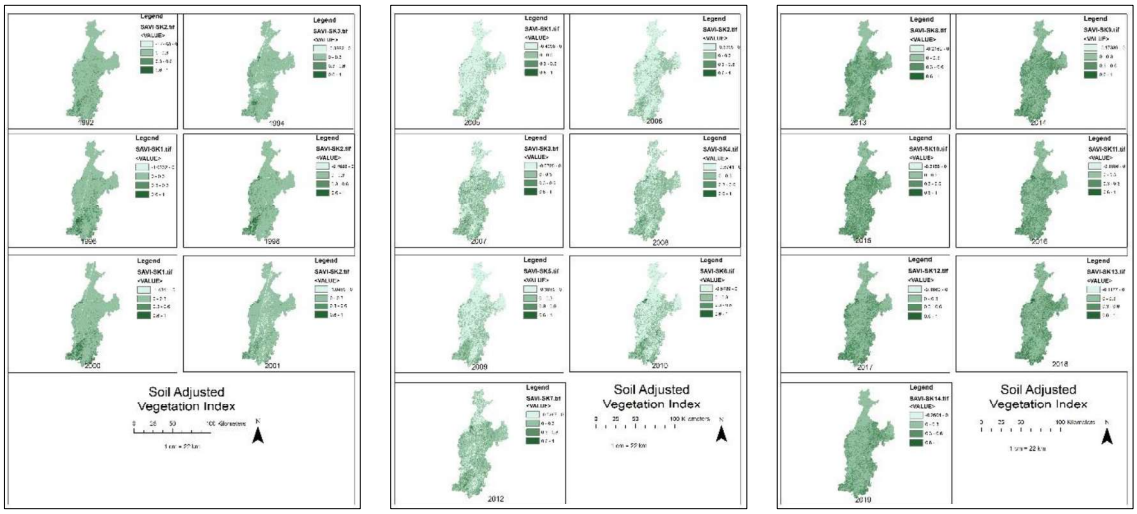
Figure 5.97: Max and Min values of NDVI and SAVI over Sabarkantha district

The threshold values of maximum, minimum NDVI with the maximum, minimum SAVI was shown in above Figure 5.97. The minimum NDVI value is -0.97 and maximum NDVI value is 0.93 and the minimum SAVI value is -1.44 and maximum SAVI value is 1.40.

The Vegetation Condition Index Map and Soil Adjusted Vegetation Index Map shown in Below Map 5.34 and 5.35 respectively for Sabarkantha district.



Map 5.34: Vegetation Condition Index Map of Sabarkantha District



Map 5.35: Soil Adjusted Vegetation Index Map of Sabarkantha District

5.8.6 Comparative analysis of vegetation stress analysis over North Gujarat region

The temporal analysis of VCI values over different years has provided valuable insights into the changing state of vegetation health. Such analyses are instrumental in assessing the impact of drought, climate variability, or other factors on the region's ecosystems and agriculture. They also assist in decision-making and resource management to mitigate the effects of changing environmental conditions on vegetation.

Compare the minimum NDVI with the minimum SAVI to assess which index was more sensitive to stress or reduced vegetation cover, considering the soil adjustment factor in SAVI. SAVI, with its soil adjustment factor, is designed to compensate for soil brightness and can be more sensitive to areas with sparse vegetation or stress.

The results of VCI index shows that moderate drought having 20.8 percent and light drought having 55.10 percent during study period in the **Banaskantha** district. The results of SAVI shows that minimum vegetation was observed in 2018 year as 46.59% and maximum vegetation was observed in 1996 year as 78.48%. Similarly, NDVI shows that minimum vegetation was observed in 2000 year as 70.47% and maximum vegetation was observed in 2013 year as 97.24%. The average vegetation in district was 64.61% during study period.

The results of VCI index shows that Moderate drought conditions, and Light drought conditions covers area of 29.4 Sq.km and 186.7 Sq.km respectively. The average drought percentage 12.15 % in the **Gandhinagar** district. The results of SAVI shows that minimum vegetation was observed in 2015 year as 40.58% and maximum vegetation was observed in 1994 year as 74.55%. Similarly, NDVI shows that minimum vegetation was observed in 2006 year as 63.71% and maximum

vegetation was observed in 1992 year as 89.45%. The average vegetation in district was 59.12% during study period.

The results of VCI index shows that moderate drought having 23.6 percent and light drought having 53.25 percent during study period in **Mehsana** district. The results SAVI shows that minimum vegetation was observed in 2014 year as 46.15% and maximum vegetation was observed in 1992 year as 80.86%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 55.99% and maximum vegetation was observed in 1992 year as 93.55%. The average vegetation in Mehsana district was 59.83% during study period.

The results of VCI index shows that 10.5 Sq.km area under extreme dry conditions 46.6 sqkm area as severe dry and 4439.70 Sq.km area as moderate dry conditions in **Patan** district. The average drought percentage 34 % in the district. The results SAVI shows that minimum vegetation was observed in 2010 year as 16.35% and maximum vegetation was observed in 2019 year as 89.19%. Similarly, NDVI shows that minimum vegetation was observed in 2005 year as 15.75% and maximum vegetation was observed in 2019 year as 98.55%. The average vegetation in district was 57.80% during study period.

The results of VCI index shows that maximum extreme dry area was 24.5 Sq.km severe dry area as 24.00 Sq.km and moderate dry area as 779.0 Sq.km during the study period. The average drought percentage 28 % in the **Sabarkantha** district. The results SAVI shows that minimum vegetation was observed in 2009 year as 37.41% and maximum vegetation was observed in 1992 year as 87.60%. Similarly, NDVI shows that minimum vegetation was observed in 2010 year as 40.90% and maximum vegetation was observed in 2019 year as 93.40%. The average vegetation in district was 63.47% during study period.

This results also provides valuable insights into the geographical extent of the drought impact. This information is crucial for informed decision-making in drought response and mitigation strategies over North Gujarat districts.

5.9 TREND ANALYSIS OF METEOROLOGICAL DROUGHT INDICES OVER THE STUDY AREA

Linear regression analysis is a parametric test and one of the most commonly used methods to detect a trend in a data series. The relationship between two variables (dependent and independent) by fitting a linear equation to the observed data this can be done by using the scatter plot. Linear regression is extensively used to determine long-term trends in various meteorological parameters and various drought indices. A positive slope value indicates an increasing trend, and a negative

value indicates a decreasing trend. A numerical measure of this association between the variables is the correlation coefficient, which range between -1 to +1.

Also, Mann-Kendall Test and Sen's Slope Estimation are two non-parametric test used to detect the presence of a significant trend (upward or downward) in a time series dataset. In the Mann-Kendall trend test, the value of Z is a test statistic that measures the strength and direction of a trend in a time series dataset. The sign (positive or negative) and magnitude of the Z statistic provide information about the nature of the trend.

A positive Z value indicates an upward (increasing) trend in the data. This means that the data points tend to increase over time. A larger positive Z value corresponds to a stronger upward trend, indicating a more significant increase in the variable being analyzed.

A negative Z value indicates a downward (decreasing) trend in the data. This means that the data points tend to decrease over time. A larger negative Z value corresponds to a stronger downward trend, indicating a more significant decrease in the variable being analyzed.

If the Z value is close to zero (near zero or with an absolute value less than a critical threshold), it suggests that there is no significant trend in the data. In other words, there is no clear upward or downward trend observed.

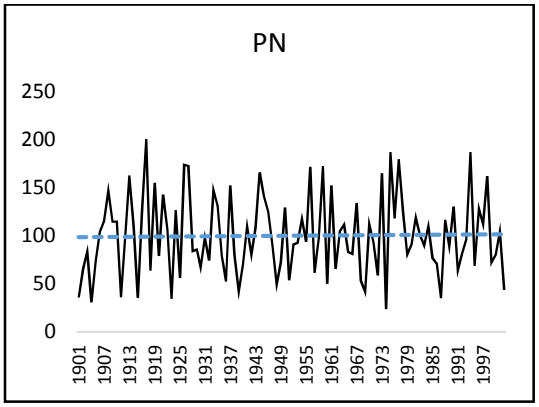
Similar, Sen's slope estimator is a statistical method used to estimate the magnitude and direction of a linear trend in a dataset. It is particularly useful for analyzing time series data where there may be a trend, and it is designed to be robust and resistant to outliers.

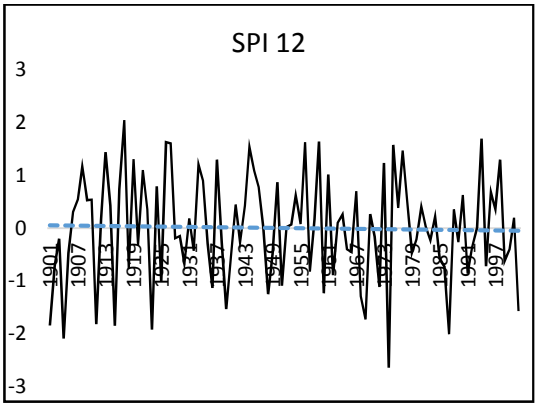
5.9.1 Trend Analysis of Meteorological Drought Indices for Banaskantha district

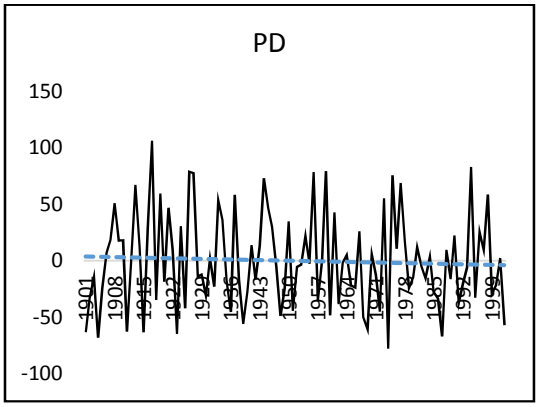
The time series (1901-2002) of the meteorological drought indices for Percent of Normal, Percentage of departure from mean, and Deciles is shown in Figure 5.98.Also, other indices SPI, RDI, SPEI, CZI and MCZI with time scale of 12-month is shows good results so the trend with linear regression is shown below Figure 5.98 for Banaskantha district. The temporal analysis of drought indices indicated that almost all of the drought indices were capable of identifying the major historic drought years.

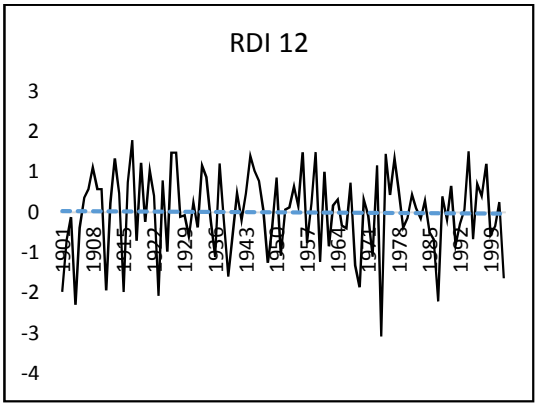
A linear regression analysis showing an increasing trend in the graph which demonstrates a positive and statistically significant relationship between the variables. The positive and negative value implies increasing and declining rainfall trend and other indices. Based on trend analysis, most of the indices is indicating an

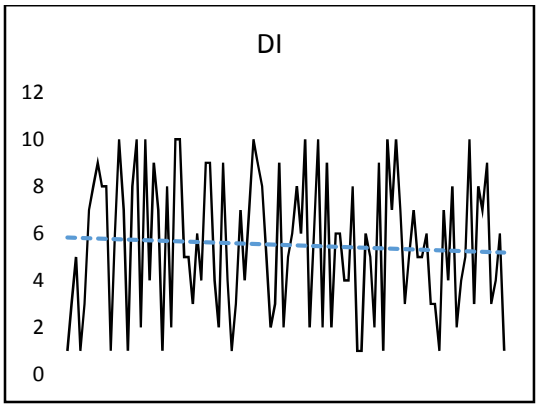
upward trend. The R squared (R^2) value provides insight into the strength of the linear relationship. A higher R^2 indicates that the model explains a larger portion of the variation in the dependent variable. In this case, a strong increasing trend suggests a higher R^2 value.

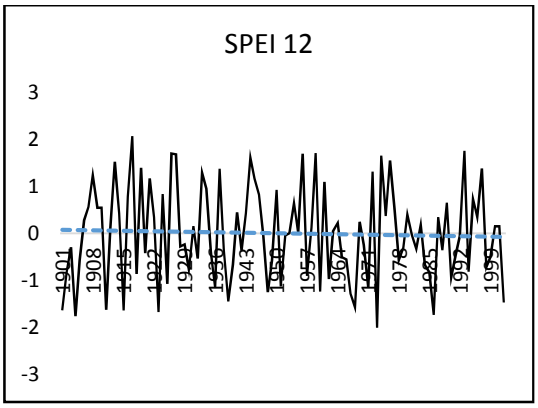












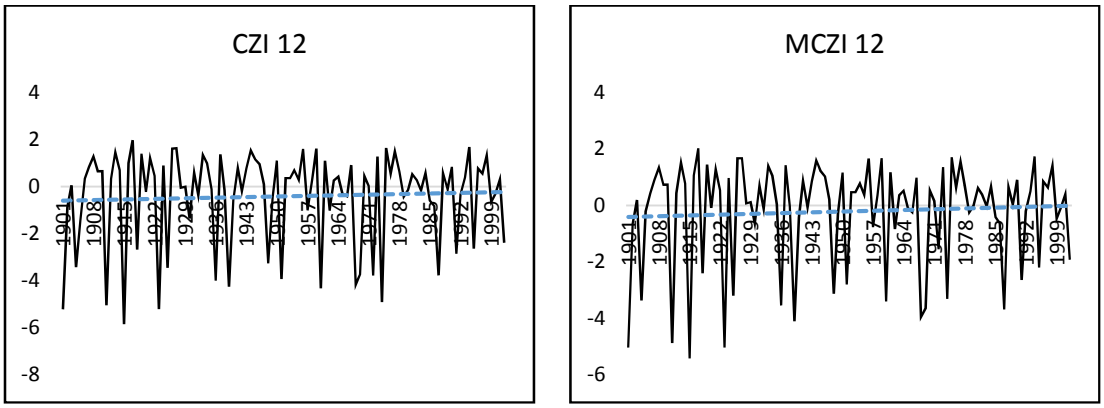


Figure 5.98: Time Series plot of various drought indices for Banaskantha district

Trend Analysis of Rainfall and Temperature data for Banaskantha district

The results of Mann Kendall (MK) test and Sen's slope test for rainfall data (1901-2002) for different season's viz., for summer, winter, monsoon and annual series is shown in below Table 5.151(a) for Banaskantha district. Also, for monthly temperature data trend test is shown in Table 5.151 (b). The statistical significance at 95% confidence level as per Mann- Kendall and Sen's slope estimator are used for trend analysis over the Banaskantha region.

Table 5.151: MK trend test & Sen's slope estimator for Banaskantha district

(a) MK trend test & Sen's slope estimator for Rainfall data

Time series	Test Z	B
Summer	-0.661	-0.011
Winter	2.651	0.094
Monsoon	-0.479	-0.377
Annual	-0.307	-0.245

The value of Sen's slope estimator represents the estimated rate of change or trend in the data over time. A positive value indicates an upward or increasing trend. A negative value indicates a downward or decreasing trend. The results of MK test and Sen's slope for Banaskantha district is shown in below Table 5.151 (b).

(b) MK trend test & Sen's slope estimator for Temperature data

Time series	Test Z	B
January	1.337	0.005
February	2.585	0.011
March	2.195	0.009
April	2.427	0.009
May	0.819	0.002

June	-0.471	-0.001
July	-1.632	-0.005
August	-1.239	-0.003
September	0.048	0.000
October	1.221	0.004
November	3.082	0.012
December	4.670	0.015
Annual	3.523	0.005
(March to May)	2.725	0.007
(June to August)	-1.450	-0.003
(September to November)	2.046	0.006
(Dec, Jan and Feb)	4.003	0.010

The annual precipitation data (1901-2002) was divided into summer, winter, monsoon and annual for analysis. The annual rainfall recorded at Banaskantha shows a significant negative trend with Z value of -0.307 and its corresponding Sen's slope value is -0.245. For summer season rainfall shows a significant negative trend with Z value of -0.661 and its corresponding Sen's slope value is -0.011. Similar, for winter season rainfall shows a significant positive trend with Z value of 2.651 and its corresponding Sen's slope value is 0.094. The major observation in this rainfall data series is that it shows negative trend for the summer season during 1901 to 2002. Also, the trend during monsoon season was decreased. This might have affected the drought phenomena in this region.

By analyzing temperature trends, it's possible to identify prolonged periods of above average temperatures, which can contribute to the development of drought conditions. Analyzing long-term temperature data trends is crucial for assessing the impact of climate change on drought patterns. Temperature trend analysis helps to detect these changes and plan for adaptation and mitigation strategies.

The trend analysis of temperature (1901-2002) recorded at Banaskantha shows a significant falling trend for July month with Z value of -1.632 and its corresponding Sen's slope value is -0.005. However, increasing trend for December month with Z value of 4.670 and its corresponding Sen's slope value is 0.015 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 4.003 and Sen's slope value as 0.010 during study period, which shows that annual temperature is increasing over the decades.

For example, Sen's slope estimator to analyze annual temperature data a Sen's slope value of +0.05 degrees Celsius per year, it means that the temperatures are increasing at a rate of 0.05 degrees Celsius per year. If the Sen's slope value were -0.02 degrees celsius per year, it would indicate a decreasing trend of 0.02 degrees Celsius per year.

Trend Analysis of SPI, RDI and SPEI for Banaskantha district

Trend analysis of drought indices such as SPI (Standardized Precipitation Index), RDI (Reconnaissance Drought Index), and SPEI (Standardized Precipitation Evapotranspiration Index) is a common practice in hydrology and climate science to assess long-term changes in drought patterns. These indices are used to monitor and quantify drought severity and duration. The results of the applied Mann–Kendall and Sen's Slope estimator statistical tests for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the area are presented in below Table 5.151(c) for Banaskantha district.

For example SPI 3 value shows that Z value as 2.21 which means during these three months of SPI gives positive results which means wet condition increases as rainfall occur during these months but when the time series increases up to 12 moths Z value as -0.31 so the rainfall decrease and dry condition increases.

(C) MK trend test & Sen's slope estimator for SPI, RDI and SPEI drought indices

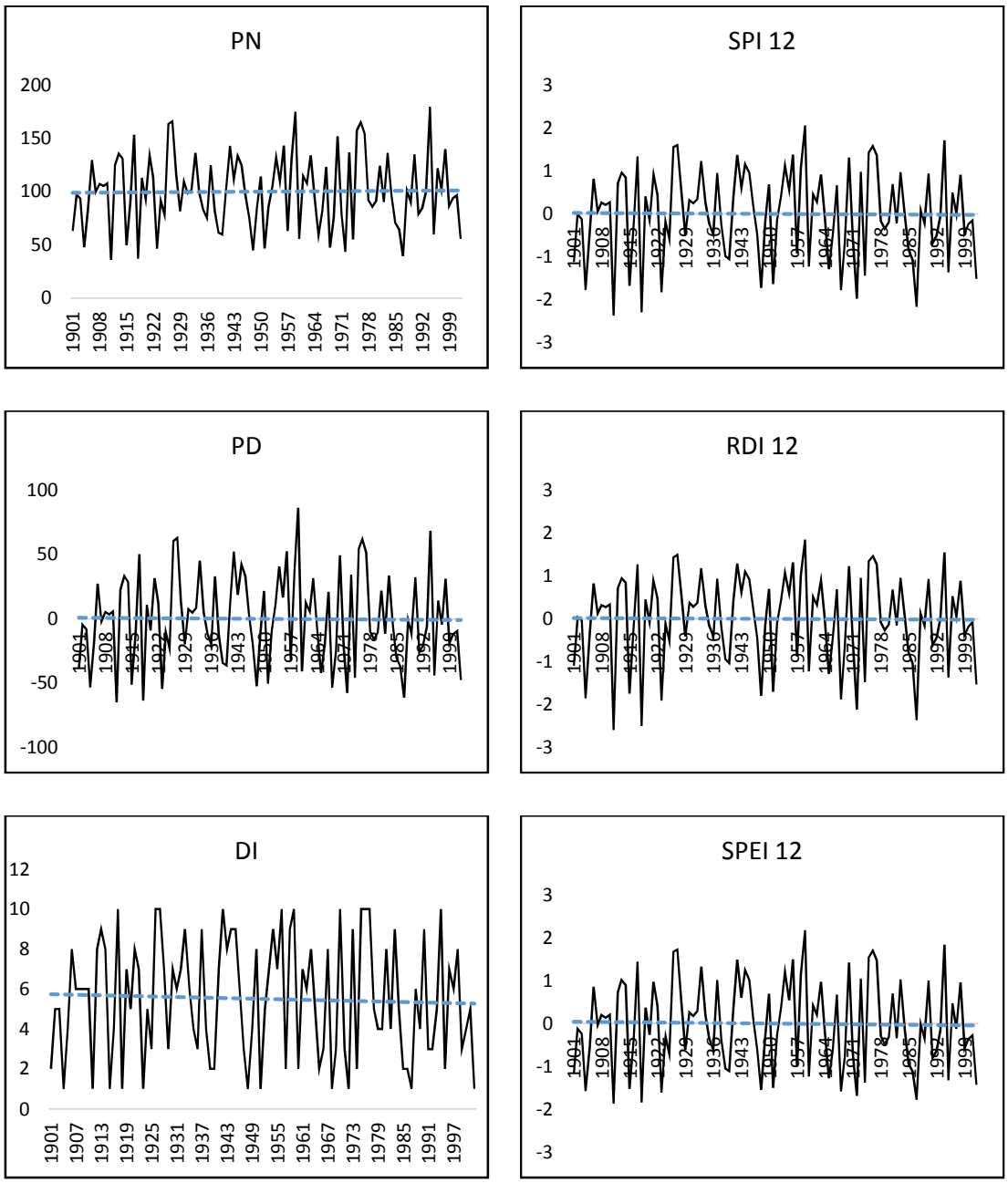
	SPI		RDI		SPEI	
Time series	**Test Z**	**B**	**Test Z**	**B**	**Test Z**	**B**
3	2.21	-0.44	2.18	-0.07	-0.22	-0.01
4	2.65	-0.48	2.63	-0.19	-0.35	0.05
5	2.30	-0.43	2.25	-0.14	-0.49	-0.05
6	1.96	-0.37	1.95	-0.10	0.32	-0.17
7	1.86	-0.31	1.82	-0.03	-0.26	0.06
8	1.45	-0.21	1.47	0.01	-0.62	0.19
9	1.01	-0.22	0.99	-0.07	-0.53	0.06
10	0.13	0.01	0.15	0.10	-0.40	0.07
11	-0.16	0.12	-0.22	0.18	-0.31	0.05
12	-0.31	0.13	-0.31	0.18	-0.28	0.06

The Mann-Kendall test helps identify whether there is a systematic upward or downward trend in the data. From the above Table 5.151(c) it was observed that SPI and RDI behave in nearly same manner for all time scales while SPEI shows negative trend for initial months' time scale. For 12 month time scale all three indices gave nearly same results.

For SPI value of Z is -0.31 with Sen's slope value as 0.13. For RDI value of Z is -0.31 with Sen's slope value as 0.18 and for SPEI value of Z is -0.28 with Sen's slope value as 0.060.By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

5.9.2 Trend Analysis of Meteorological Drought Indices for Gandhinagar district

The time series (1901-2002) of the meteorological drought indices for Percent of Normal, Percentage of departure from mean, Deciles, Rainfall anomaly index is shown in below Figure5.99. Also, for other indices SPI, RDI, SPEI, CZI and MCZI with time scale of 12-month is shows better results so the trend with linear regression is shown below Figure 5.99 for Gandhinagar district. The temporal analysis of drought indicated that almost all of the drought indices were capable of identifying the major historic drought years.



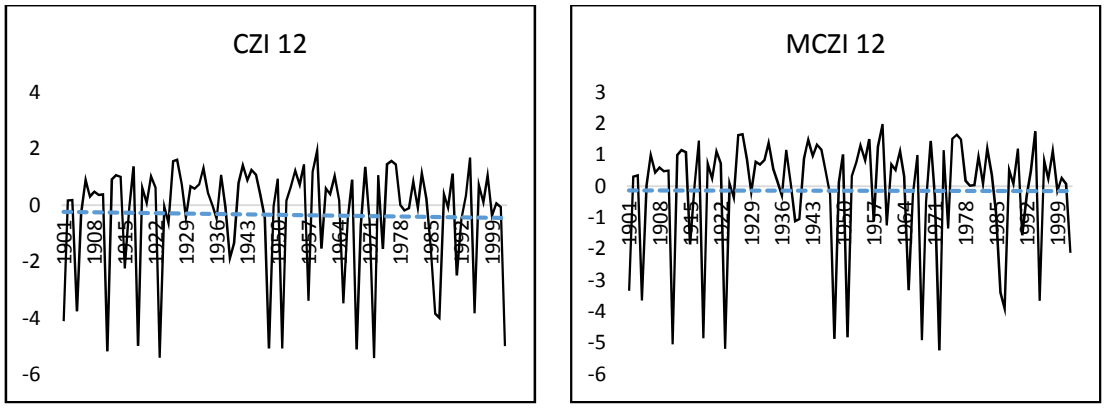


Figure 5.99: Time Series plot of various drought indices for Gandhinagar district

Trend Analysis of Rainfall and Temperature data for Gandhinagar district

The results Mann Kendall (MK) test and Sen's slope test for rainfall data (1901-2002) for different season's viz., for summer, winter, Monsoon and Annual series is shown in below Table 5.152(a) for Gandhinagar district. Also, for monthly temperature trend test is shown in Table 5.152(b). The statistical significance at 95% confidence level as per Mann- Kendall and Sen's slope estimator are used for trend analysis over the Gandhinagar region.

Table 5.152: MK trend test & Sen's slope estimator for Gandhinagar district

(a) MK trend test & Sen's slope estimator for Rainfall data

Time series	**Test Z**	**B**
Summer	-1.646	-0.038
Winter	1.913	0.076
Monsoon	-0.134	-0.130
Annual	-0.057	-0.032

(b) MK trend test & Sen's slope estimator for Temperature data

Time series	**Test Z**	**B**
January	1.130	0.004
February	3.023	0.013
March	2.653	0.010
April	2.800	0.010
May	0.899	0.001
June	0.412	0.000
July	-1.059	-0.003
August	-0.812	-0.002
September	0.531	0.000

October	1.470	0.005
November	3.124	0.014
December	4.544	0.014
Annual	3.869	0.006
(March to May)	3.182	0.007
(June to August)	-0.888	-0.002
(September to November)	2.460	0.007
(Dec, Jan and Feb)	4.042	0.009

The annual precipitation data (1901-2002) was divided into summer, winter, monsoon and annual for analysis. The annual rainfall recorded at Gandhinagar shows a significant negative trend with Z value of -0.057 and its corresponding Sen's slope value is -0.032. For summer season rainfall shows a significant negative trend with Z value of -1.646 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.913 and its corresponding Sen's slope value is 0.076. The major observation in this rainfall data series is that it shows negative trend for the summer season during 1901 to 2002. Also, the trend during monsoon season was slightly decreased. This might have affected the drought phenomena in this region.

The results of MK test and Sen's slope for Temperature data in Gandhinagar district is shown in below Table 5.152 (b). The trend analysis of temperature (1901-2002) recorded at Gandhinagar shows a significant falling trend for July month with Z value of -1.059 and its corresponding Sen's slope value is -0.003. However, increasing trend for December month with Z value of 4.544 and its corresponding Sen's slope value is 0.014 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 4.042 and Sen's slope value as 0.009 during study period, which shows that annual temperature is increasing over the decades.

Trend Analysis of SPI, RDI and SPEI for Gandhinagar district

The results of Trend analysis of drought indices such as SPI (Standardized Precipitation Index), RDI (Reconnaissance Drought Index), and SPEI (Standardized Precipitation Evapotranspiration Index) for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the area are presented in below Table 5.152(c) for Gandhinagar district.

(C) MK Trend Test & Sen's Slope Estimation for SPI, RDI and SPEI drought indices

	SPI		**RDI**		**SPEI**	
Time series	**Test Z**	**B**	**Test Z**	**B**	**Test Z**	**B**
3	1.85	-0.22	1.70	-0.16	1.79	-0.41
4	1.91	-0.31	1.82	-0.41	-1.54	0.10
5	1.43	-0.31	1.34	-0.27	-1.90	0.17

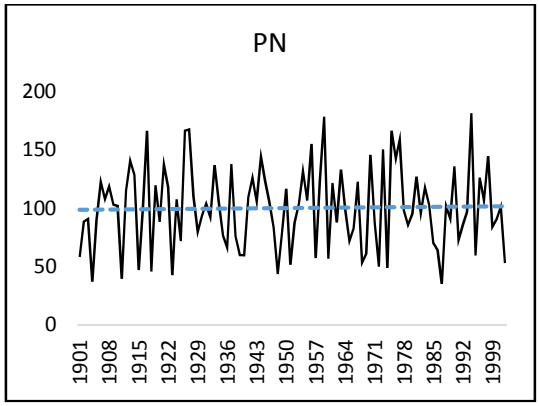
6	1.25	-0.33	1.46	-0.25	-0.74	0.13
7	1.25	-0.35	1.13	-0.30	-0.68	0.19
8	0.38	-0.02	0.35	0.07	-0.48	0.19
9	0.15	0.02	0.12	0.12	-0.29	0.02
10	-0.37	0.12	-0.38	0.18	-0.13	-0.01
11	-0.25	0.27	-0.29	0.30	-0.06	-0.06
12	-0.06	0.03	-0.07	0.09	-0.06	-0.06

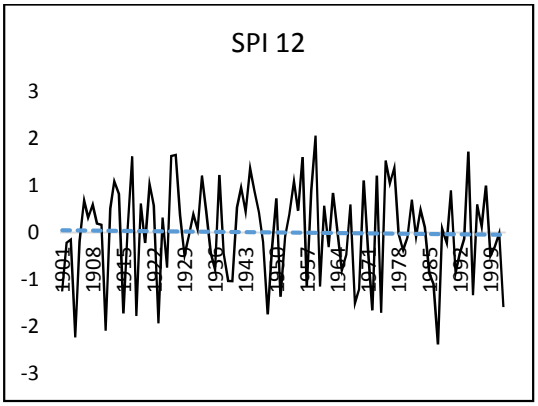
From the above Table 5.152(c) it was observed that SPI and RDI behave in nearly same manner for all time scales while SPEI shows different trend for time scale. For 12 month time scale all three indices gave nearly same results.

For SPI value of Z is -0.06 with Sen's slope value as 0.03. For RDI value of Z is -0.07 with Sen's slope value as 0.09 and for SPEI value of Z is -0.06 with Sen's slope value as -0.060.By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

5.9.3 Trend Analysis of Meteorological Drought Indices for Mehsana district

The time series (1901-2002) of the meteorological drought indices for Percent of Normal, Percentage of departure from mean, Deciles, Rainfall anomaly index is shown in below Figure 5.100. Also, for other indices SPI, RDI, SPEI, CZI and MCZI with time scale of 12-month is shows better results so the trend with linear regression is shown below Figure 5.100 for Mehsana district. The temporal analysis of drought indicated that almost all of the drought indices were capable of identifying the major historic drought years.





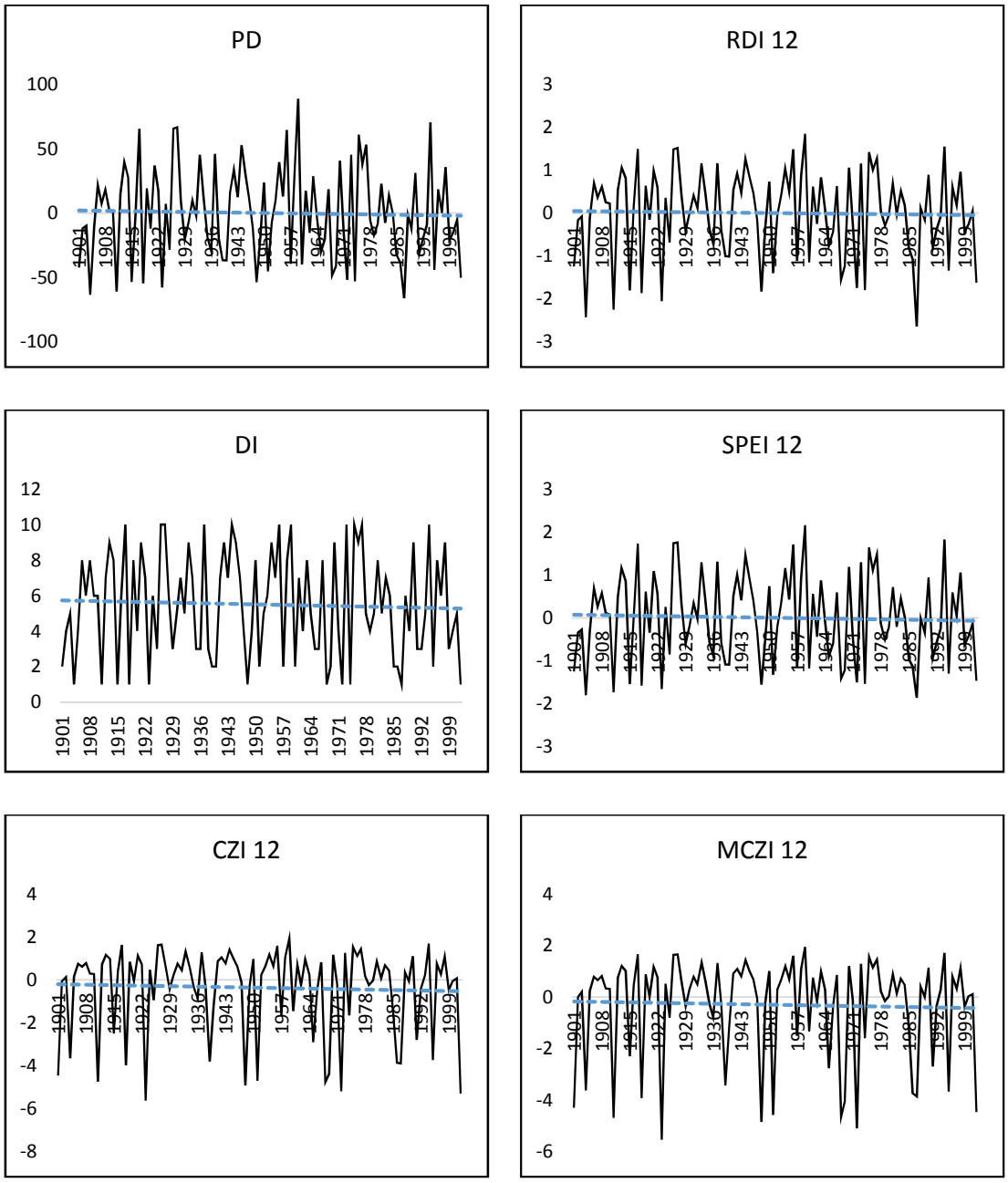


Figure 5.100: Time Series plot of various drought indices for Mehsana district

Trend Analysis of Rainfall and Temperature data for Mehsana district

The results Mann Kendall (MK) test and Sen's slope test for rainfall data (1901-2002) for different season's viz., for summer, winter, Monsoon and Annual series is shown in below Table 5.153 (a) for Mehsana district. Also, for monthly temperature trend test is shown in Table 5.153 (b). The statistical significance at 95% confidence level as per Mann- Kendall and Sen's slope estimator are used for trend analysis over the Mehsana region.

Table 5.153: MK Trend Test & Sen's Slope estimator for Mehsana district

(a) MK Trend Test & Sen's Slope estimator for Rainfall data

Time series	Test Z	B
Summer	-1.650	-0.044
Winter	2.046	0.109
Monsoon	-0.432	-0.371
Annual	-0.211	-0.171

(b) MK Trend Test & Sen's Slope Estimation for Temperature data

Time series	Test Z	B
January	1.135	0.004
February	2.874	0.012
March	2.451	0.009
April	2.773	0.010
May	0.902	0.002
June	0.137	0.001
July	-1.397	-0.004
August	-0.902	-0.002
September	0.277	0.001
October	1.242	0.004
November	2.978	0.013
December	4.569	0.013
Annual	3.574	0.005
(March to May)	3.017	0.007
(June to August)	-1.090	-0.002
(September to November)	2.290	0.006
(Dec, Jan and Feb)	3.964	0.009

The annual precipitation data (1901-2002) was divided into summer, winter, monsoon and annual for analysis. The annual rainfall recorded at Mehsana shows a significant negative trend with Z value of -0.211 and its corresponding Sen's slope value is -0.171. For summer season rainfall shows a significant negative trend with Z value of -1.650 and its corresponding Sen's slope value is -0.044. Similar, for winter season rainfall shows a significant positive trend with Z value of 2.046 and its corresponding Sen's slope value is 0.109. The major observation in this rainfall data series is that it shows negative trend for the summer season during 1901 to 2002. Also, the trend during monsoon season was slightly decreased. This might have affected the drought phenomena in this region.

The results of MK test and Sen's slope for Temperature data in Mehsana district is shown in below Table 5.153 (b). The trend analysis of temperature (1901-2002) recorded at Mehsana shows a significant falling trend for July month with Z value of -

1.397 and its corresponding Sen's slope value is -0.004. However, increasing trend for December month with Z value of 4.569 and its corresponding Sen's slope value is 0.013 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 3.964 and Sen's slope value as 0.009 during study period, which shows that annual temperature is increasing over the decades.

Trend Analysis of SPI, RDI and SPEI for Mehsana district

The results of the applied Mann–Kendall and Sen's Slope estimator statistical tests for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the area are presented in below Table 5.153(c) for Mehsana district.

(C) Trend Test & Sen's Slope Estimation for SPI, RDI and SPEI drought indices

	SPI		RDI		SPEI	
Time series	**Test Z**	**B**	**Test Z**	**B**	**Test Z**	**B**
3	1.78	-0.36	1.75	-0.03	-1.31	-0.01
4	2.05	-0.42	2.03	-0.12	-1.38	0.07
5	1.90	-0.41	1.90	-0.12	-1.91	0.23
6	1.42	-0.27	1.42	-0.03	-0.38	-0.06
7	1.30	-0.23	1.33	0.02	-0.57	0.18
8	0.56	-0.02	0.56	0.13	-0.63	0.12
9	0.57	0.09	0.54	0.18	-0.50	0.11
10	-0.17	0.16	-0.21	0.22	-0.32	0.12
11	-0.27	0.22	-0.27	0.25	-0.24	0.05
12	-0.21	0.14	-0.22	0.18	-0.21	0.04

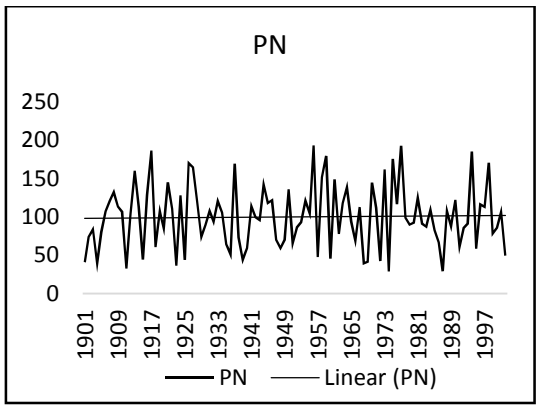
From the above Table 5.153(c) it was observed that SPI and RDI shows similar results for different time scales while SPEI shows different trend for time scale. For 12 month time scale all three indices gave nearly same results.

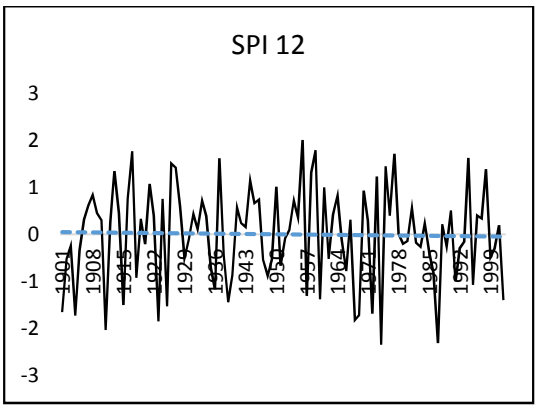
For SPI value of Z is -0.21 with Sen's slope value as 0.14. For RDI value of Z is -0.22 with Sen's slope value as 0.189 and for SPEI value of Z is -0.21 with Sen's slope value as -0.040.By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

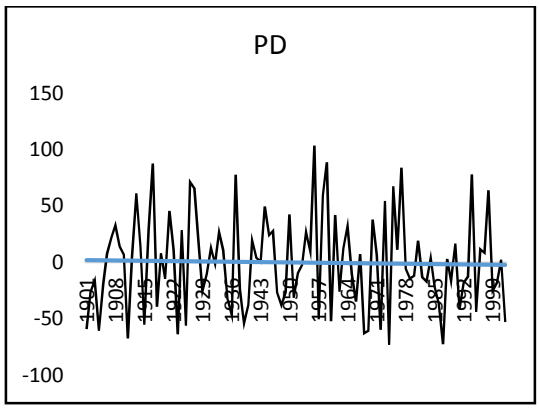
5.9.4 Trend Analysis of Meteorological Drought Indices for Patan district

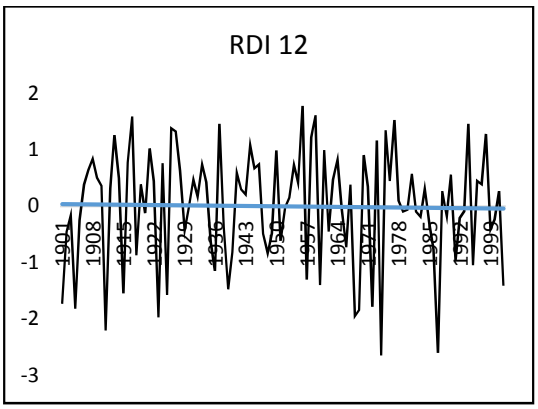
The time series (1901-2002) of the meteorological drought indices for Percent of Normal, Percentage of departure from mean, Deciles, Rainfall anomaly index is

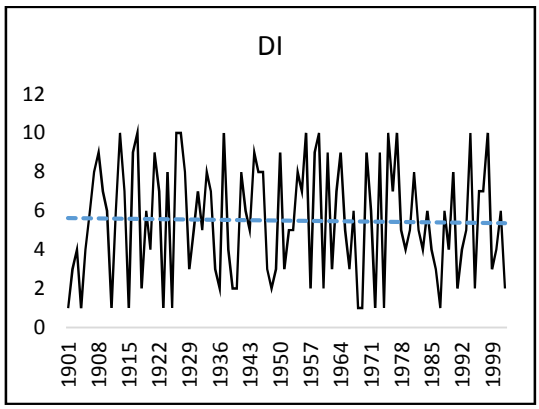
shown in below Figure 5.101. Also, for other indices SPI, RDI, SPEI, CZI and MCZI with time scale of 12-month is shows better results so the trend with linear regression is shown below Figure 5.101 for Patan district. The temporal analysis of drought indicated that almost all of the drought indices were capable of identifying the major historic drought years.

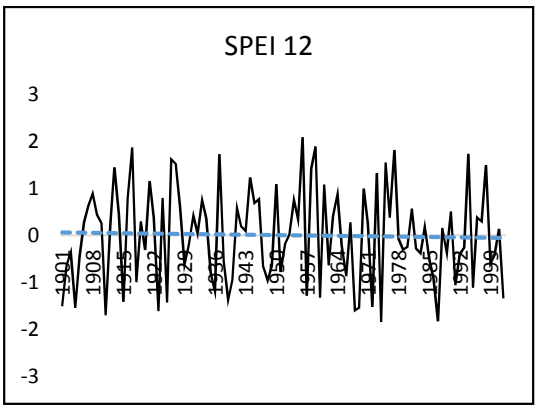












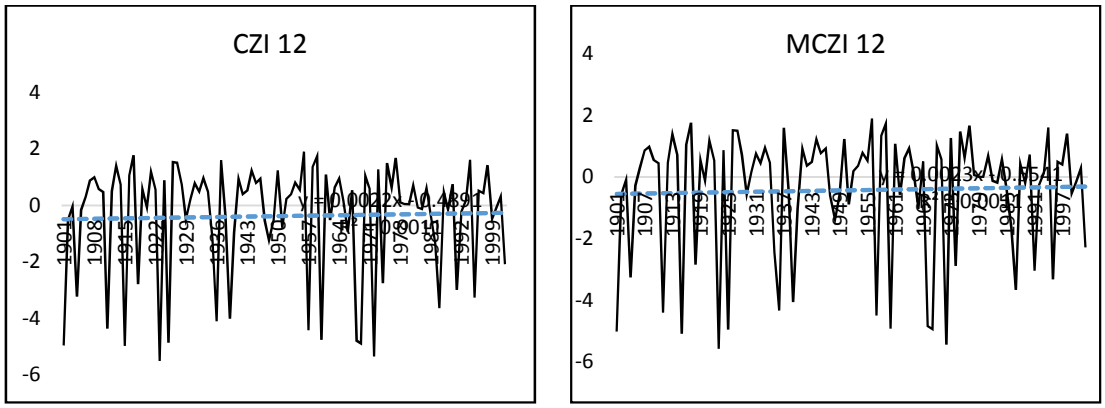


Figure 5.101: Time Series plot of various drought indices for Patan district

Trend Analysis of Rainfall and Temperature data for Patan district

The results of Mann Kendall (MK) test and Sen's slope test for rainfall data (1901-2002) for different season's viz., for summer, winter, monsoon and annual series is shown in below Table 5.154 (a) for Patan district. Also, for monthly temperature trend test is shown in Table 5.154 (b). The statistical significance at 95% confidence level as per Mann- Kendall and Sen's slope estimator are used for trend analysis over the Patan region.

Table 5.154: MK Trend test & Sen's slope estimator for Patan district

(a) MK Trend test & Sen's slope estimator for Rainfall data

Time series	Test Z	B
Summer	-0.769	-0.008
Winter	2.540	0.108
Monsoon	-0.664	-0.547
Annual	-0.378	-0.254

(b) MK Trend test & Sen's slope estimator for Temperature data

Time series	Test Z	B
January	1.188	0.005
February	2.826	0.011
March	2.380	0.009
April	2.549	0.009
May	0.923	0.002
June	-0.271	-0.001
July	-1.751	-0.005
August	-1.236	-0.003
September	-0.083	0.000
October	1.132	0.004
November	2.868	0.012

December	4.360	0.013
Annual	3.565	0.005
(March to May)	2.960	0.007
(June to August)	-1.432	-0.003
(September to November)	1.939	0.005
(Dec, Jan and Feb)	3.928	0.009

The annual precipitation data (1901-2002) was divided into summer, winter, monsoon and annual for analysis. The annual rainfall recorded at Patan shows a significant negative trend with Z value of -0.378 and its corresponding Sen's slope value is -0.-0.254. For summer season rainfall shows a significant negative trend with Z value of -0.769 and its corresponding Sen's slope value is -0.008. Similar, for winter season rainfall shows a significant positive trend with Z value of 2.540 and its corresponding Sen's slope value is 0.108. The major observation in this rainfall data series is that it shows negative trend for the summer season during 1901 to 2002. Also, the trend during monsoon season was slightly decreased. This might have affected the drought phenomena in this region.

The results of MK test and Sen's slope for Temperature data in Patan district is shown in below Table 5.154 (b). The trend analysis of temperature (1901-2002) recorded at Patan shows a significant falling trend for July month with Z value of -1.751 and its corresponding Sen's slope value is -0.005. However, increasing trend for December month with Z value of 4.360 and its corresponding Sen's slope value is 0.013 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 3.928 and Sen's slope value as 0.009 during study period, which shows that annual temperature is increasing over the decades.

Trend Analysis of SPI, RDI and SPEI for Patan district

The results of the applied Mann–Kendall and Sen's Slope estimator statistical tests for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the area are presented in below Table 5.154(c) for Patan district.

(C) MK Trend test & Sen's slope estimator for SPI, RDI and SPEI drought indices

	SPI		RDI		SPEI	
Time series	**Test Z**	**B**	**Test Z**	**B**	**Test Z**	**B**
3	2.24	-0.38	2.22	-0.05	-0.77	-0.18
4	2.54	-0.47	2.55	-0.16	-0.18	-0.11
5	2.45	-0.50	2.45	-0.24	-0.68	-0.01
6	1.77	-0.33	1.78	-0.05	0.84	-0.23
7	1.78	-0.33	1.77	-0.06	-0.31	0.01
8	1.56	-0.24	1.54	-0.02	-0.99	0.44
9	1.80	-0.35	1.81	-0.19	-0.74	0.22

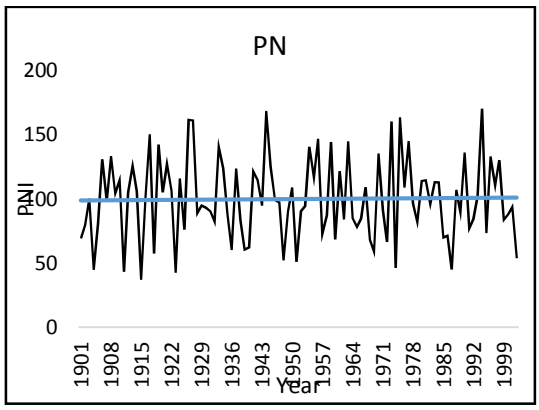
10	0.13	-0.02	0.12	0.07	-0.53	0.22
11	-0.42	0.32	-0.48	0.36	-0.36	0.18
12	-0.38	0.24	-0.37	0.29	-0.38	0.17

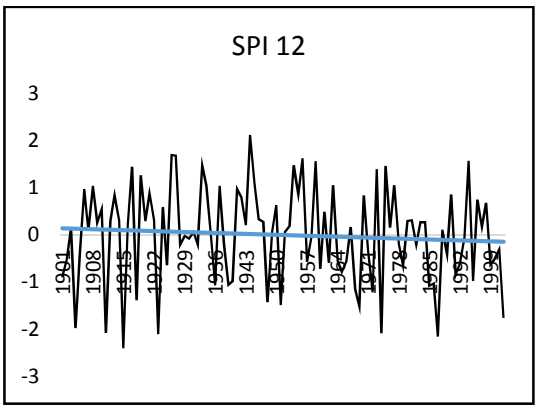
From the above Table 5.154(c) it was observed that SPI and RDI shows similar results for different time scales while SPEI shows different trend for time scale. For 12 month time scale all three indices gave nearly same results. For SPI value of Z is -0.38 with Sen's slope value as 0.24.

For RDI value of Z is -0.37 with Sen's slope value as 0.29 and for SPEI value of Z is -0.38 with Sen's slope value as 0.17.By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

5.9.5 Trend Analysis of Meteorological Drought Indices for Sabarkantha district

The time series (1901-2002) of the meteorological drought indices for Percent of Normal, Percentage of departure from mean, Deciles, Rainfall anomaly index is shown in below Figure 5.102. Also, for other indices SPI, RDI, SPEI, CZI and MCZI with time scale of 12-month is shows better results so the trend with linear regression is shown below Figure 5.102 for Sabarkantha district. The temporal analysis of drought indicated that almost all of the drought indices were capable of identifying the major historic drought years.





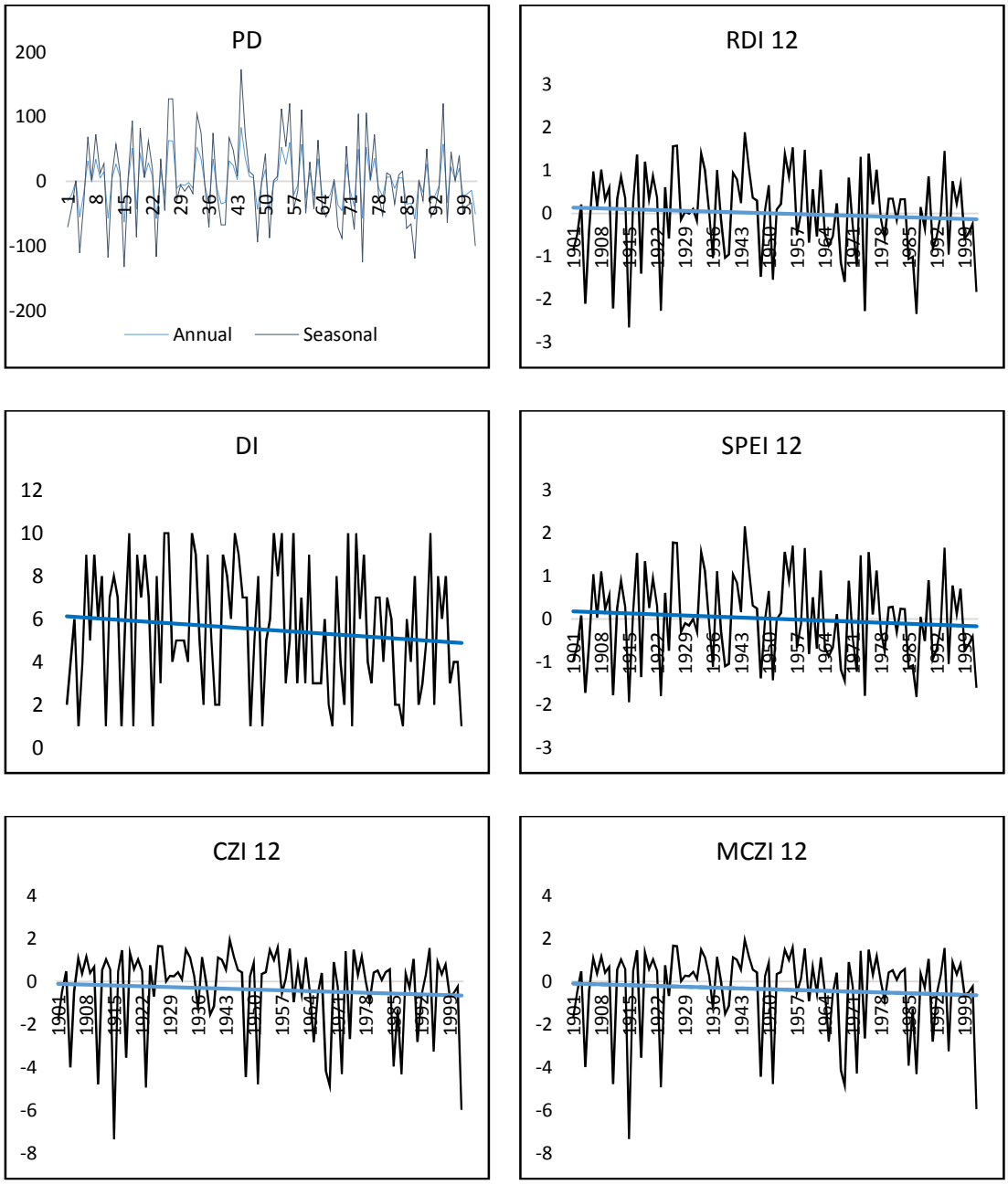


Figure 5.102: Time Series plot of various drought indices for Sabarkantha district

Trend Analysis of Rainfall and Temperature data for Sabarkantha district

The results of Mann Kendall (MK) test and Sen's slope test for rainfall data (1901-2002) for different season's viz., for summer, winter, monsoon and annual series is shown in below Table 5.155 (a) for Sabarkantha district. Also, for monthly temperature trend test is shown in Table5.155 (b). The statistical significance at 95% confidence level as per Mann- Kendall and Sen's slope estimator are used for trend analysis over the Sabarkantha region.

Table 5.155: MK Trend test & Sen's slope estimator for Sabarkantha district

(a) MK Trend Test & Sen's slope estimator for Rainfall data

Time series	Test Z	B
Summer	-1.340	-0.038
Winter	1.456	0.058
Monsoon	-0.950	-0.823
Annual	-0.944	-0.723

(b) MK Trend Test & Sen's slope estimator for Temperature data

Time series	Test Z	B
January	1.164	0.005
February	2.808	0.012
March	2.517	0.010
April	2.722	0.010
May	0.649	0.002
June	0.375	0.001
July	-1.167	-0.003
August	-0.718	-0.002
September	0.468	0.001
October	1.307	0.005
November	3.243	0.014
December	4.643	0.013
Annual	3.743	0.006
March to May	3.005	0.008
June to August	-0.753	-0.002
September to November	2.502	0.007
Dec, Jan and Feb	4.077	0.010

The annual rainfall recorded at Sabarkantha shows a significant negative trend with Z value of -0.944 and its corresponding Sen's slope value is -0.724. For summer season rainfall shows a significant negative trend with Z value of -1.340 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.456 and its corresponding Sen's slope value is 0.058. The major observation in this rainfall data series is that it shows negative trend for the summer season during 1901 to 2002. Also, the trend during monsoon season was slightly decreased. This might have affected the drought phenomena in this region.

The results of MK test and Sen's slope for Temperature data in Patan district is shown in below Table 5.155 (b). The trend analysis of temperature (1901-2002) recorded at Patan shows a significant falling trend for July month with Z value of -1.167 and its corresponding Sen's slope value is -0.003. However, increasing trend

for December month with Z value of 4.643 and its corresponding Sen's slope value is 0.013 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 4.077 and Sen's slope value as 0.010 during study period, which shows that annual temperature is increasing over the decades.

Trend Analysis of SPI, RDI and SPEI for Sabarkantha district

The results of the applied Mann–Kendall and Sen's Slope estimator statistical tests for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the area are presented in below Table 5.155(c) for Sabarkantha district.

(C) MK Trend test & Sen's slope estimator for SPI, RDI and SPEI drought indices

	SPI		RDI		SPEI	
Time series	**Test Z**	**B**	**Test Z**	**B**	**Test Z**	**B**
3	1.61	-0.25	1.60	0.06	-1.03	0.09
4	1.46	-0.22	1.44	0.04	-0.85	0.05
5	1.02	-0.14	1.00	0.08	-1.83	0.20
6	0.93	-0.17	0.93	0.03	-0.74	0.07
7	0.73	-0.18	0.68	0.02	-1.55	0.35
8	-0.07	0.19	-0.10	0.29	-1.10	0.26
9	-0.29	0.13	-0.32	0.20	-1.09	0.22
10	-1.37	0.39	-1.41	0.44	-1.06	0.20
11	-0.91	0.27	-0.94	0.31	-1.00	0.18
12	-0.94	0.23	-0.96	0.26	-0.94	0.17

From the above Table 5.155(c) it was observed that SPI and RDI shows similar results for different time scales while SPEI shows different trend for time scale. For 12 month time scale all three indices gave nearly same results. For SPI value of Z is -0.94 with Sen's slope value as 0.23.

For RDI value of Z is -0.96 with Sen's slope value as 0.26 and for SPEI value of Z is -0.94 with Sen's slope value as 0.17.By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. From the results it was observed that Sen's slope value for RDI is showing higher value than SPI and SPI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

5.9.6 Comparative analysis of Trend Analysis of Meteorological Drought Indices over North Gujarat region

Mann-Kendall Test and Sen's Slope Estimation these two non-parametric test is used to detect the presence of a significant trend (upward or downward) in a time

series dataset for summer, winter, monsoon and annual rainfall data series. Also, for temperature data. The results of Trend analysis of drought indices such as SPI (Standardized Precipitation Index), RDI (Reconnaissance Drought Index), and SPEI (Standardized Precipitation Evapotranspiration Index) for different time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 were analyzed.

The Comparative analysis of MK test and Sen's slope estimator shows that there is maximum negative trend was observed in Sabarkantha district compared to other districts for rainfall data. The annual rainfall recorded at Sabarkantha shows a significant negative trend with Z value of -0.944 and its corresponding Sen's slope value is -0.724. For summer season rainfall shows a significant negative trend with Z value of -1.340 and its corresponding Sen's slope value is -0.038. Similar, for winter season rainfall shows a significant positive trend with Z value of 1.456 and its corresponding Sen's slope value is 0.058.

The comparative analysis of trend analysis of temperature (1901-2002) shows a significant falling trend for July month with average Z value of -1.167 and its corresponding Sen's slope value is -0.003. However, increasing trend for December month with Z value of 4.51 and its corresponding Sen's slope value is 0.018 during 1901 to 2002. During (Dec, Jan and Feb) the Z statistics values as 4.077 and Sen's slope value as 0.010 during study period, which shows that annual temperature is increasing over the decades.

The results of the Mann–Kendall and Sen's Slope estimator tests for different drought indices with various time scales viz. 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 for SPI, RDI, SPEI over the North Gujarat districts shows similar results that in Sabarkantha district having maximum Z value for above said indices. From the above results it was observed that SPI and RDI shows similar results for different time scales while SPEI behave in some different trend for time scale.

The results of for SPI index shows that value of Z is -0.94 with Sen's slope value as 0.23. For RDI index value of Z is -0.96 with Sen's slope value as 0.26 and for SPEI index value of Z is -0.94 with Sen's slope value as 0.17.For 12 month time scale all three indices gave nearly same results.

By comparing results of SPI, RDI and SPEI indices shows that there is an increasing trend as time scales is increased. It was also observed that Sen's slope value for RDI is showing higher value than SPI and SPEI. Also, maximum trend value of Z statistics for RDI indices is obtained. The falling trend indicates the increasing severity of meteorological drought in the region.

By analyzing rainfall, temperature trends, it's possible to identify prolonged periods of above average values, which can contribute to the development of drought conditions. Analyzing long-term rainfall and temperature trends is crucial for

assessing the impact of climate change on drought patterns. Rising global temperatures, driven by human activities, can alter the frequency and intensity of drought events.

The falling trend indicates the increasing severity of meteorological drought in the region. In the face of climate change, it could be possible that drought severity hit stronger, which requires effective and contingency planning. The current study will be helpful in prescribing the irrigation facilities during the crop growing periods, identifying the appropriate regions for water harvesting structure construction, suitable crop selection, etc.

5.10 DEVELOPMENT OF DROUGHT SEVERITY MAPS USING VARIOUS INDICES OVER THE STUDY AREA

Land Surface Temperature (LST):

LST data is expressed in degrees Celsius (°C) and can vary significantly across different land cover types and over time. It is influenced by various factors, including solar radiation, weather conditions, land cover, and water availability. Land surface temperature refers to the temperature of the Earth's surface as measured from space or the air. It provides valuable information about the thermal characteristics of the Earth's surface. LST is a key parameter in drought monitoring and analysis because it can indicate the presence of drought conditions. During droughts, land surface temperatures can increase due to reduced soil moisture and Evapotranspiration, which leads to higher temperatures in the affected areas.

Temperature Condition Index (TCI):

The TCI is a drought indicator that is derived from LST data and is used to assess the impact of temperature on vegetation and crops. TCI is often calculated in conjunction with other indices, such as the Vegetation Condition Index (VCI) and the Vegetation Health Index (VHI), to provide a more comprehensive assessment of drought conditions. An increase in TCI indicates that land surface temperatures are above the normal range for a specific location, which may be indicative of drought stress on vegetation. TCI is particularly useful for monitoring the impact of high temperatures on agricultural and natural ecosystems, as extreme heat can lead to reduced soil moisture and increased Evapotranspiration, which can exacerbate drought conditions.

Vegetation Health Index (VHI):

The VHI is a useful tool for classifying and assessing drought conditions based on the health and vigor of vegetation. The VHI is typically derived from remote sensing

data, such as satellite imagery, and it combines information about vegetation greenness (NDVI - Normalized Difference Vegetation Index) and temperature (LST - Land Surface Temperature). This index is valuable for monitoring and classifying drought conditions as it provides insights into the impact of drought on vegetation. It's important to note that VHI is a relative index, and its interpretation can be influenced by factors such as the specific vegetation type and the time of year.

Below section shows the results of these indices over North Gujarat districts. It also gives the area experiences different drought conditions for different years.

5.10.1 Drought severity estimation using various indices over Banaskantha district

The spatial distribution of surface temperature using LST is shown in below Table 5.156 for Banaskantha district. However, the same for the years 1994 to 2019 are showing in below Figure 5.103.

Table 5.156: Classification of LST for Banaskantha district

Classification	Range	2006	2007	2008	2009	2010
Low Temperature	00 to 15	0.0	0.0	0.0	0.0	0.0
Medium Temperature	15 to 25	38.5	42.2	11.4	9.5	0.0
Average Temperature	25 to 35	2178.4	5542.5	1061.8	1402.8	640.4
High Temperature	35 to 45	8368.1	5045.1	9551.0	8220.2	9516.0

The results of 2006 shows that 8368.10 sq.km area of the district was under high temperature (35 to 45°C) which 78.27 % of the district. Also, 2178.40 sq.km area of the district having average temperature (25 to 35°C) which is 20.48% of the total area of the district. The dry soil area is usually visualized by high LST. Also, LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas.

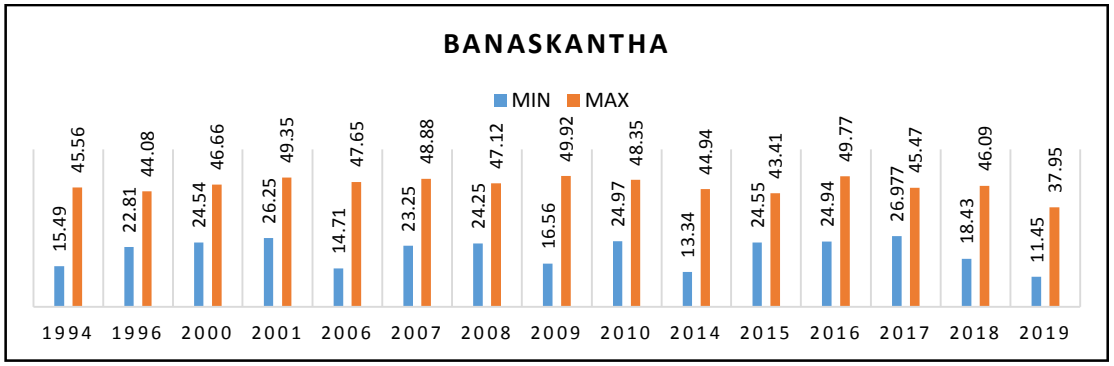


Figure 5.103: Maximum and Minimum LST for Banaskantha district

From the above Figure 5.103 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Banaskantha district. The maximum area under 25 to 35 degree temperature was observed in 2007 year which is 5542.50 Sq.km area and minimum area was observed in 2015 year which 236.30 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was observed in 2008 year with 9551.0 Sq.km area and minimum area was observed in 2007 year with 5045.10 Sq.km.

The results also shows that average 7877.60 Sq.km area of the district under high temperature during the study period 1994 to 2019 years. The average minimum temperature was 22.80^{o}C and average maximum temperature was 45.09^{o}C during study period. The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. The rising temperatures can lead to more frequent and severe drought events, impacting water resources and ecosystems. It was also observed that the annual average mean LST value has been increased 3.25°C during study period.

Results of Temperature Condition Index and Vegetation Health Index for Banaskantha district

Temperature Condition Index (TCI) and Vegetation Health Index (VHI) are both important components of drought analysis, particularly when studying and monitoring drought conditions in a region. These indices provide valuable insights into how climate conditions and drought impact vegetation.

Drought severity classes such as extreme drought, severe drought, and moderate drought based on the TCI threshold values. These thresholds values as for Extreme Drought: TCI > [0 to 20], Severe Drought: [20 to 40], Moderate Drought: [40 to 60], Low Drought: [60 to 80], No Drought: [80 to 100].

The severity of drought can be categorized based TCI and VHI and analyzed. The higher TCI values and lower VHI values may indicate more severe drought conditions, while lower TCI values and higher VHI values suggest healthier vegetation with sufficient water availability. Understanding and monitoring this relationship between TCI and VHI contribute to effective drought assessment, allowing for timely interventions and management strategies in areas affected by water scarcity and temperature stress.

The results of TCI and VHI classification is shown below Table 5.157 and Table 5.158 respectively for Banaskantha district. The Classification done by thresholding technique to classify each pixel into the defined drought severity classes based on TCI values. Then after calculate the area of each severity class by counting the number of pixels classified into each category and converting it to square kilometres.

Table 5.157: Classification of TCI Index for Banaskantha district

Classification	Range	2010	2014	2015	2016	2017	2018
Extreme Dry	0 to 20	3498.4	3741.8	1510.4	1110.9	2687.2	4566.5
Severe Dry	20 to 40	6280.9	6497.0	6058.3	5127.2	5603.7	5667.3
Moderate Dry	40 to 60	752.7	328.2	2716.0	3654.8	2084.4	394.4
Low Dry	60 to 80	71.9	62.0	323.5	679.2	254.8	2.4
No Drought	80 to 100	27.0	1.9	22.6	58.7	0.6	0.3

(Area in Sq.km)

The results of the TCI indices for the 2018 year shows that 4566.50 sq. km. area and 5667.30 Sq.km area fall under extreme dry and severe dry conditions, which are 42.95 % and 53.31%, of the total area of the Banaskantha district respectively. The study also, observed that moderately dry area is 394.40 Sq.km area which is 3.70% of the study area.

The average drought area in Banaskantha district is 3206.50 sq.km or 30.15% of the district during study period. The average dry conditions varies from 17.5% to 44.20%.

The Vegetation Health Index (VHI) is a valuable tool for drought analysis using Landsat data as it provides insights into the health and condition of vegetation over time. By establishing thresholds for VHI values which is similar to TCI, it is possible to classify different levels of drought severity. Lower VHI values may indicate severe or extreme drought conditions, helping to categorize regions based on the extent of vegetation stress.

VHI, derived from indices like NDVI, reflects the physiological activity and greenness of vegetation. During periods of drought, water stress affects plants, leading to reduced photosynthesis and chlorophyll content. A decrease in VHI values indicates potential vegetation stress and can be an early indicator of drought impact on the ecosystem. Below Table 5.158 shows the results of VHI index for Banaskantha district each class shows particular sq.km area for various years.

Table 5.158: Classification of VHI for Banaskantha district

Classification	Range	2009	2010	2014	2015	2018
Extreme Drought	< 10	0.5	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	12.7	11.2	10.6	0.0	1.3
Moderate Drought	20 to 30	675.8	17.1	2317.4	523.8	2458.3
Light Drought	30 to 40	4860.2	3541.0	5739.5	3374.8	4238.4
No Drought	> 40	5082.4	7061.6	2563.2	6732.3	3932.8

(Area in Sq.km)

The results of the VHI indices for the 2018 year shows that 2458.30 sq. km. area and 4238.40 Sq.km area fall under moderate drought and light drought conditions, which are 23.12 % and 39.86 %, of the total area of the Banaskantha district respectively. The study also, observed that the area is 3932.80 Sq.km area which is 36.99 % of the study area having no drought conditions.

Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas. Also, from the results it was observed that average 3 to 5% of area having severe drought conditions, 12 to 20% area having moderate drought conditions and 20 to 50% area having light drought conditions and 20 to 30% percentage area having no drought conditions during study period.

Graphical Representation of TCI and VHI for Banaskantha district

Trend analysis of the Vegetation Health Index (VHI), Land Surface Temperature (LST), and Temperature Condition Index (TCI) is an essential part of assessing the impact of drought over time. Threshold values for both TCI and VHI that indicate different levels of drought severity. By comparing these threshold values, categorize the severity of drought conditions in North Gujarat region. For example, high TCI and low VHI values might indicate areas experiencing extreme drought. By examining trends insights into the evolving drought conditions and their effects on vegetation and the environment.

The inverse relationship between TCI and VHI is particularly relevant in the context of drought monitoring. Analysts and researchers use these indices to assess the impact of drought on vegetation. A decrease in VHI, coupled with an increase in TCI, can signal the presence of drought conditions and stress on plant health.

Below Figure 5.104 and 5.105 shows drought severity classification for Temperature condition index and Vegetation health index respectively.

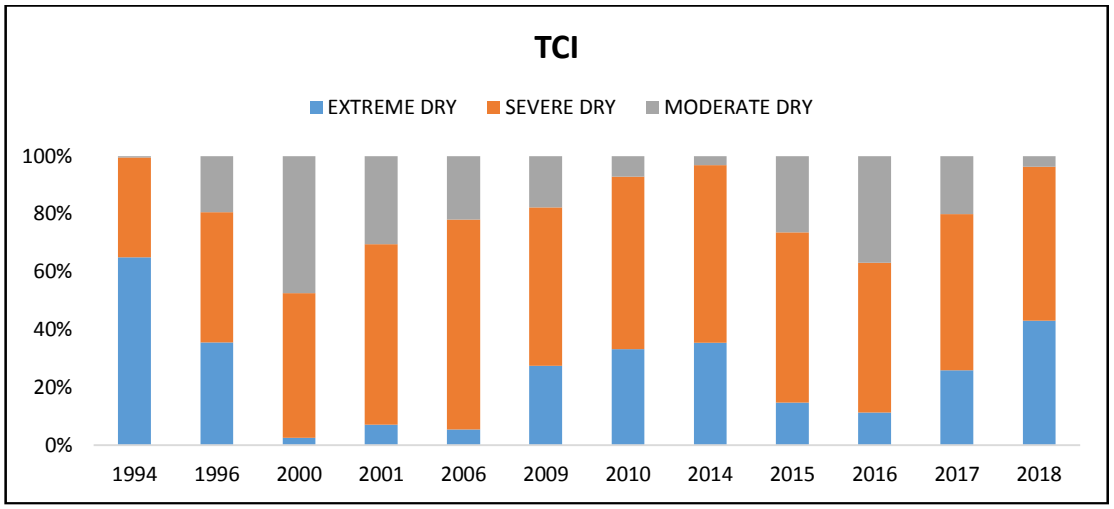


Figure 5.104: Drought severity distribution using TCI over Banaskantha district

From the above Figure 5.104 shows that the maximum extreme dry area was observed in 1994 which is 64.9% (6903.0 Sq.km area).Also, maximum severe dry area was observed in 2006 which is 71.9% (7639.8 Sq.km area). The Moderate dry was observed in 2008 year which is 60.5% (6429.6 Sq.km area). It was also observed that average extreme dry area was around 18%, severe dry area as 45% and moderate dry area was 30% during the study period.

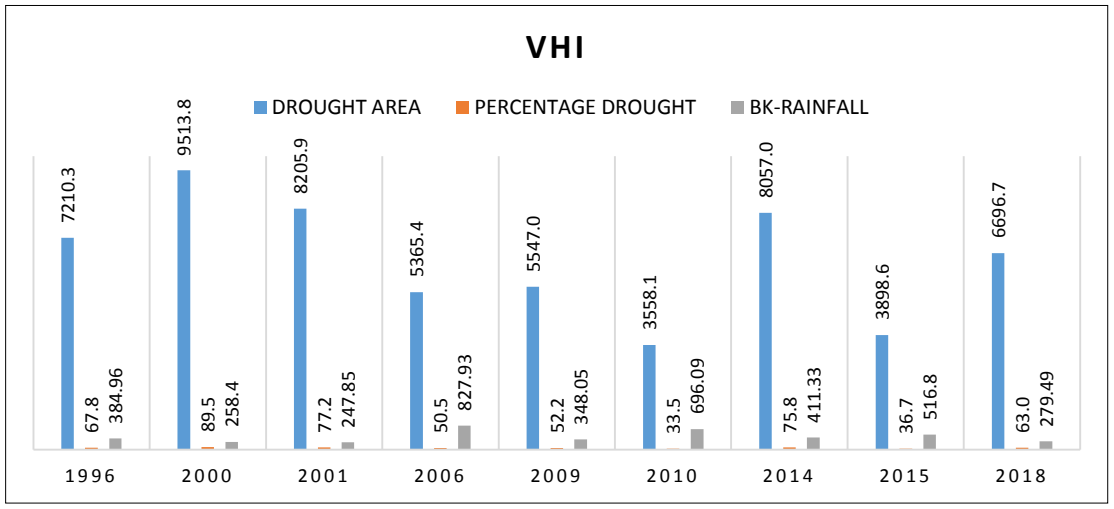


Figure 5.105: Drought severity distribution using VHI over Banaskantha district

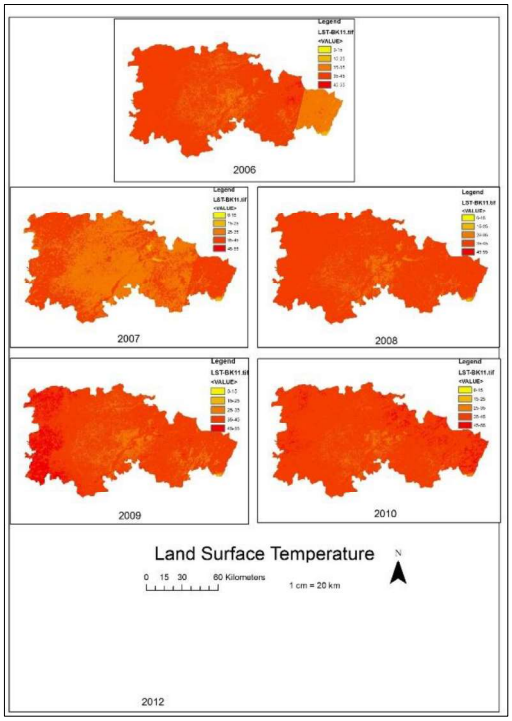
The results of VHI indices for the year 1996 to 2018 is also analysed for different years interval which is shown in below Figure 5.105. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year. The analysis showed that as the rainfall in the area increases, the dryness decreases.

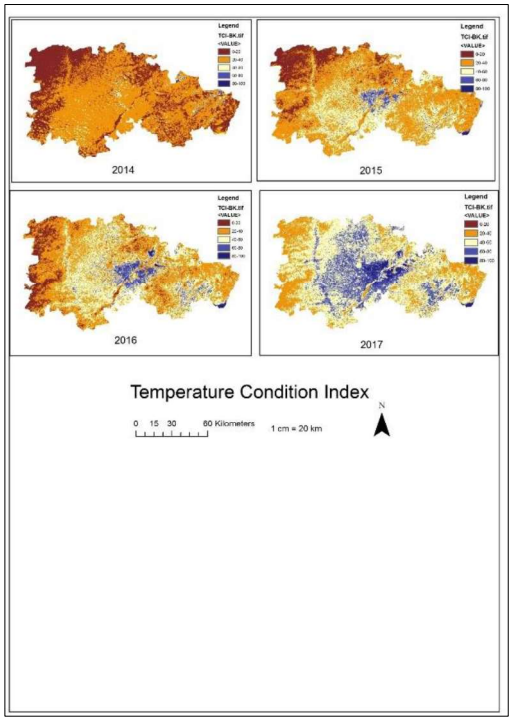
The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2000 with 9513.8 sq. km, which is 89.5%, and during that year the rainfall was 258.40 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 3558.10 sq. km which is 33.5% of the area, and during that year the rainfall was 696.09 mm in the study region. The average percentage of dry area was 60.7% in Banaskantha district with annual average rainfall 445.20 mm during study period.

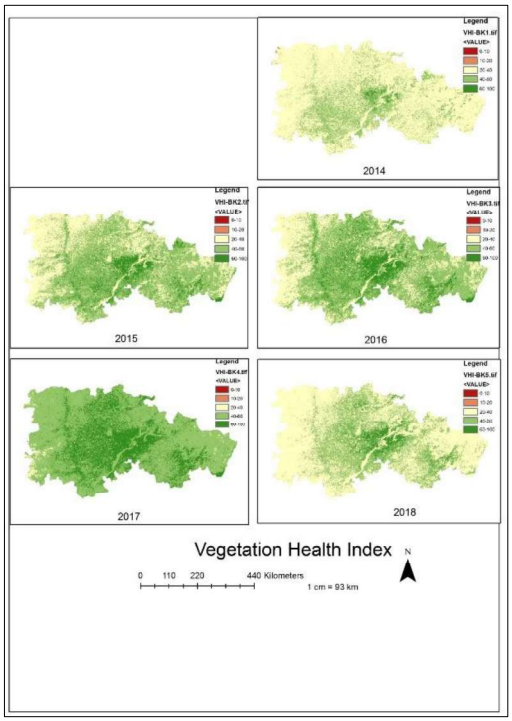
Farmers and land managers can use TCI data to make informed decisions about irrigation and resource allocation. By identifying areas with higher temperature conditions indicative of drought stress, they can prioritize efforts to mitigate the impact on crops. Reflects surface temperature and can indicate stress in vegetation caused by factors such as drought. High TCI values may suggest increased temperature stress on vegetation.

Looking at the above Tables 5.157 and 5.158 and Figures 5.104 and 5.105 with respect to the TCI and VHI for Banaskantha district it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased which can be also observed in Map.

The spatio temporal maps of LST, TCI and VHI is shown below Maps 5.36, 5.37 and 5.38 respectively for Banaskantha district.







Map 5.36: Land Surface Temperature Map of Banaskantha District

Map 5.37: Temperature Condition Index Map of Banaskantha District

Map 5.38: Vegetation Condition Index Map of Banaskantha District

5.10.2 Drought severity estimation using various indices over Gandhinagar district

The spatial distribution of surface temperature using LST is shown in below Table 5.159 for Gandhinagar district. However, the same for the years 2006 to 2019 are showing in below Figure 5.106.

Table 5.159: Classification of LST for Gandhinagar district

Classification	Range	2006	2007	2014	2015	2019
Low Temperature	00 to 15	0.0	0.0	1.8	0.0	4.0
Medium Temperature	15 to 25	1.2	0.0	18.5	0.0	64.8
Average Temperature	25 to 35	1118.3	754.4	843.7	410.1	1003.6
High Temperature	35 to 45	604.8	970.1	816.9	1296.8	587.6
Very High Temperature	45 to 55	0.1	0.0	43.5	17.5	64.5

(Area in Sq.km)

The results of 2006 shows that 604.8 Sq.km area of the district was under high temperature (35 to 45^{o}C) which 35 % of the district. Also, 1118.3 Sq.km area of the district having average temperature (25 to 35^{o}C) which is 64.71% of the total area of the district. The dry soil area is usually visualized by high LST. Also, LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas.

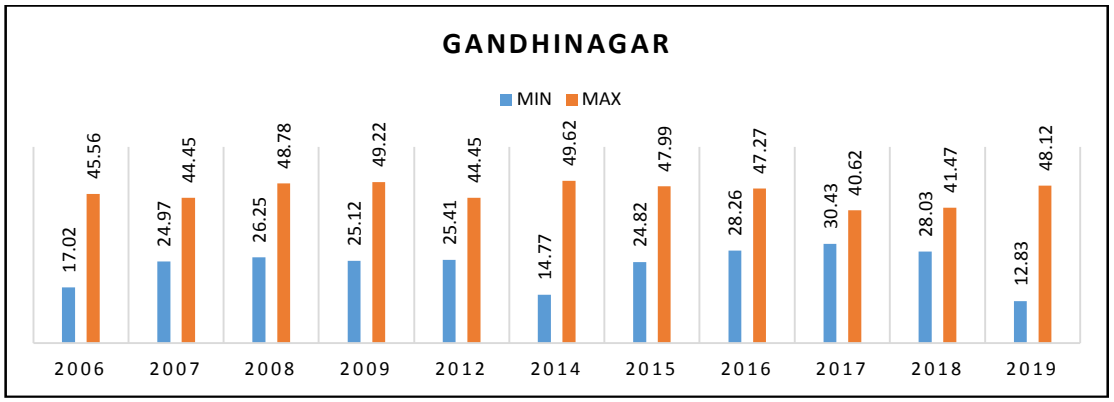


Figure 5.106: Maximum and Minimum LST for Gandhinagar district

From the above Figure 5.106 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Gandhinagar district. The maximum area under 25 to 35 degree temperature was observed in 2006 year which is 1118.3 Sq.km area and minimum area was observed in 2015 year which 410.10 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 1296.80 sq.km area and minimum area 587.60 sq.km. The results also shows that average 835.20 sq.km area or 48.43% of the district under high temperature during the study period. The average minimum temperature was 23.45ºC and average maximum temperature was 46.14ºC during study period.

The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. The rising temperatures can lead to more frequent and severe drought events, impacting water resources and ecosystems. It was also observed that the annual average mean LST value has been increased 2.68°C during study period.

Temperature Condition Index and Vegetation Health Index for Gandhinagar district

Table 5.160: Classification of TCI for Gandhinagar district

Classification	Range	2006	2007	2014	2015	2016	2017
Extreme Dry	0 to 20	66.8	1.7	397.4	61.4	3.0	46.3
Severe Dry	20 to 40	1003.7	435.7	1173.8	743.1	365.2	723.4
Moderate Dry	40 to 60	649.8	1093.7	141.4	594.3	1053.1	785.2
Low Dry	60 to 80	3.6	186.7	10.6	321.3	280.5	157.4
No Drought	80 to 100	0.5	6.7	1.1	4.2	22.6	12.1

(Area in Sq.km)

The results of the TCI indices shown in above Table 5.160 the 2017 year shows that 46.30 sq. km. area and 723.40 sq.km area fall under extreme dry and severe dry conditions, which are 2.67 % and 41.84%, of the total area of the Gandhinagar

district respectively. The study also, observed that moderately dry area is 785.20 Sq.km area which is 45.43% of the study area.

The average drought area in Banaskantha district is 3206.50 sq.km or 30.15% of the district during study period. The average dry conditions percentage in Gandhinagar area ranges from 4.0 % to 30.5%.

Table 5.161: Classification of Vegetation Health Index for Gandhinagar district

Classification	Range	2006	2014	2015	2016	2017	2018
Extreme Drought	< 10	1.1	0.0	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	2.5	0.7	0.0	0.0	0.2	1.2
Moderate Drought	20 to 30	26.7	136.2	4.6	0.5	61.6	114.8
Light Drought	30 to 40	139.3	682.8	307.0	126.3	508.4	309.0
No Drought	> 40	1554.8	904.7	1412.8	1597.6	1154.3	1299.4

(Area in Sq.km)

The results of the VHI indices shown in above Table 5.161 the 2018 year shows that 114.8 sq. km. area and 309.0 Sq.km area fall under moderate drought and light drought conditions, which are 6.64 % and 17.88 %, of the total area of the Gandhinagar district respectively. The study also, observed that the area is 1299.40 Sq.km area which is 75.19 % of the study area having no drought conditions. Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas.

Also, from the results it was observed that average 0 to 1% of area having severe drought conditions, 3 to 10% area having moderate drought conditions and 15 to 40% area having light drought conditions and 50 to 70% percentage area having no drought conditions.

Graphical Representation of TCI and VHI for Gandhinagar district

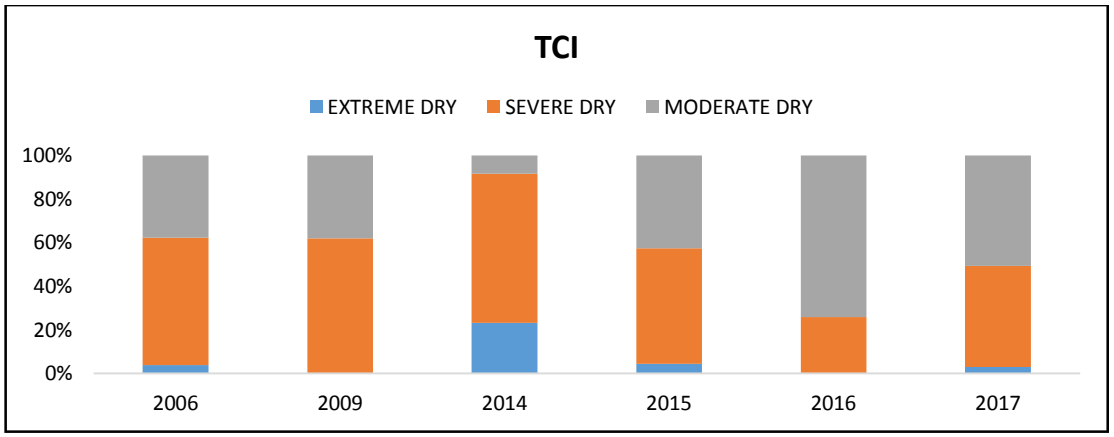


Figure 5.107: Drought severity distribution using TCI over Gandhinagar district

From the above Figure 5.107 shows that the maximum extreme dry area was observed in 2014 which is 23.10% (397.40 Sq.km area). Also, maximum severe dry area was observed in 2014 which is 68.10% (1173.80 sq.km area). The Moderate dry was observed in 2016 year which is 61.1% (1053.6 sq.km area).

From the above Figure 5.107 it was also observed that average extreme dry area was around 5%, severe dry area as 30% and moderate dry area was 30% during the study period.

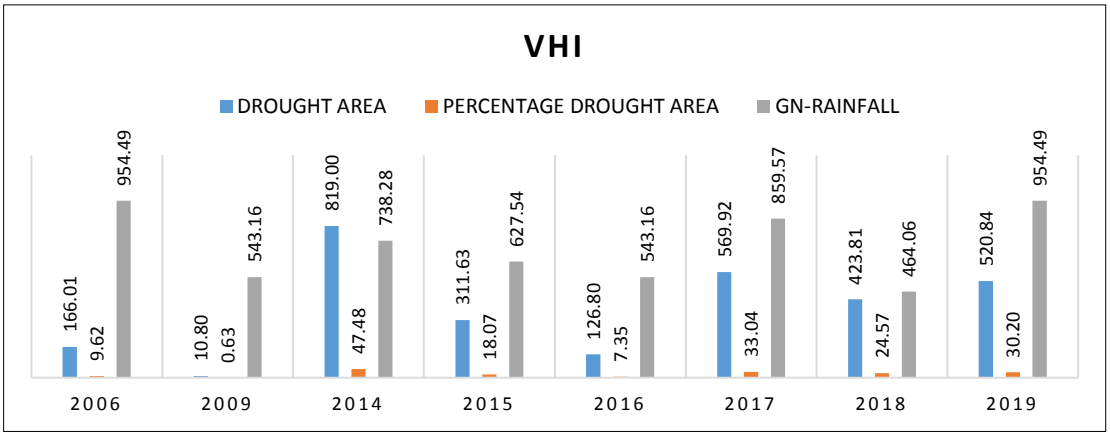


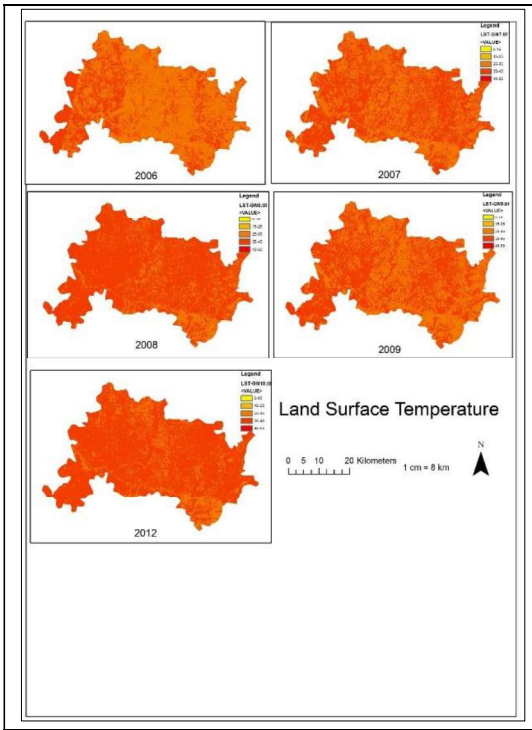
Figure 5.108: Drought severity distribution using VHI over Gandhinagar district

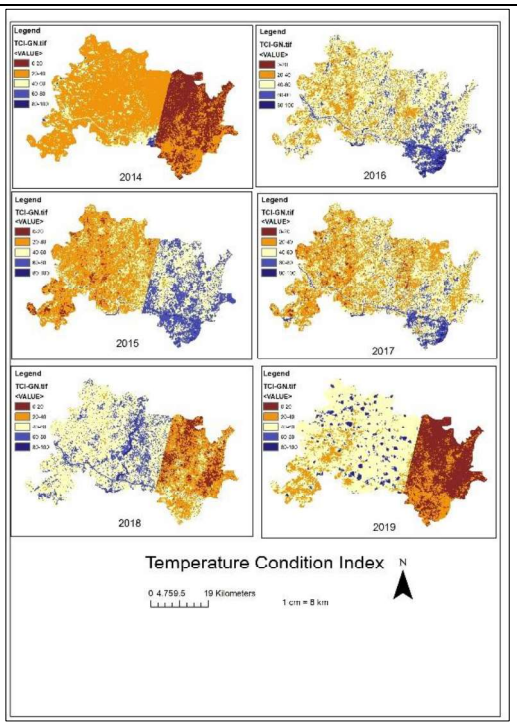
The results of VHI indices for the year 2006 to 2019 is also analysed for different years interval which is shown in below Figure 5.108 for Gandhinagar district. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year. The analysis showed that as the rainfall in the area increases, the dryness decreases.

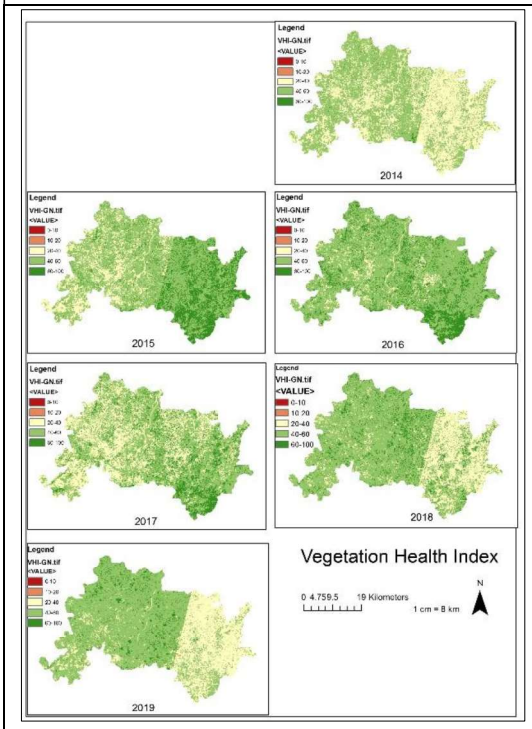
The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 819 sq. km, which is 47.48%, and during that year the rainfall was 738.28 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 126.80 sq. km which is 7.35% of the area, and during that year the rainfall was 543.16 mm in the study region. The average percentage of dry area was 21.37% in Gandhinagar district with annual average rainfall 710.59 mm during study period.

Looking at the above Tables 5.160, 5.161 and Figure 5.107, 5.108 with respect to the TCI and VHI for Gandhinagar district it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased which can be also observed in Map.

The spatio temporal maps of LST, TCI and VHI is shown below Maps 5.39, 5.40 and 5.41 respectively for Gandhinagar district.







Map 5.39: Land Surface Temperature Map of Gandhinagar District

Map 5.40: Temperature Condition Index Map of Gandhinagar District

Map 5.41: Vegetation Condition Index Map of Gandhinagar District

5.10.3 Drought severity estimation using various indices over Mehsana district

The spatial distribution of surface temperature using LST is shown in below Table 5.162 for Mehsana district. However, the same for the years 1992 to 2019 are showing in below Figure 5.109.

Table 5.162: Classification of LST for Mehsana district

Classification	Range	2006	2007	2008	2009	2010
Low Temperature	00 to 15	0.0	0.0	0.0	0.0	0.0
Medium Temperature	15 to 25	14.0	5.8	3.9	6.8	0.2
Average Temperature	25 to 35	1531.5	1990.8	336.7	790.4	147.1
High Temperature	35 to 45	2841.3	2394.8	4051.2	3580.9	4236.7
Very High Temperature	45 to 55	5.1	0.4	0.1	13.6	7.9

(Area in Sq.km)

The results of 2006 shows that 2841.30 Sq.km area of the district was under high temperature (35 to 45ºC) which 64.70 % of the district. Also, 1531.5 Sq.km area of the district having average temperature (25 to 35ºC) which is 34.87% of the total area of the district. The dry soil area is usually visualized by high LST.

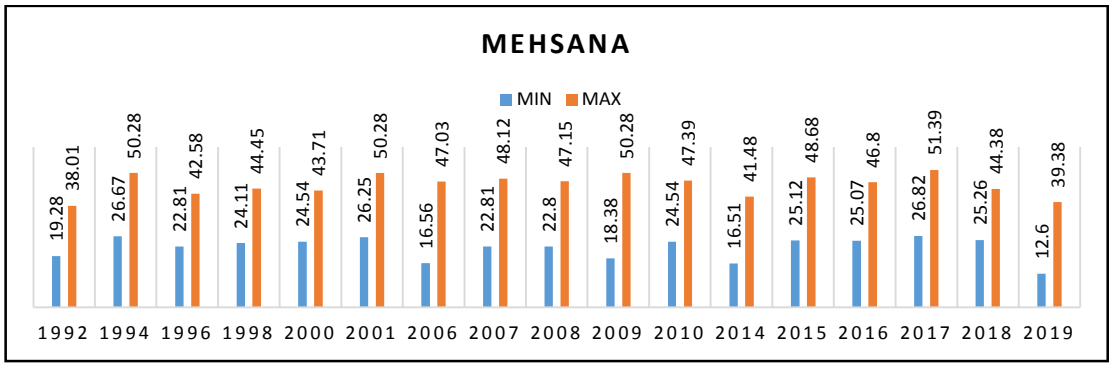


Figure 5.109: Maximum and Minimum LST for Mehsana district

From the above Figure 5.109 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Mehsana district. The maximum area under 25 to 35 degree temperature was observed in 2001 year which is 3425.70 Sq.km area and minimum area was observed in 2010 year which 147.10 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 4236.70 sq.km area and minimum area 942.60 sq.km.

The results also shows that average 3088.10 sq.km area or 70.23% of the district under high temperature during the study period 1992 to 2019 years. The average minimum temperature was 22.36ºC and average maximum temperature was 45.96ºC during study period. The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. The rising temperatures can lead to more frequent and severe drought events, impacting water resources and ecosystems. It was also observed that the annual average mean LST value has been increased 2.88°C during study period.

Temperature Condition Index and Vegetation Health Index for Mehsana district

Table 5.163: Classification of TCI for Mehsana district

Classification	Range	2009	2010	2014	2015	2016	2017
Extreme Dry	0 to 20	216.2	443.4	1113.6	928.4	346.2	356.3
Severe Dry	20 to 40	2384.3	2928.6	2993.7	2987.7	2797.5	2762.4
Moderate Dry	40 to 60	1730.5	980.2	194.5	454.3	1217.6	1215.1
Low Dry	60 to 80	54.2	34.4	63.3	14.8	23.6	50.2
No Drought	80 to 100	6.2	5.3	26.9	6.7	6.5	7.9

(Area in Sq.km)

The results of the TCI indices shown in above Table 5.163 for the 2017 year shows that 356.30 sq. km. area and 2762.40 sq.km area fall under extreme dry and severe dry conditions, which are 8.11 % and 62.91%, of the total area of the Mehsana district respectively. The study also, observed that moderately dry area is 1215.10 sq.km area which is 28.49 % of the study area. The average drought area in Mehsana district is 1262.50 sq.km or 28.80% of the district during study period. The average dry conditions percentage in Gandhinagar area ranges from 10.9% to 48.90%.

Table 5.164: Classification of VHI for Mehsana district

Classification	Range	2006	2008	2009	2010	2014	2016
Extreme Drought	< 10	2.6	0.0	0.1	0.1	0.0	0.0
Severe Drought	10 to 20	11.9	11.2	19.8	24.4	0.4	0.1
Moderate Drought	20 to 30	399.5	19.5	18.9	39.8	511.3	171.4
Light Drought	30 to 40	1573.3	1140.0	1302.9	1751.1	2232.4	1508.7
No Drought	> 40	2404.8	3221.1	3050.3	2576.5	1647.8	2711.7

(Area in Sq.km)

The results of the VHI indices shown in above Table 5.164 for the 2016 year shows that 171.40 sq. km. area and 1508.70 Sq.km area fall under moderate drought and light drought conditions, which are 3.90% and 34.35%, of the total area of the Mehsana district respectively. The study also, observed that the area is 2711.70 Sq.km area which is 61.75 % of the study area having no drought conditions. Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas. Also, from the results it was observed that average 5 to 10% of area having severe drought conditions, 10 to 30% area having moderate drought conditions and 30 to 55% area having light drought conditions and 20 to 45% percentage area having no drought conditions.

Graphical Representation of TCI and VHI for Mehsana district

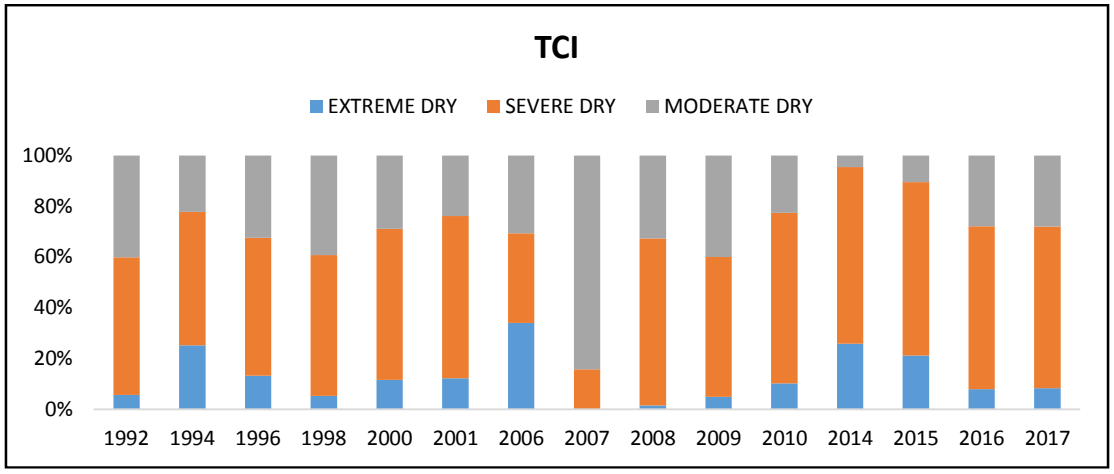


Figure 5.110: Drought severity distribution using TCI over Mehsana district

From the above Figure 5.110 shows that the maximum extreme dry area was observed in 2006 which is 33.70% (1481.10 Sq.km area).Also, maximum severe dry area was observed in 2014 which is 68.20% (2993.70 Sq.km area). The Moderate dry was observed in 2007 year which is 72.50% (3181.40 Sq.km area).

From the above Figure 5.110 it was also observed that average extreme dry area was around 12%, severe dry area as 48.90% and moderate dry area was 28.0% during the study period.

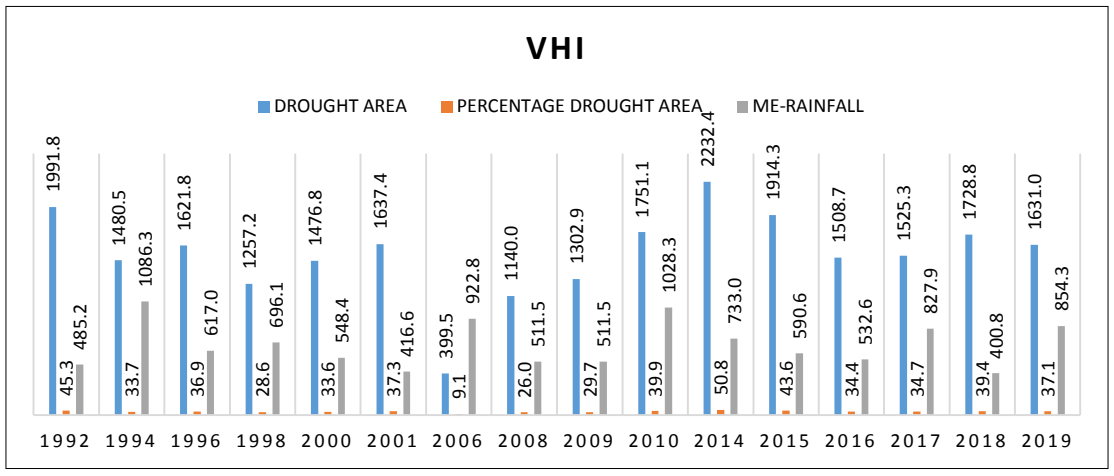


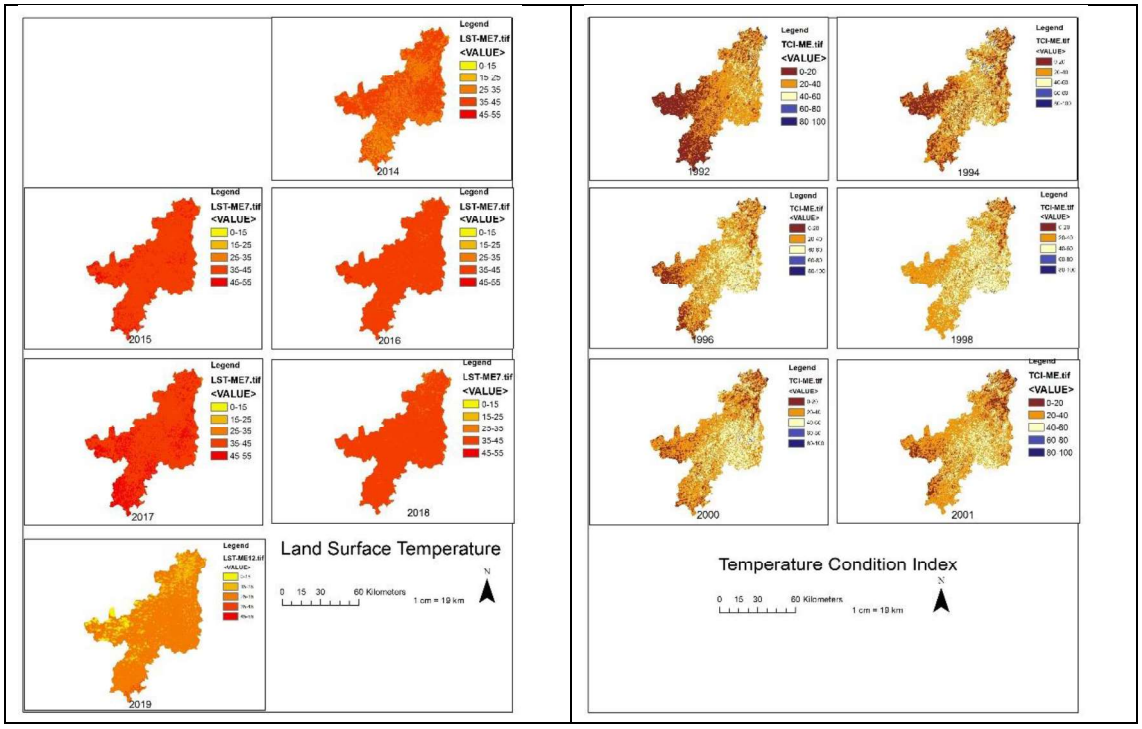
Figure 5.111: Drought severity distribution using VHI over Mehsana district

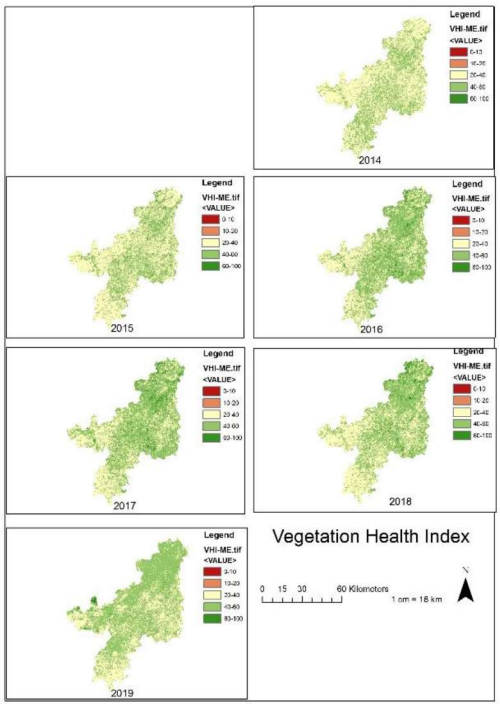
The results of VHI indices for the year 1992 to 2019 is also analyzed for different year's interval which is shown in below Figure 5.111 for Mehsana district. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year.

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 2232.40 sq. km, which is 50.8%, and during that year the rainfall was 733.0 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 399.50 sq. km which is 9% of the area, and during that year the rainfall was 922.90 mm in the study region. The average percentage of dry area was 35.02% in Mehsana district with annual average rainfall 672.70 mm during study period.

Looking at the above Tables 5.163, 5.164 and Figure 5.110, 5.111 with respect to the TCI and VHI for Mehsana district it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased which can be also observed in Map.

The spatio temporal maps of LST, TCI and VHI is shown below Maps 5.42, 5.43 and 5.44 respectively for Mehsana district.





Map 5.42: Land Surface Temperature Map of Mehsana District

Map 5.43: Temperature Condition Index Map of Mehsana District

Map 5.44: Vegetation Condition Index Map of Mehsana District

5.10.4 Drought severity estimation using various indices over Patan district

The spatial distribution of surface temperature using LST is shown in below Table 5.165 for Patan district. However, the same for the years 1992 to 2019 are showing in below Figure 5.112.

Table 5.165: Classification of LST for Patan district

Classification	Range	2014	2015	2016	2017	2018	2019
Low Temperature	00 to 15	0.0	0.0	0.0	0.0	0.0	0.0
Medium Temperature	15 to 25	51.2	35.1	86.2	75.1	69.5	42.1
Average Temperature	25 to 35	1510.9	1428.0	1328.0	1214.1	1324.5	1452.4
High Temperature	35 to 45	4459.9	4559.1	4328.1	4132.6	4412.8	4129.5
Very High Temperature	45 to 55	0.0	0.0	280.4	600.1	222.4	405.8

(Area in Sq.km)

The results of 2006 shows that 4459.10 sq.km area of the district was under high temperature (35 to 45^{o}C) which 74.03 % of the district. Also, 1510.90 sq.km area of the district having average temperature (25 to 35^{o}C) which is 25.08% of the total area of the district. Also, LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas.

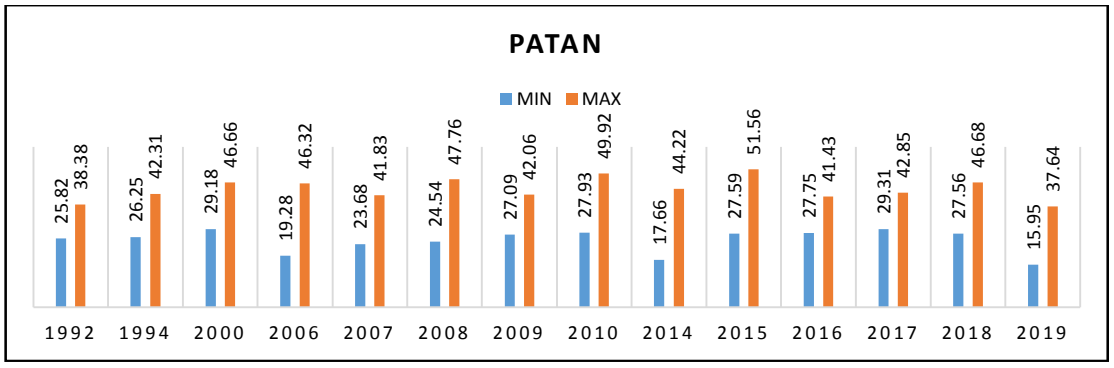


Figure 5.112: Maximum and Minimum LST for Patan district

From the above Figure 5.112 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Patan district. The maximum area under 25 to 35 degree temperature was observed in 2007 year which is 1583.10 sq.km area and minimum area was observed in 2006 year which 86.60 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 5937.0 sq.km area and minimum area 4129.50 sq.km.

The results also shows that average 4489.70 sq.km area or 74.54% of the district under high temperature during the study period. The average minimum temperature was 24.97°C and average maximum temperature was 44.26°C during study period. The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. It was also observed that the annual average mean LST value has been increased 2.65°C during study period.

Temperature Condition Index and Vegetation Health Index for Patan district

Table 5.166: Classification of TCI for Patan district

Classification	Range	2014	2015	2016	2017	2018
Extreme Dry	0 to 20	710.6	1266.0	320.9	390.0	1176.0
Severe Dry	20 to 40	4632.4	3903.2	3886.0	3981.5	3291.1
Moderate Dry	40 to 60	571.8	820.6	1656.2	1517.4	1420.6
Low Dry	60 to 80	76.3	32.0	147.7	127.4	119.2
No Drought	80 to 100	30.9	1.9	10.2	3.9	13.6

(Area in Sq.km)

The results of the TCI indices shown in above Table 5.166 for the 2018 year shows that 1176.0 sq. km. area and 3291.10 Sq.km area fall under extreme dry and severe dry conditions, which are 19.52 % and 54.64%, of the total area of the Patan district respectively. The study also, observed that moderately dry area is 1420.60 Sq.km area which is 23.68% of the study area. The average drought area in Patan district is 1387.60 sq.km or 23.02% of the district during study period. The average dry

conditions percentage in Patan area ranges from 12.5% to 62.4% for extreme dry to moderate dry.

Table 5.167: Classification of VHI for Patan district

Classification	Range	2006	2007	2008	2009	2010
Extreme Drought	< 10	0.0	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	0.5	19.8	0.1	0.1	20.1
Moderate Drought	20 to 30	4380.6	3504.5	5.1	2.7	3501.8
Light Drought	30 to 40	1263.8	1700.5	3875.6	3316.8	1703.5
No Drought	> 40	378.8	799.0	2143.0	2704.1	799.0

(Area in Sq.km)

The results of the VHI indices shown in above Table 5.167 for the 2010 year shows that 3501.8 sq.km area and 1703.5 sq.km area fall under moderate drought and light drought conditions, which are 79.74% and 38.79%, of the total area of the Patan district respectively. The study also, observed that the area is 799 Sq.km area which is 18.20 % of the study area having no drought conditions. Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas.

Also, from the results it was observed that average 2 to 20% of area having severe drought conditions, 20 to 40% area having moderate drought conditions and 30 to 60% area having light drought conditions and 30 to 50% percentage area having no drought conditions.

Graphical Representation of TCI and VHI for Patan district

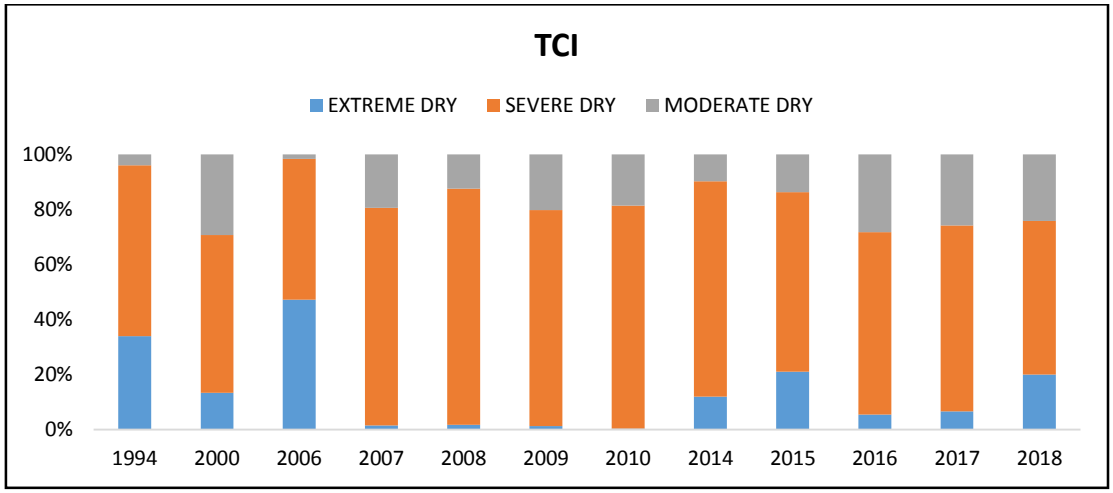


Figure 5.113: Drought severity distribution using TCI over Patan district

From the above Figure 5.113 shows that the maximum extreme dry area was observed in 2006 which is 47.10% (2839.20 Sq.km area).Also, maximum severe dry

area was observed in 2008 which is 84.80% (5108.40 Sq.km area). The Moderate dry was observed in 2000 year which is 28.0% (1688.50 Sq.km area).

From the above Figure it was also observed that average extreme dry area was around 12%, severe dry area as 48.90% and moderate dry area was 28.0% during the study period.

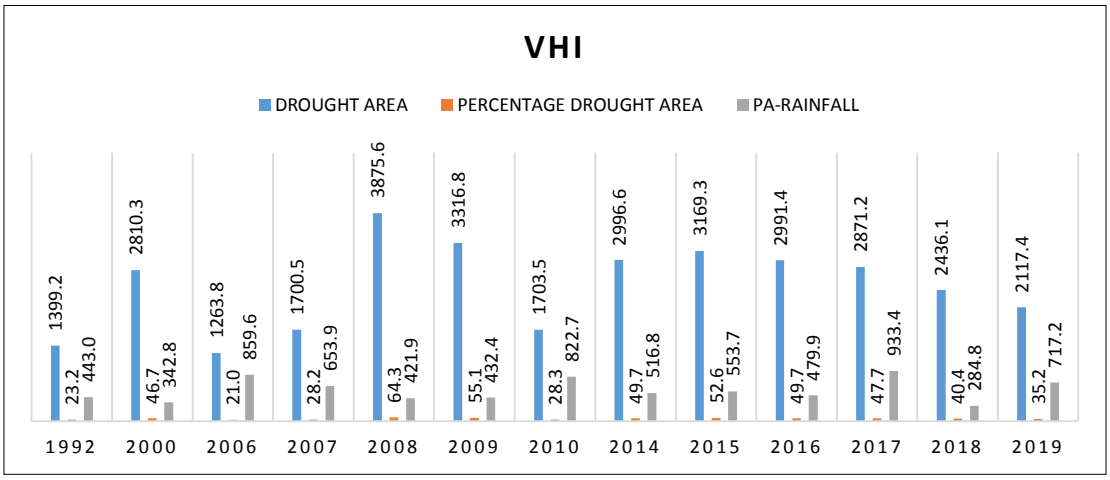


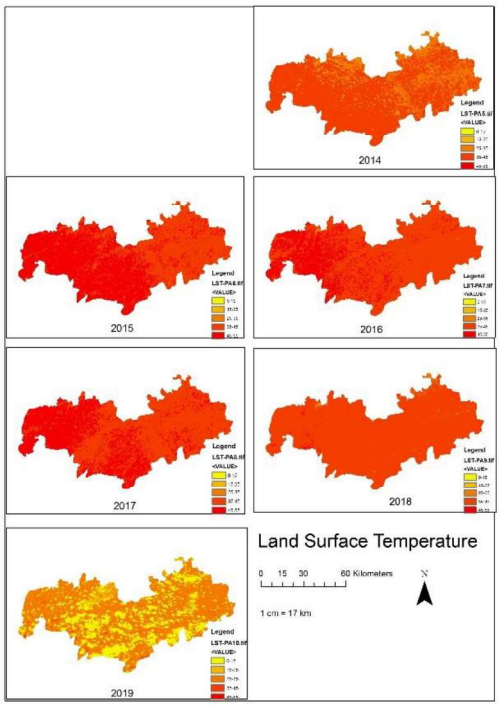
Figure 5.114: Drought severity distribution using VHI over Patan district

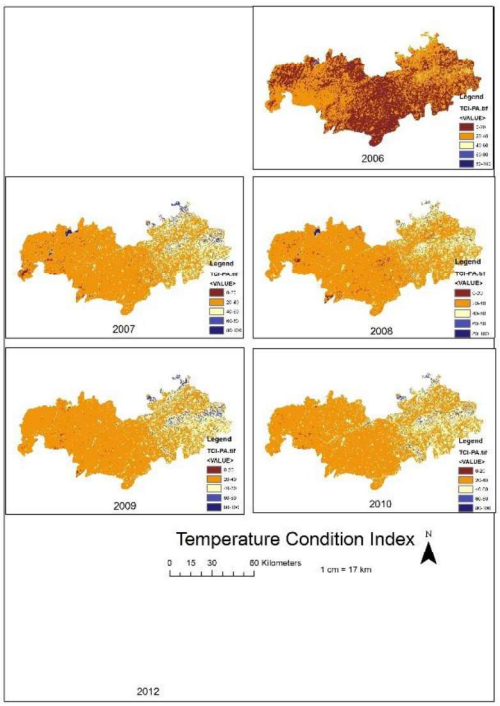
The results of VHI indices for the year 1992 to 2019 is also analysed for different years interval which is shown in below Figure 5.114 for Patan district. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year.

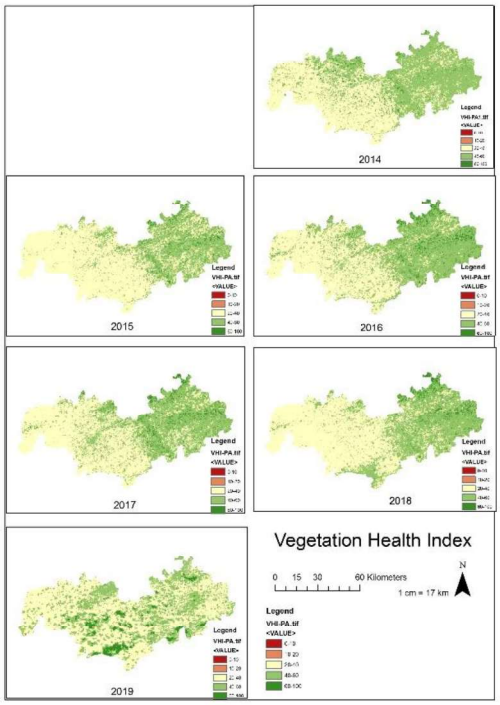
The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2008 with 3875.6 sq. km, which is 64.30%, and during that year the rainfall was 421.9 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 1263.80 sq. km which is 21.0% of the area, and during that year the rainfall was 859.60 mm in the study region. The average percentage of dry area was 41.70% in Patan district with annual average rainfall 574.0 mm during study period.

Looking at the above Tables 5.166,5.167 and Figure 5.113, 5.114 with respect to the TCI and VHI for Banaskantha district it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased which can be also observed in Map.

The spatio temporal maps of LST, TCI and VHI is shown below Maps 5.45, 5.46 and 5.47 respectively for Patan district.







Map 5.45: Land Surface Temperature Map of Patan District

Map 5.46: Temperature Condition Index Map of Patan District

Map 5.47: Vegetation Condition Index Map of Patan District

5.10.5 Drought severity estimation using various indices over Sabarkantha district

The spatial distribution of surface temperature using LST is shown in below Table 5.168 for Sabarkantha district. However, the same for the years 1992 to 2019 are showing in below Figure 5.115.

Table 5.168: Classification of LST for Sabarkantha district

Classification	Range	2014	2015	2016	2017	2018	2019
Low Temperature	00 to 15	1.2	0.3	0.0	0.0	0.0	44.4
Medium Temperature	15 to 25	5.4	11.8	0.0	15.6	18.4	138.9
Average Temperature	25 to 35	387.9	2103.1	299.5	321.4	330.5	1031.7
High Temperature	35 to 45	2905.2	1937.6	3871.0	3741.5	3475.1	1439.5
Very High Temperature	45 to 55	888.8	135.6	18.0	110.7	365.2	1534.0

(Area in Sq.km)

The results of 2014 shows that 2905.20 Sq.km area of the district was under high temperature (35 to 45°C) which 69.36 % of the district. Also, 387.90 Sq.km area of the district having average temperature (25 to 35°C) which is 9.26% of the total area of the district. The dry soil area is usually visualized by high LST. Also, LST analysis has shown higher surface temperature in built-up and bare surfaces and low in healthy vegetated areas.

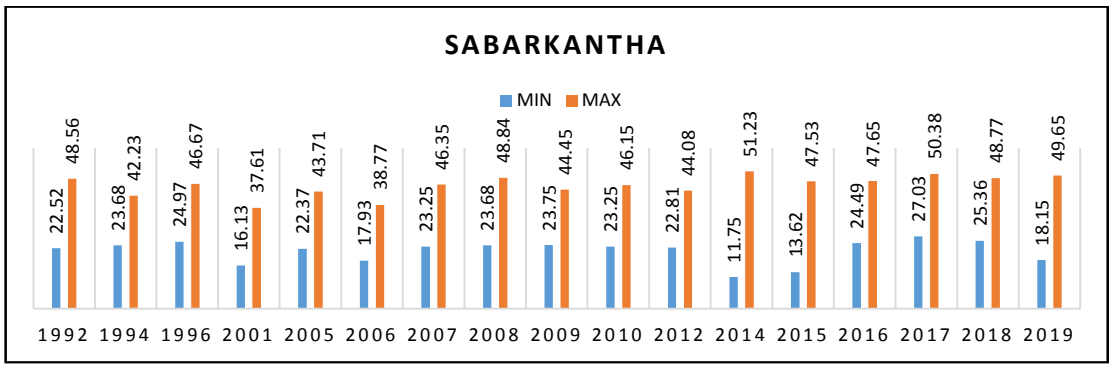


Figure 5.115: Maximum and Minimum LST for Sabarkantha district

From the above Figure 5.115 shows the time series plot of maximum and minimum temperature obtain using LST methodology for Sabarkantha district. The maximum area under 25 to 35 degree temperature was observed in 2006 year which is 3543.90 Sq.km area and minimum area was observed in 2005 year which 280.70 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 3905.70 Sq.km area and minimum area 535.90 Sq.km. The results also shows that average 3955.10 Sq.km area or 94.43% of the district under high temperature during the study period. The average minimum temperature was 21.46°C and average maximum temperature was 46.04°C during study period.

The Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. It was also observed that the annual average mean LST value has been increased 2.30°C during study period.

Temperature Condition Index and Vegetation Health Index for Sabarkantha district

Table 5.169: Classification of TCI for Sabarkantha district

Classification	Range	2014	2015	2016	2017	2018	2019
Extreme Dry	0 to 20	1092.2	270.8	219.4	394.8	150.1	141.5
Severe Dry	20 to 40	2415.4	1399.9	2117.2	2674.6	1234.6	1103.6
Moderate Dry	40 to 60	656.5	2470.1	1730.3	1001.9	2654.1	2869.4
Low Dry	60 to 80	21.1	43.7	81.8	82.0	60.4	40.5
No Drought	80 to 100	3.3	4.0	39.8	35.1	89.6	33.2

(Area in Sq.km)

The results of the TCI indices shown in above Table 5.169 for the 2019 year shows that 141.50 sq. km. area and 1103.60 Sq.km area fall under extreme dry and severe dry conditions, which are 3.37% and 26.35%, of the total area of the Sabarkantha district respectively. The study also, observed that moderately dry area is 2869.40 Sq.km area which is 68.15% of the study area. The average drought area in Sabarkantha district is 1353.0 Sq.km or 32.30 % of the district during study period. The average dry conditions percentage in Sabarkantha area ranges from 7.9% to 55.80% for extreme dry to moderate dry during study period.

Table 5.170: Classification of VHI for Sabarkantha district

Classification	Range	2007	2008	2009	2010	2012
Extreme Drought	< 10	0.0	0.0	0.0	0.0	0.0
Severe Drought	10 to 20	0.0	89.4	3.0	0.8	3.0
Moderate Drought	20 to 30	161.0	2845.1	863.6	555.3	796.4
Light Drought	30 to 40	2118.1	934.5	1767.4	2162.7	1535.4
No Drought	> 40	1909.5	333.4	1554.5	1469.8	1853.6

(Area in Sq.km)

The results of the VHI indices shown in above Table 5.170 for the 2012 year shows that 796.40 sq. km. area and 1535.40 Sq.km area fall under moderate drought and light drought conditions, which are 19.0% and 36.66%, of the total area of the Sabarkantha district respectively. The study also, observed that the area is 1853.60 Sq.km area which is 44.25 % of the study area having no drought conditions. Similar for remaining year the results were analyzed for maximum and minimum drought percentage area estimations and the years experiencing maximum amount of drought areas.

Also, from the results it was observed that average 1 to 5% of area having severe drought conditions, 20 to 60% area having moderate drought conditions and 25 to 45% area having light drought conditions and 35 to 55% percentage area having no drought conditions.

Graphical Representation of TCI and VHI for Sabarkantha district

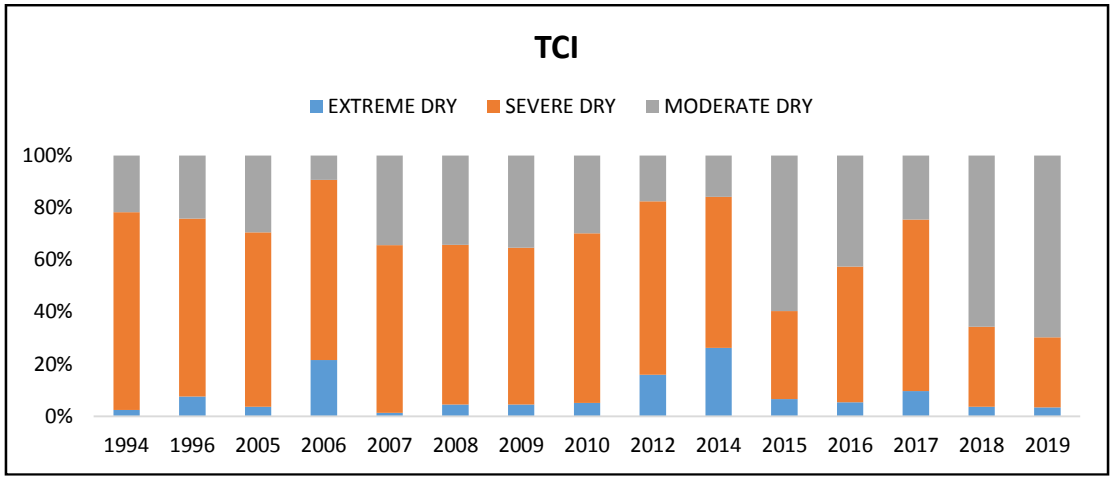


Figure 5.116: Drought severity distribution using TCI over Sabarkantha district

From the above Figure 5.116 shows that the maximum extreme dry area was observed in 2014 which is 26.10% (1092.20 sq.km area). Also, maximum severe dry area was observed in 1994 which is 73.60% (3081.10 sq.km area). The Moderate dry was observed in 2019 year which is 68.50% (2869.40 sq.km area).

From the above Figure it was also observed that average extreme dry area was around 10%, severe dry area as 56.0% and moderate dry area was 35.0% during the study period.

The results of VHI indices for the year 1996 to 2019 is also analyzed for different year's interval which is shown in below Figure 5.117 for Sabarkantha district. The graph shows comparisons of the amount of dry area, percentage of dry area with corresponding annual rainfall for the year.

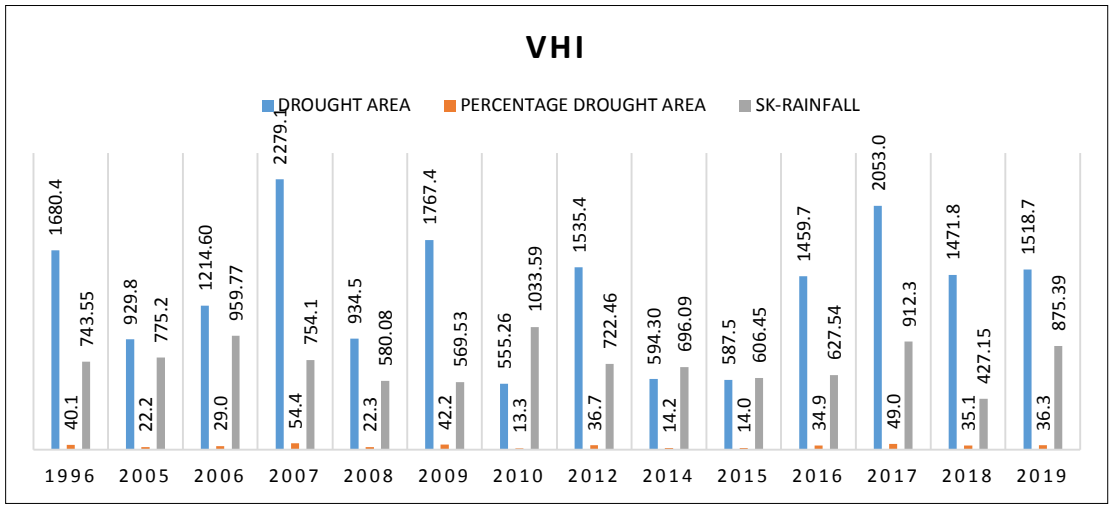
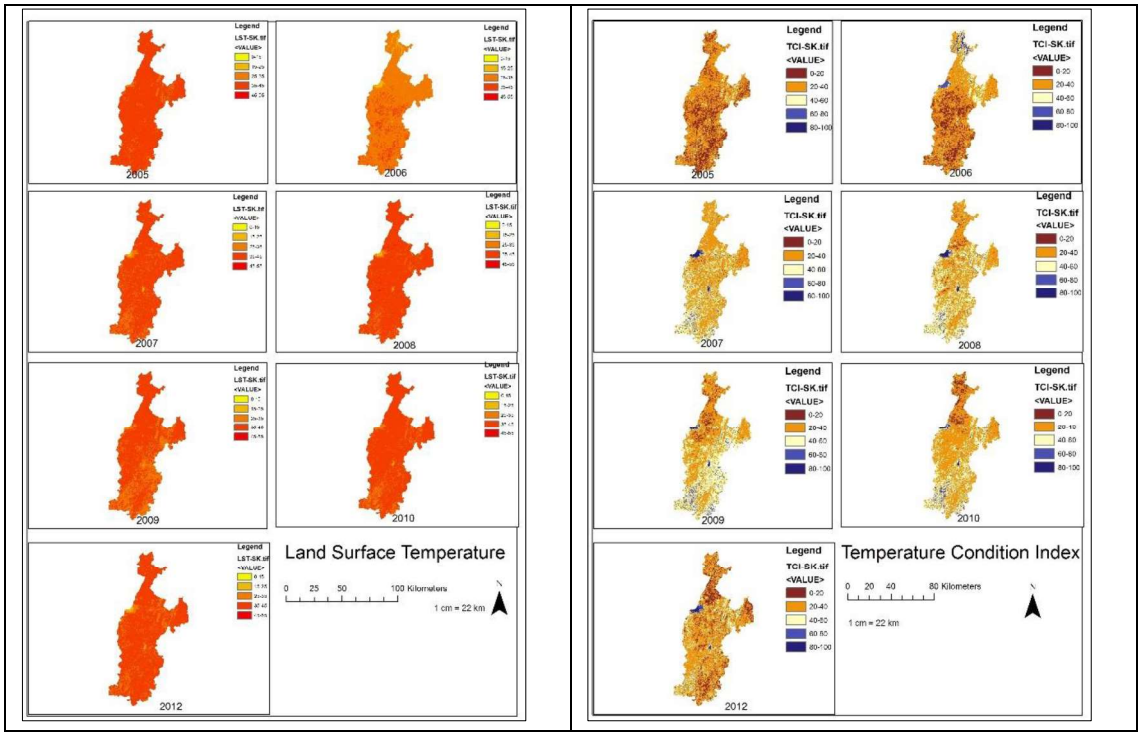


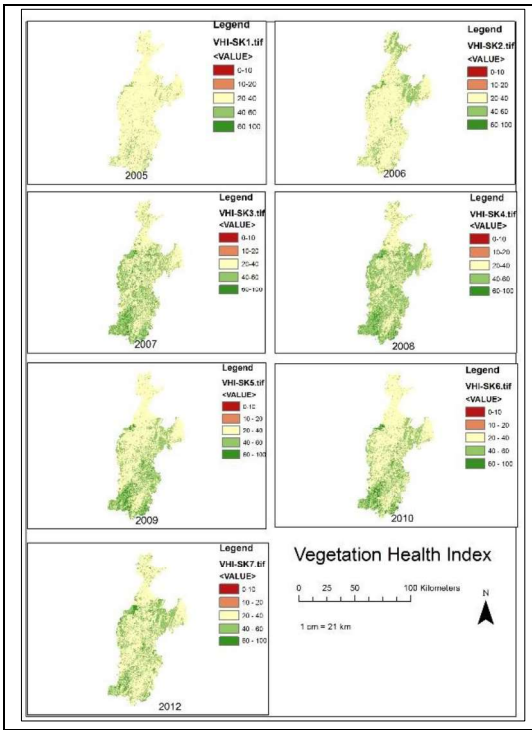
Figure 5.117: Drought severity distribution using VHI over Sabarkantha district

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2007 with 2279.10 sq. km, which is 54.40%, and during that year the rainfall was 580.08 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 555.30 sq. km which is 13.30% of the area, and during that year the rainfall was 1033.59 mm in the study region. The average percentage of dry area was 31.70% in Sabarkantha district with annual average rainfall 734.50 mm during study period.

Looking at the above Tables 5.169, 5.170 and Figure 5.116, 5.117 with respect to the TCI and VHI for Banaskantha district it is clearly evident that the severity of drought increases year wise in the same time no drought condition decreased which can be also observed in Map.

The spatio temporal maps of LST, TCI and VHI is shown below Maps 5.48, 5.49 and 5.50 respectively for Sabarkantha district.





Map 5.48: Land Surface Temperature Map of Sabarkantha District

Map 5.49: Temperature Condition Index Map of Sabarkantha District

Map 5.50: Vegetation Condition Index Map of Sabarkantha District

5.10.6 Comparative Analysis of different Indices over North Gujarat district

The time series plot of LST, and observe the trends in land surface temperature. Increasing LST values over time can indicate a warming trend and potentially more frequent drought conditions. Also, when monitored over time, can serve as early warning indicators for the onset and progression of drought conditions Higher LST values are often associated with drought conditions, as the lack of moisture and reduced Evapotranspiration result in warmer surface temperatures.

TCI is derived from thermal infrared bands of satellite imagery and reflects the temperature conditions of the Earth's surface. Higher TCI values indicate higher surface temperatures. Elevated temperatures can result from various factors, including reduced water availability, which may lead to stress in vegetation. In the context of drought or environmental stress, increased temperature conditions (higher TCI) can be associated with reduced water availability and increased stress on vegetation. As vegetation experiences stress, the NDVI component of VHI tends to decrease, indicating a decline in vegetation health.

Results obtained for Banaskantha district

The results of **Banaskantha** district shows that maximum area for 25 to 35 degree temperature was observed in 2007 year which is 5542.50 Sq.km area and minimum area was observed in 2015 year which 236.30 Sq.km. Similarly, for the maximum

area under 35 to 45 degree temperature was observed in 2008 year with 9551.0 Sq.km area and minimum area was observed in 2007 year with 5045.10 Sq.km. The results also shows that average 7877.60 Sq.km area of the district under high temperature during the study period 1994 to 2019 years. The average minimum temperature was 22.80^{o}C and average maximum temperature was 45.09^{o}C during study period.

From the analysis of TCI it was observed that the maximum extreme dry area was observed in 1994 which is 64.9 % (6903.0 Sq.km area).Also, maximum severe dry area was observed in 2006 which is 71.9% (7639.8 Sq.km area). The Moderate dry was observed in 2008 year which is 60.5% (6429.6 Sq.km area). The average extreme dry area was around 18%, severe dry area as 45% and moderate dry area was 30% during the study period.

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2000 with 9513.8 sq. km, which is 89.5%, and during that year the rainfall was 258.40 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 3558.10 sq. km which is 33.5% of the area, and during that year the rainfall was 696.09 mm in the study region. The average percentage of dry area was 60.7% in **Banaskantha** district with annual average rainfall 445.20 mm during study period.

Results obtained for Gandhinagar district

The results of **Gandhinagar** district shows that maximum area under 25 to 35 degree temperature was observed in 2006 year which is 1118.3 Sq.km area and minimum area was observed in 2015 year which 410.10 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 1296.80 Sq.km area and minimum area 587.60 Sq.km. The results also shows that average 835.20 Sq.km area or 48.43% of the district under high temperature during the study period.

From the analysis of TCI it was observed that the maximum extreme dry area was observed in 2014 which is 23.10% (397.40 Sq.km area).Also, maximum severe dry area was observed in 2014 which is 68.10% (1173.80 Sq.km area). The Moderate dry was observed in 2016 year which is 61.1% (1053.6 Sq.km area). The average extreme dry area was around 5%, severe dry area as 30% and moderate dry area was 30% during the study period.

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2014 with 819 sq. km, which is 47.48%, and during that year the rainfall was 738.28 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 126.80 sq. km which is 7.35% of the area, and during that year the rainfall was 543.16 mm in the study region. The average percentage of

dry area was 21.37% in **Gandhinagar** district with annual average rainfall 710.59 mm during study period.

Results obtained for Mehsana district

The results of **Mehsana** district shows maximum area under 25 to 35 degree temperature was observed in 2001 year which is 3425.70 Sq.km area and minimum area was observed in 2010 year which 147.10 Sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 4236.70 Sq.km area and minimum area 942.60 Sq.km. The results also shows that average 3088.10 Sq.km area or 70.23% of the district under high temperature during the study period. The average minimum temperature was 22.36^{o}C and average maximum temperature was 45.96^{o}C during study period.

The results of TCI shows that maximum extreme dry area was observed in 2006 which is 33.70% (1481.10 Sq.km area).Also, maximum severe dry area was observed in 2014 which is 68.20% (2993.70 Sq.km area). The Moderate dry was observed in 2007 year which is 72.50% (3181.40 Sq.km area). The average extreme dry area was around 12%, severe dry area as 48.90% and moderate dry area was 28.0% during the study period.

The results of the VHI index shows that the maximum percentage of dry areas in the year 2014 with 2232.40 sq. km, which is 50.8%, and during that year the rainfall was 733.0 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 399.50 sq. km which is 9% of the area, and during that year the rainfall was 922.90 mm in the study region. The average percentage of dry area was 35.02% in **Mehsana** district with annual average rainfall 672.70 mm during study period.

Results obtained for Patan district

The results of **Patan** districts shows that maximum area under 25 to 35 degree temperature was observed in 2007 year which is 1583.10 Sq.km area and minimum area was observed in 2006 year which 86.60 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 5937.0 sq.km area and minimum area 4129.50 Sq.km. The results also shows that average 4489.70 sq.km area or 74.54% of the district under high temperature during the study period. The average minimum temperature was 24.97^{o}C and average maximum temperature was 44.26^{o}C during study period.

The results of TCI index shows that the maximum extreme dry area was observed in 2006 which is 47.10% (2839.20 sq.km area). Also, maximum severe dry area was observed in 2008 which is 84.80% (5108.40 sq.km area). The Moderate dry was observed in 2000 year which is 28.0% (1688.50 sq.km area).

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2008 with 3875.6 sq. km, which is 64.30%, and during that year the rainfall was 421.9 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2006 with 1263.80 sq. km which is 21.0% of the area, and during that year the rainfall was 859.60 mm in the study region. The average percentage of dry area was 41.70% in **Patan** district with annual average rainfall 574.0 mm during study period.

Results obtained for Sabarkantha district

The results obtain for **Sabarkantha** district maximum area under 25 to 35 degree temperature was observed in 2006 year which is 3543.90 sq.km area and minimum area was observed in 2005 year which 280.70 sq.km. Similarly for the maximum area under 35 to 45 degree temperature was 3905.70 Sq.km area and minimum area 535.90 Sq.km. The results also shows that average 3955.10 sq.km area or 94.43% of the district under high temperature during the study period. The average minimum temperature was 21.46^{o}C and average maximum temperature was 46.04^{o}C during study period.

The results of TCI shows that maximum extreme dry area was observed in 2014 which is 26.10% (1092.20 sq.km area).Also, maximum severe dry area was observed in 1994 which is 73.60% (3081.10 sq.km area). The Moderate dry was observed in 2019 year which is 68.50% (2869.40 sq.km area).

The results of the VHI index that it was observed that the maximum percentage of dry areas in the year 2007 with 2279.10 sq. km, which is 54.40%, and during that year the rainfall was 580.08 mm in the study region. Similarly, the minimum percentage of dry areas in the year 2010 with 555.30 sq. km which is 13.30% of the area, and during that year the rainfall was 1033.59 mm in the study region. The average percentage of dry area was 31.70% in district with annual average rainfall 734.50 mm during study period.

A consistent increase in TCI can indicate prolonged periods of above-average land surface temperatures. Observe how TCI values correspond to changes in VHI. For instance, when TCI increases and VHI decreases, it suggests that elevated temperatures are negatively affecting vegetation health.

5.11 CONSTRUCTION OF COMPARSIONS MATRIX OF VARIOUS DROUGHT INDICES OVER THE STUDY AREA

The correlation matrix provides a convenient way to display and analyze relationships between different variables. The entries in a correlation matrix

represent the correlation coefficients between pairs of variables. Correlation Matrix can be used to get a relationship between two variables in a tabular format. Positive numbers indicate positive correlations, while negative numbers indicate negative correlations. The closer the number is to 1 (or -1), the stronger the correlation.

A correlation matrix is a statistical method which shows that how strong and in what direction variables (viz, SPI, RDI, SPEI, CZI, and MCZI) are correlated. The correlation coefficient measures the extent to which two pairs of variables are related which two pairs amongst. (SPI3, SPI4, SPI5, SPI6, SPI7, SPI8, SPI9, SPI10, SPI11 and SPI 12).The procedure is carried out for RDI3, RDI 4, RDI 5, RDI 6, RDI 7, RDI 8, RDI 9, RDI 10, RDI 11 and RDI 12. Similarly, for SPEI, CZI and MCZI indices. These coefficients typically range from -1 to 1, where -1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no correlation.

5.11.1 Correlation matrix of meteorological drought indices for Banaskantha district

The selection of time step in identification of onset of any long-term drought is very important. Different Drought indices compared at 1-month to 12-month time steps. Here 1-month time step may lead to erroneous assessment of drought characteristics because sometimes a short term excess may terminate the long term drought and divide a prevailing drought event in to two short events and so this may not be useful to estimation or prediction. Therefore, while comparing drought indices, the drought severity should be computed using higher time step of the drought index. The time step should be chosen in such a way, that it gives higher correlation.

A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales as described and are given in Table 5.171 for Banaskantha district. The results can help to understand how different drought indices time scales relate to each other.

The values on the diagonal (from top-left to bottom-right) represent the correlation of each SPI time scale with itself, which is always 1.00. The off-diagonal values represent the correlations between different SPI time scales. This correlation matrix can help to understand the relationships between different drought indices time scales and can be useful for drought monitoring and assessment.

Table 5.171: Correlation matrix of drought indices for Banaskantha district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1.000									
SPI 4	0.924	1.000								
SPI 5	0.896	0.962	1.000							
SPI 6	0.833	0.902	0.942	1.000						
SPI 7	0.828	0.898	0.939	0.995	1.000					
SPI 8	0.732	0.805	0.850	0.889	0.891	1.000				
SPI 9	0.388	0.404	0.412	0.401	0.398	0.517	1.000			
SPI 10	0.043	0.121	0.110	0.066	0.062	0.068	0.408	1.000		
SPI 11	0.030	0.107	0.101	0.036	0.039	0.058	0.363	0.780	1.000	
SPI 12	0.046	0.125	0.114	0.054	0.054	0.062	0.295	0.693	0.918	1.000

(B) Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1.000									
RDI 4	0.857	1.000								
RDI 5	0.802	0.935	1.000							
RDI 6	0.738	0.878	0.944	1.000						
RDI 7	0.734	0.874	0.941	0.996	1.000					
RDI 8	0.632	0.764	0.834	0.870	0.870	1.000				
RDI 9	0.390	0.400	0.418	0.390	0.389	0.532	1.000			
RDI 10	0.015	0.119	0.086	0.048	0.048	0.034	0.351	1.000		
RDI 11	-0.005	0.095	0.068	0.014	0.019	0.009	0.313	0.767	1.000	
RDI 12	0.002	0.102	0.069	0.019	0.021	0.007	0.260	0.675	0.923	1.000

(C) China Z index and Modified China Z index

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1.000			
CZI 6	0.158	1.000		
CZI 9	-0.045	0.190	1.000	
CZI 12	-0.016	0.196	0.951	1.000

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1.000			
MCZI 6	0.203	1.000		
MCZI 9	-0.080	0.199	1.000	
MCZI 12	-0.041	0.196	0.951	1.000

(D) Standardized Precipitation Evapotranspiration Index

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1.000									
SPEI 4	0.963	1.000								
SPEI 5	0.657	0.689	1.000							
SPEI 6	0.142	0.135	0.295	1.000						
SPEI 7	0.042	0.027	0.011	0.459	1.000					
SPEI 8	0.018	0.017	0.036	0.419	0.784	1.000				
SPEI 9	0.018	0.019	-0.012	0.319	0.695	0.913	1.000			
SPEI 10	0.017	0.021	-0.014	0.319	0.688	0.906	0.998	1.000		
SPEI 11	0.017	0.019	-0.009	0.317	0.684	0.904	0.995	0.998	1.000	
SPEI 12	-0.077	-0.077	-0.035	0.138	0.477	0.607	0.630	0.627	0.630	1.000

High positive correlations can be shown in green colour, while high negative correlations can be shown in red colour. Whereas yellow colour shows average correlation.

The results shows that SPI3, SPI6, SPI9 and SPI12 were well correlated with most of the other drought indices. Similarly, SPEI3, SPEI6, SPEI9 and SPEI 12 showed a

little less correlation with a similar time scale of other drought indices. Also, RDI3, RDI6, RDI9 and RDI 12 showed a high correlation with a similar time scale of other drought indices.

Some observation from Table 5.171 shows that SPI 4 is not very well correlated with SPI 10, SPI 11, and SPI 12. Also, SPI 7 is not correlated with SPI 10, SPI 11. The statistically significant correlation is moderate upto 8 month scale and gives higher significance at higher scales of 9 to 12 month. Also, SPI 10 is very well correlated with SPI 11, SPI 11 with SPI 12 so as long time scale considered the results will improved.

The results of SPI indices for different time scale ranging from 0.03 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.02 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.017 to 1.0. The CZI and SPEI indices had the lowest correlation than SPI.

The frequency of a statistically significant correlation was moderate for monthly scales, where it reached its maximum at a 3-month scale, followed by a 6-month scale, and less frequently at a 9-month scale and no significance at a 12-month scale.

5.11.2 Correlation matrix of meteorological drought indices for Gandhinagar district

A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales is shown below in Table 5.172 for Gandhinagar district. A linear correlation co-efficient (r) was used for the meteorological variables, time series data and various drought index results in the study area during 1901-2002 for Gandhinagar district is shown below. The results can help to understand how different drought indices time scales relate to each other.

Table 5.172: Correlation matrix of drought indices for Gandhinagar district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1.000									
SPI 4	0.974	1.000								
SPI 5	0.960	0.980	1.000							
SPI 6	0.938	0.952	0.969	1.000						
SPI 7	0.937	0.951	0.969	0.997	1.000					
SPI 8	0.823	0.831	0.842	0.850	0.853	1.000				
SPI 9	0.458	0.476	0.490	0.483	0.484	0.577	1.000			
SPI 10	0.138	0.131	0.124	0.107	0.118	0.144	0.418	1.000		
SPI 11	0.208	0.221	0.222	0.195	0.211	0.214	0.377	0.816	1.000	
SPI 12	0.180	0.193	0.187	0.168	0.181	0.157	0.288	0.709	0.899	1.000

(B)Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1.000									
RDI 4	0.685	1.000								
RDI 5	0.669	0.921	1.000							
RDI 6	0.761	0.800	0.821	1.000						
RDI 7	0.673	0.898	0.926	0.882	1.000					
RDI 8	0.608	0.745	0.790	0.697	0.811	1.000				
RDI 9	0.234	0.398	0.422	0.142	0.386	0.463	1.000			
RDI 10	0.144	0.029	0.110	0.073	0.070	0.127	0.350	1.000		
RDI 11	0.252	0.134	0.208	0.183	0.181	0.216	0.327	0.816	1.000	
RDI 12	0.203	0.107	0.167	0.165	0.151	0.156	0.242	0.719	0.909	1.000

(C) China Z index and Modified China Z index

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1.000			
CZI 6	0.278	1.000		
CZI 9	-0.199	0.210	1.000	
CZI 12	-0.157	0.195	0.933	1.000

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1.000			
MCZI 6	0.291	1.000		
MCZI 9	-0.210	0.194	1.000	
MCZI 12	-0.188	0.184	0.962	1.000

(D) Standardized Precipitation Evapotranspiration Index

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1.000									
SPEI 4	0.035	1.000								
SPEI 5	0.008	0.456	1.000							
SPEI 6	0.105	0.169	0.377	1.000						
SPEI 7	0.040	0.024	0.048	0.451	1.000					
SPEI 8	0.029	0.115	0.049	0.362	0.799	1.000				
SPEI 9	-0.035	0.086	-0.029	0.268	0.670	0.871	1.000			
SPEI 10	-0.022	0.074	-0.031	0.266	0.660	0.862	0.996	1.000		
SPEI 11	-0.010	0.088	-0.020	0.267	0.652	0.862	0.993	0.997	1.000	
SPEI 12	-0.013	0.088	-0.021	0.269	0.650	0.864	0.993	0.997	1.000	1.000

The results shows that SPI3, SPI6, SPI9 and SPI12 were well correlated with most of the other drought indices. Similarly, SPEI3, SPEI6, SPEI9 and SPEI 12 showed a little less correlation with a similar time scale of other drought indices. Also, RDI3, RDI6, RDI9 and RDI 12 showed a high correlation with a similar time scale of other drought indices.

The results of SPI indices for different time scale ranging from 0.18 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.07 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.02 to 1.0. The CZI and SPEI indices had the lowest correlation then SPI. The statistically significant correlation is moderate upto 10 month scale and gives higher significance at higher scale 12 month for SPI indices. Also, SPI5 is also give good correlation between them.

Some observation from Table 5.172 shows that SPI 5 is not very well correlated with SPI 10, SPI 11, and SPI 12. Also, SPI 7 is not correlated with SPI 10, SPI 11 and

SPI 12. The statistically significant correlation is moderate upto 09 month scale and gives higher significance at higher scales of 10 to 12 month. Also, SPI 10 is very well correlated with SPI 11, SPI 11 with SPI 12 so as long time scale considered the results will improved.

The frequency of a statistically significant correlation was moderate for monthly scales, where it reached its maximum at a 3-month scale, followed by a 6-month scale, and less frequently at a 9-month scale and no significance at a 12-month scale.

5.11.3 Correlation matrix of meteorological drought indices for Mehsana district

A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales is shown below in Table 5.173 for Mehsana district. The results can help to understand how different drought indices time scales relate to each other.

Table 5.173: Correlation matrix of drought indices for Mehsana district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1.000									
SPI 4	0.940	1.000								
SPI 5	0.930	0.982	1.000							
SPI 6	0.872	0.907	0.935	1.000						
SPI 7	0.870	0.907	0.935	0.998	1.000					
SPI 8	0.753	0.790	0.811	0.835	0.835	1.000				
SPI 9	0.486	0.521	0.521	0.499	0.498	0.605	1.000			
SPI 10	0.127	0.156	0.135	0.121	0.122	0.135	0.412	1.000		
SPI 11	0.144	0.203	0.199	0.154	0.160	0.174	0.366	0.781	1.000	
SPI 12	0.142	0.210	0.196	0.158	0.162	0.153	0.296	0.693	0.899	1.000

(B) Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1.000									
RDI 4	0.891	1.000								
RDI 5	0.861	0.959	1.000							
RDI 6	0.791	0.855	0.908	1.000						
RDI 7	0.787	0.854	0.908	0.997	1.000					
RDI 8	0.654	0.721	0.760	0.804	0.804	1.000				
RDI 9	0.487	0.554	0.566	0.527	0.526	0.636	1.000			
RDI 10	0.121	0.170	0.128	0.112	0.113	0.094	0.359	1.000		
RDI 11	0.100	0.181	0.167	0.123	0.128	0.116	0.331	0.781	1.000	
RDI 12	0.094	0.188	0.159	0.117	0.121	0.090	0.264	0.698	0.909	1.000

(C) China Z index and Modified China Z index

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1			
CZI 6	0.165086	1		
CZI 9	-0.13093	0.203989	1	
CZI 12	-0.10294	0.190122	0.906394	1

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1			
MCZI 6	0.196319	1		
MCZI 9	-0.12999	0.203989	1	
MCZI 12	-0.10537	0.190122	0.906394	1

(D) Standardized Precipitation Evapotranspiration Index

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1.000									
SPEI 4	0.974	1.000								
SPEI 5	0.498	0.498	1.000							
SPEI 6	0.161	0.143	0.336	1.000						
SPEI 7	0.043	0.042	0.068	0.441	1.000					
SPEI 8	0.057	0.066	0.056	0.358	0.761	1.000				
SPEI 9	0.023	0.038	-0.017	0.269	0.657	0.875	1.000			
SPEI 10	0.009	0.026	-0.027	0.266	0.646	0.863	0.996	1.000		
SPEI 11	0.016	0.037	-0.019	0.262	0.635	0.861	0.992	0.997	1.000	
SPEI 12	0.016	0.036	-0.019	0.264	0.635	0.862	0.992	0.997	1.000	1.000

The results of SPI3, SPI6, SPI9 and SPI12 were well correlated with most of the other drought indices. Similarly, SPEI3, SPEI6, SPEI9 and SPEI 12 showed a little less correlation with a similar time scale of other drought indices. Also, RDI3, RDI6, RDI9 and RDI 12 showed a high correlation with a similar time scale of other drought indices.

The results of SPI indices for different time scale ranging from 0.12 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.09 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.023 to 1.0. The CZI, MCZI and SPEI indices had the lowest correlation then SPI and RDI. The statistically significant correlation is moderate upto month scale and gives higher significance at higher scale 12 month for SPI and RDI indices. Also, SPI6, SPI11 and SPI12 is also give good correlation between them.

Some observation from Table 5.173 shows that SPI 6 is not very well correlated with SPI 10, SPI 11, and SPI 12. Also, SPI 7 is not correlated with SPI 10, SPI 11 and SPI 12. The statistically significant correlation is moderate upto 09 month scale and gives higher significance at higher scales of 10 to 12 month. Also, SPI 10 is very well correlated with SPI 11, SPI 11 with SPI 12 so as long time scale considered the results will improved. Similar analysis was observed for SPEI, CZI and MCZI indexes.

This means that the SPI and RDI has good capability for drought estimation while the SPEI, CZI and MCZI have weak capabilities for estimating drought. This is because the SPI is completely based on precipitation, while the RDI is based on precipitation and PET. Based on this above comparative analysis it is concluded that

SPI indices gives best results for modelling and management of drought in Mehsana district.

5.11.4 Correlation matrix of meteorological drought indices for Patan district

A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales is shown below in Table 5.174 for Patan district. The results can help to understand how different drought indices time scales relate to each other.

Table 5.174: Correlation matrix of drought indices for Patan district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1.000									
SPI 4	0.961	1.000								
SPI 5	0.948	0.983	1.000							
SPI 6	0.872	0.897	0.921	1.000						
SPI 7	0.873	0.897	0.921	1.000	1.000					
SPI 8	0.799	0.817	0.837	0.898	0.898	1.000				
SPI 9	0.497	0.508	0.507	0.501	0.501	0.579	1.000			
SPI 10	0.126	0.166	0.159	0.126	0.126	0.146	0.403	1.000		
SPI 11	0.112	0.161	0.160	0.083	0.084	0.134	0.340	0.773	1.000	
SPI 12	0.148	0.191	0.181	0.115	0.115	0.151	0.293	0.702	0.921	1.000

(B) Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1.000									
RDI 4	0.926	1.000								
RDI 5	0.898	0.965	1.000							
RDI 6	0.804	0.858	0.899	1.000						
RDI 7	0.804	0.857	0.898	1.000	1.000					
RDI 8	0.705	0.735	0.769	0.852	0.853	1.000				
RDI 9	0.469	0.478	0.479	0.466	0.467	0.564	1.000			
RDI 10	0.089	0.142	0.118	0.087	0.088	0.092	0.343	1.000		
RDI 11	0.066	0.126	0.113	0.030	0.032	0.078	0.298	0.764	1.000	
RDI 12	0.097	0.152	0.127	0.052	0.053	0.083	0.257	0.691	0.928	1.000

(C) China Z index and Modified China Z index

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1			
CZI 6	0.19626	1		
CZI 9	-0.0977	0.1762	1	
CZI 12	-0.07536	0.13191	0.9531	1

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1			
MCZI 6	0.17389	1		
MCZI 9	-0.05533	0.18191	1	
MCZI 12	-0.0412	0.15292	0.94936	1

(D) Standardized Precipitation Evapotranspiration Index

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1.000									
SPEI 4	0.486	1.000								
SPEI 5	0.930	0.636	1.000							
SPEI 6	0.252	0.137	0.259	1.000						
SPEI 7	0.031	0.031	0.028	0.411	1.000					
SPEI 8	0.000	-0.041	0.001	0.329	0.759	1.000				
SPEI 9	-0.044	-0.067	-0.055	0.252	0.681	0.905	1.000			
SPEI 10	-0.048	-0.071	-0.062	0.259	0.673	0.894	0.995	1.000		
SPEI 11	-0.035	-0.063	-0.050	0.258	0.664	0.888	0.991	0.996	1.000	
SPEI 12	-0.034	-0.062	-0.049	0.258	0.664	0.889	0.991	0.996	1.000	1.000

The results of SPI indices for different time scale ranging from 0.11 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.03 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.001 to 1.0. The CZI, MCZI and SPEI indices had the lowest correlation then SPI and RDI. The statistically significant correlation is moderate for month scale and gives higher significance at higher scale 12 month for SPI and RDI indices. Also, SPI6, SPI11 and SPI12 is also give good correlation between them.

Some observation from Table 5.174 shows that SPEI 3, SPEI 4 and SPEI 5 is not very well correlated with SPEI 9, SPEI 10, SPEI 11, and SPEI 12 it is showing negative correlation. From the analysis it was observed that from SPEI 7 results will improved. Similar observation for SPI, RDI, CZI and MCZI index is carried out.

Based on this above comparative analysis it is concluded that SPI indices gives best results for modelling and management of drought in Patan district.

5.11.5 Correlation matrix of meteorological drought indices for Sabarkantha district

A correlation matrix is developed for SPI, RDI, SPEI, CZI and MCZI indices at various time scales is shown below in Table 5.175for Sabarkantha district. The results can help to understand how different drought indices time scales relate to each other.

Table 5.175: Correlation matrix of drought indices for Sabarkantha district

(A) Standardized Precipitation Index

	SPI 3	SPI 4	SPI 5	SPI 6	SPI 7	SPI 8	SPI 9	SPI 10	SPI 11	SPI 12
SPI 3	1									
SPI 4	0.90277	1								
SPI 5	0.8722	0.95846	1							
SPI 6	0.8488	0.92763	0.96739	1						
SPI 7	0.82961	0.91793	0.96012	0.98859	1					
SPI 8	0.66813	0.74712	0.7862	0.77797	0.78123	1				
SPI 9	0.3618	0.41567	0.39792	0.33699	0.33405	0.46449	1			
SPI 10	-0.0352	0.0291	0.00482	-0.0281	-0.0322	0.01272	0.42595	1		
SPI 11	0.0004	0.0964	0.0971	0.05791	0.05672	0.0606	0.34628	0.76891	1	
SPI 12	0.01252	0.10718	0.09919	0.06314	0.05711	0.03012	0.26952	0.68657	0.90088	1

(B) Reconnaissance Drought Index

	RDI 3	RDI 4	RDI 5	RDI 6	RDI 7	RDI 8	RDI 9	RDI 10	RDI 11	RDI 12
RDI 3	1									
RDI 4	0.8498	1								
RDI 5	0.78016	0.92059	1							
RDI 6	0.74381	0.86459	0.93458	1						
RDI 7	0.72824	0.85494	0.92966	0.98993	1					
RDI 8	0.58161	0.70563	0.77473	0.78146	0.7842	1				
RDI 9	0.4233	0.52268	0.50942	0.41725	0.4113	0.52776	1			
RDI 10	-0.0157	0.07967	0.03243	-0.0071	-0.0145	-0.0034	0.37216	1		
RDI 11	-0.0175	0.10882	0.10007	0.06221	0.05545	0.0331	0.30444	0.76132	1	
RDI 12	-0.0121	0.11282	0.09219	0.05403	0.04254	-0.0008	0.23287	0.68408	0.90777	1

(C) China Z index and Modified China Z index

	CZI 3	CZI 6	CZI 9	CZI 12
CZI 3	1			
CZI 6	0.15822	1		
CZI 9	-0.0453	0.19045	1	
CZI 12	-0.0165	0.19627	0.95125	1

	MCZI 3	MCZI 6	MCZI 9	MCZI 12
MCZI 3	1			
MCZI 6	0.20257	1		
MCZI 9	-0.0805	0.19926	1	
MCZI 12	-0.0412	0.19644	0.95132	1

(D) Standardized Precipitation Evapotranspiration Index

	SPEI 3	SPEI 4	SPEI 5	SPEI 6	SPEI 7	SPEI 8	SPEI 9	SPEI 10	SPEI 11	SPEI 12
SPEI 3	1									
SPEI 4	0.91804	1								
SPEI 5	0.46043	0.47961	1							
SPEI 6	0.11633	0.10028	0.29447	1						
SPEI 7	0.06229	0.04373	0.08429	0.49446	1					
SPEI 8	0.09877	0.09263	0.06212	0.40156	0.77712	1				
SPEI 9	0.06116	0.05612	-0.0283	0.30906	0.68099	0.89194	1			
SPEI 10	0.04763	0.0479	-0.0394	0.29936	0.66691	0.88221	0.99799	1		
SPEI 11	0.05101	0.05083	-0.0386	0.29551	0.66241	0.88131	0.99589	0.99827	1	
SPEI 12	0.05133	0.05039	-0.0394	0.29838	0.66203	0.88292	0.99586	0.99809	0.99976	1

The drought indices were highly correlated to each other for a similar time scale. For instance, SPI3, SPI6, SPI9 and SPI12 were well correlated with most of the other drought indices. Similarly, SPEI3, SPEI6, SPEI9 and SPEI 12 showed a little less correlation with a similar time scale of other drought indices. Also, RDI3, RDI6, RDI9

and RDI 12 showed a high correlation with a similar time scale of other drought indices.

The results of SPI indices for different time scale ranging from 0.0004 to 1.0. Similarly, for results of RDI indices for different time scale ranging from 0.003 to 1.0. Also, results of SPEI indices for different time scale ranging from 0.004 to 1.0. The CZI, MCZI and SPEI indices had the lowest correlation then SPI and RDI. The statistically significant correlation is moderate for month scale and gives higher significance at higher scale 12 month for SPI and RDI indices. Also, SPI6, SPI11 and SPI12 is also give good correlation between them.

5.11.6 Comparative analysis of Correlation matrix over North Gujarat region

Correlation matrix analysis is a statistical technique used to examine the relationships between multiple variables in a dataset. It is a powerful tool for understanding how variables are related to each other. The correlation matrix is a square matrix where each cell represents the correlation between two variables. It ranges from -1 (perfect negative correlation) to 1 (perfect positive correlation), with 0 indicating no linear correlation. Different drought indices used and it responded differently at various time scales and in different districts under study.

From the above results it is observed that the “High positive correlations can be shown in Green colour (ranges from 0.66 to 0.99), while high negative correlations can be shown in Red colour (ranges from -0.02 to -0.06). Whereas Yellow colour (ranges from 0.11 to 0.59) shows an average correlation between them”.

Based on this above comparative analysis it is concluded that SPI and RDI indices with 12 months’ time scale gives best results (=0.99) for modelling and management of drought in North Gujarat district. While SPEI and CZI, MCZI index gives some less correlation between them.

Overall for North Gujarat districts meteorological drought indices (SPI and RDI) with higher time steps is found to be good choice for assessment of drought characteristics and monitoring of drought condition, because of its capability of timely detection of drought onset and realistic quantification of severity of drought events in study area.

5.12 DEVELOPMENT OF DROUGHT FORECASTING MODELS USING SOFT COMPUTING TECHNIQUES OVER STUDY AREA

Development of drought forecasting models and early warning of the drought phenomena is increasingly being applied in present study. In present study Fuzzy logic approach and ANFIS approach used for development of drought forecasting models.

Fuzzy Logic (FL) model operates on an if-then ‟principle, where the if ‟is a vector of fuzzy premises and the then ‟is a vector of fuzzy consequences, to apply this principles efficiently, a Fuzzy Inference System (FIS) is a control system built using fuzzy set theory based on combining the fuzzy sets from each rule through aggregation operator to get a fuzzy set result, then defuzzify the fuzzy set for each output variable. A fuzzy set is totally characterized by a membership function (MF).

ANFIS (Adaptive Neuro-Fuzzy Inference System) is a hybrid computational model that combines the adaptability of neural networks with the interpretability of fuzzy logic. ANFIS employs a specific structure and learning algorithm to create a system capable of handling complex and uncertain relationships. ANFIS combines the principles of fuzzy logic and neural networks, using a hybrid learning algorithm to adapt to data and optimize its parameters.

The performance evaluation of the models was check by calculating Coefficient of Correlation (r), Coefficient of determination (R^2), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE). If the RMSE, MAE values on data were comparatively less, the prediction model is reliable and efficient and can be used for drought prediction.

5.12.1 Fuzzy Logic approach for RDI and SPI

This study aims to develop a new meteorological drought index based on fuzzy logic (FL) approach to predict droughts condition in North Gujarat districts. Below Table 5.176 shows various combination of input data which was compared with two drought indices (viz., SPI and RDI) for each districts.

Table 5.176: Input/output data for various model developed

Model No.	Input Data	Output Data
1	Annual Rainfall	SPI 12, RDI 12
2	Annual Rainfall, Maximum Temperature, Minimum Temperature	SPI 12, RDI 12
3	Annual Rainfall, Average Temperature	SPI 12, RDI 12
4	Annual Rainfall, Average Temperature, Potential	SPI 12, RDI 12

	Evapotranspiration	
5	SPI 9, SPI 10, SPI 11 RDI 9, RDI 10, RDI 11	SPI 12 RDI 12

Model 1 is developed using input parameter as annual rainfall and output parameter as SPI12.Similar, input parameter annual rainfall and output parameter as RDI 12.

Model 2 is developed using combination of Annual Rainfall, Maximum Temperature, Minimum Temperature and output data as SPI 12, RDI 12.

Model 3 is developed using combination of Annual Rainfall and Average Temperature (average temperature eliminates the high and low rate of temperature data) and output data as SPI 12, RDI 12.

Model 4 is developed using combination of Annual Rainfall, Average Temperature and Potential Evapotranspiration as input and output data as SPI 12, RDI 12.

Model 5 is developed using input parameters as SPI 9, SPI 10, and SPI 11 with (t+1) timesteps to predict SPI 12. Similar, for RDI 9, RDI 10, RDI 11 with (t+1) timesteps to predict RDI 12.

Five Fuzzy Logic Models i.e., FL Model 1, FL Model 2, FL Model 3, FL Model 4 and FL Model 5 have been developed considering data set of 70%-30% for training and validation respectively. The performance evaluation of the Fuzzy Logic models was done by calculating Coefficient of Correlation (r), Coefficient of determination (R^2), Root Mean Squared Error (RMSE); Mean Absolute Error (MAE),. As the RMSE, MAE values on data were comparatively less, the prediction model is reliable and efficient and can be used for drought prediction. Below Table shows different combinations of model for drought forecasting model.

Fuzzy Logic Model 1 for Banaskantha district

Annual Rainfall –RDI 12, Annual Rainfall –SPI12

Below Figure 5.118 shows the steps implicated in a fuzzy based system. The system functional components can be classified into two function. First, the fuzzy rule base to describe the membership functions of the fuzzy sets to be used in the fuzzy rules. Second, the decision-making section that Rule editor perform the inference procedures on the rules.

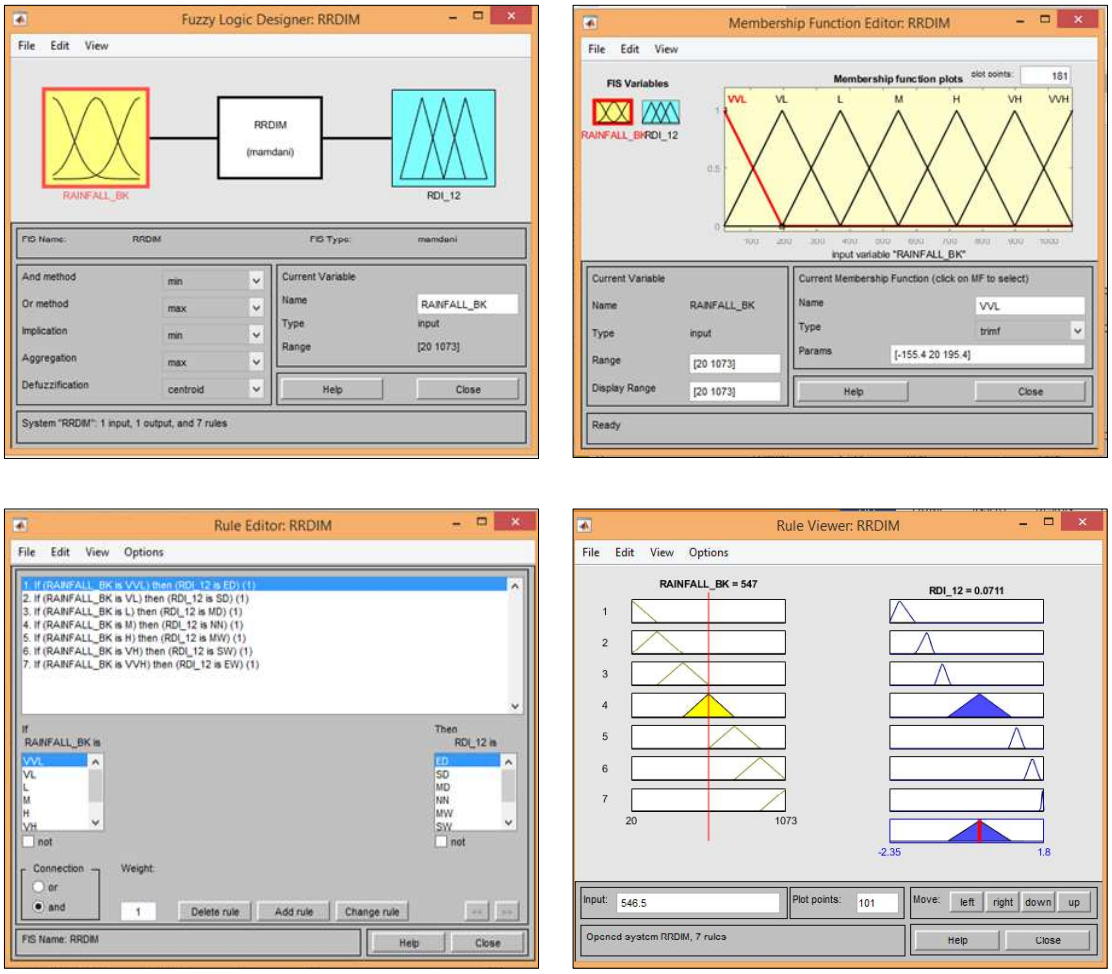


Figure 5.118: Fuzzy Logic structure of Model 1 for Banaskantha district

For development of annual rainfall and RDI 12 model, annual rainfall and SPI 12 model, the triangular membership function is most suitable for input and output parameters since computational is most straightforward in manner, which is represented. The triangular membership function is the simplest membership function, formed by using straight lines and named “Trim”. It’s nothing more than a collection of three points forming a triangle. In rule-based fuzzy systems, the relationships between variables are represented by means of fuzzy if-then rules.

The annual rainfall range is divided into seven fuzzy levels as Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH). Also, the ranges of rainfall and output variables is also shown in below Table 12.2. The linguistic expressions for various fuzzy levels are as follows Table 5.177 (a), 5.177(b):

Table 5.177: Linguistic variable for different parameters for Model 1

Parameters	**Linguistic variable**
Rainfall	Very-very low, Very low, Low, Medium, High, Very high, Very-

	very high
Maximum Temperature	Low temperature, Medium temperature, High temperature
Minimum Temperature	Low temperature, Medium temperature, High temperature
Potential evapotranspiration	Low PET, Medium PET, High PET
SPI 12 / RDI 12	Extreme dry, Severe dry, Moderate dry, Near Normal, Moderate wet, Severe wet, Extreme wet

Table: (A) Annual Rainfall ranges

Linguistic variables	**Ranges**
Very-very low	[0 20 195.4]
Very low	[20.00 195.4 371.2]
Low	[195.4 371.2 546.3]
Medium	[371.2 546.3 722.4]
High	[546.3 722.4 898.1]
Very high	[720.0 895.0 1070]
Very-very high	[898.1 1073 1248]

(B) SPI12 / RDI 12 ranges

Variables	**Ranges**
Extreme dry	[-2.35 -2.08 -1.65]
Severe dry	[-1.65 -1.33 -1.14]
Moderate dry	[-1.14 -0.92 -0.70]
Near Normal	[-0.78 0.07 0.920]
Moderate wet	[0.85 1.06 1.280]
Severe wet	[1.26 1.48 1.700]
Extreme wet	[1.71 1.75 1.800]

The performance of developed model for Banaskantha rainfall and RDI 12 (BK-R-RDI), rainfall and SPI 12 (BK-R-SPI)is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.178.

Table 5.178: Performance Indices of FL Model 1 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-RDI		BK-R-SPI	
	70%	30%	70%	30%
R	0.9677	0.9362	0.9803	0.9690
R^2	0.9364	0.8765	0.9610	0.9389
RMSE	0.2659	0.3667	0.2241	0.2664
MAE	0.2043	0.2438	0.1805	0.1981

It is observed from Table 5.178 that root mean squared error (RMSE) values vary from 0.20 to 0.27 and 0.25 to 0.37 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.95 to 0.98 and 0.93 to 0.96 respectively. Also, mean absolute error (MAE) values vary from 0.18 to 0.20 and 0.19 to 0.25 during training and testing respectively.

Fuzzy Logic Model 2 for Banaskantha district

The Model 2 is combination of annual rainfall, maximum temperature, minimum temperature as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.119 shows the steps implicated in a fuzzy based system. The triangular membership function is selected for input and output parameters which is shown below.

The rainfall range is divided into seven linguistic variables, similar for other parameters viz., maximum temperature, minimum temperature divided into three linguistic variables Also, the ranges of input and output variables is also shown in below Table.

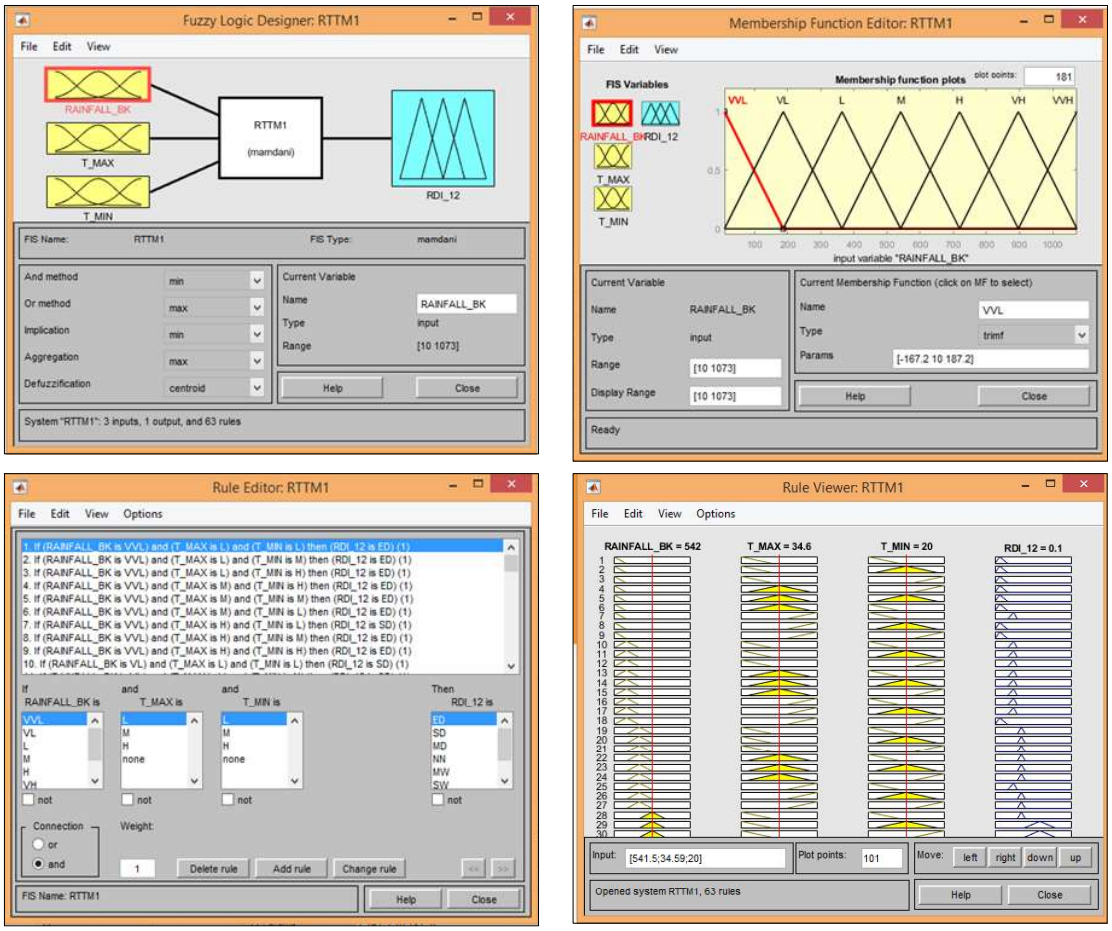


Figure 5.119: Fuzzy Logic structure of Model 2 for Banaskantha district

The linguistic expressions for fuzzy logic model 2 are as shown in below Table 5.179.

(A) Annual Rainfall ranges

Variables	**Ranges**
Very-very low	[-167.2 10.00 187.2]
Very low	[10.00 187.0 364.0]
Low	[187.0 364.0 541.0]
Medium	[364.4 541.3 719.3]
High	[541.3 719.3 896.3]
Very high	[719.3 896.3 1073]
Very-very high	[896.3 1073 1249]

(B) Maximum Temperature ranges

Variables	**Ranges**
Low Temp	[32.41 33.4 34.39]
Medium Temp	[33.59 34.6 35.59]
High Temp	[34.79 35.7 36.77]

(C) Minimum Temperature ranges

Variables	**Ranges**
Low Temp	[17.8 18.8 19.80]
Medium Temp	[19.0 20.0 20.99]
High Temp	[20.2 21.2 22.20]

(D) SPI12 / RDI 12 ranges

Variables	**Ranges**
Extreme dry	[-2.35 -2.08 -1.65]
Severe dry	[-1.65 -1.32 -1.12]
Moderate dry	[-1.10 -0.88 -0.66]
Near Normal	[-0.76 0.10 0.96]
Moderate wet	[0.88 1.10 1.32]
Severe wet	[1.31 1.53 1.75]
Extreme wet	[1.76 1.80 1.85]

The performance of developed model for Banaskantha rainfall, maximum temperature, minimum temperature and RDI 12 (BK-R-T-T-RDI), rainfall maximum temperature, minimum temperature and SPI 12 (BK-R-T-T-SPI) is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.180.

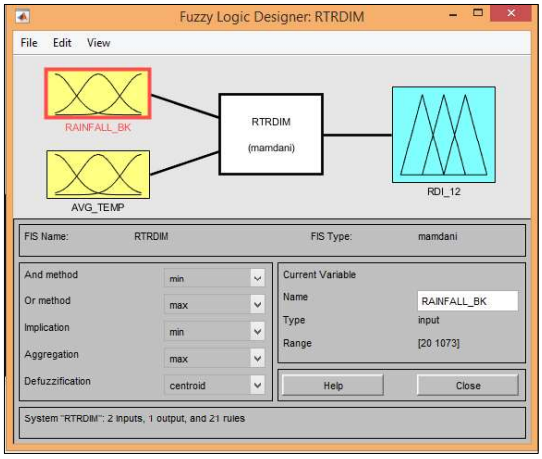
Table 5.180: Performance Indices of FL Model 2 for RDI and SPI for Banaskantha district

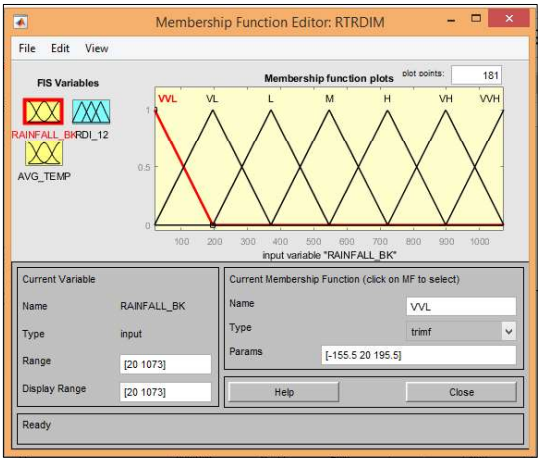
Performance Indices	BK-R-T-T-RDI		BK-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9677	0.9722	0.9680	0.9697
R^2	0.9364	0.9452	0.9370	0.9403
RMSE	0.0005	0.2548	0.2882	0.2605
MAE	0.2043	0.1973	0.2327	0.1923

It is observed from Table 5.180 that root mean squared error (RMSE) values vary from 0.0005 to 0.29 and 0.24 to 0.26 during training and testing respectively. During training and testing, values of correlation coefficient (r) 0.96 and 0.97 respectively. Also, mean absolute error (MAE) values vary from 0.20 to 0.24 and 0.18 to 0.20 during training and testing respectively.

Fuzzy Logic Model 3 for Banaskantha district

The Model 3 is combination of annual rainfall, average temperature as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.120 shows the steps implicated in a fuzzy based system. The triangular membership function is selected for input and output parameters. The rainfall range is divided into seven linguistic variables, similar for other parameters viz., average temperature is divided into three linguistic variables Also, the ranges of input and output variables is also shown in below Table 5.181.





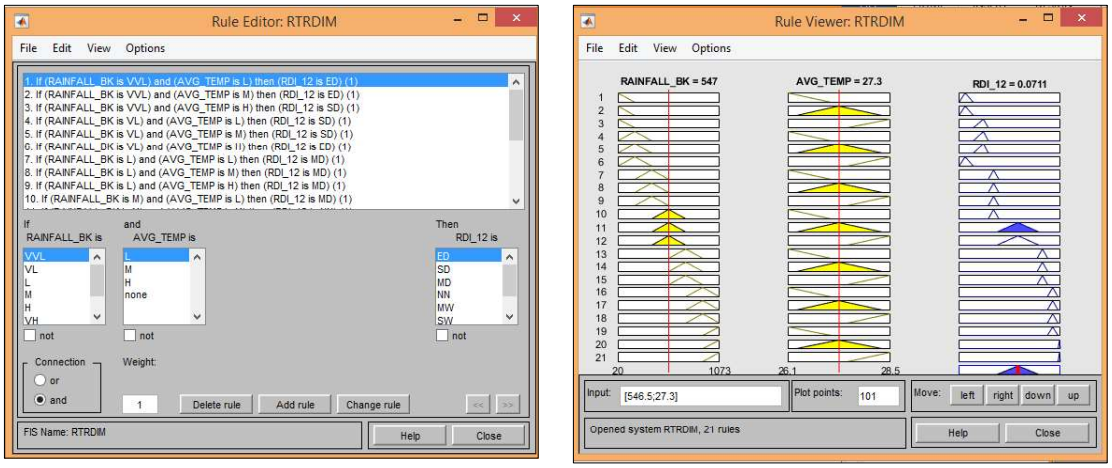


Figure 5.120: Fuzzy Logic structure of Model 3 for Banaskantha district

The linguistic expressions for fuzzy logic model 3 is shown in below Table 5.181

Table 5.181: Linguistic variable for different parameters for Model 3

(A) Annual Rainfall ranges

Variables	**Ranges**
Very-very low	[-155.5 20.0 195.5]
Very low	[20.00 195.5 371.1]
Low	[195.5 371.1 546.3]
Medium	[371.1 546.3 722.8]
High	[546.3 722.8 897.9]
Very high	[722.8 897.9 1073]
Very-very high	[897.9 1073 1247]

(B) Average Temperature ranges

Variables	**Ranges**
Low Temp	[25.09 26.10 27.11]
Medium Temp	[26.30 27.29 28.30]
High Temp	[27.49 28.50 29.51]

(C) SPI12 / RDI 12 ranges

Variables	**Ranges**
Extreme dry	[-2.331 -2.085 -1.751]
Severe dry	[-1.749 -1.337 -1.140]
Moderate dry	[-1.141 -0.924 -0.709]
Near Normal	[-0.785 0.070 0.926]
Moderate wet	[0.850 1.067 1.283]
Severe wet	[1.269 1.487 1.703]
Extreme wet	[1.711 1.756 1.800]

The performance of developed model for Banaskantha rainfall, average temperature and RDI 12 (BK-R-T-RDI), rainfall, average temperature and SPI 12 (BK - R - T – SPI) is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.182.

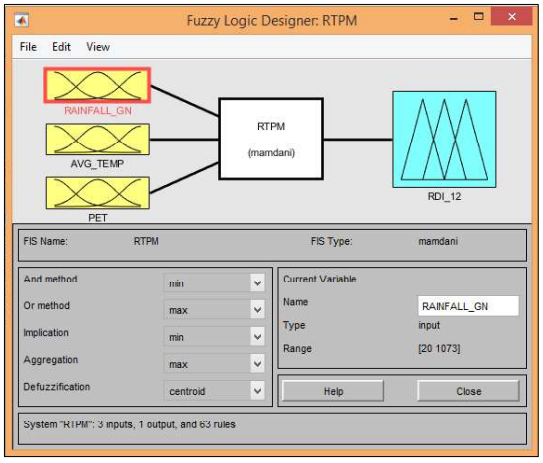
Table 5.182: Performance Indices of FL Model 3 for RDI and SPI for Banaskantha district

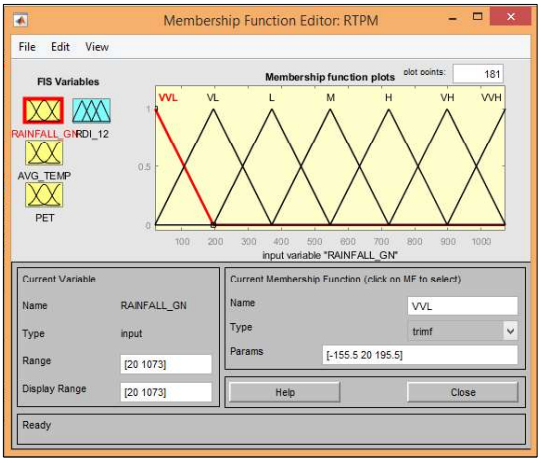
Performance Indices	BK-R-T-RDI		BK - R - T - SPI	
	70%	30%	70%	30%
R	0.9589	0.9390	0.9667	0.9663
R^2	0.9194	0.8816	0.9345	0.9337
RMSE	0.3018	0.3565	0.2928	0.2836
MAE	0.2288	0.2288	0.2266	0.2133

It is observed from Table 5.182 that root mean squared error (RMSE) values vary from 0.28 to 0.30 and 0.27 to 0.36 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.94 to 0.97 and 0.93 to 0.97 respectively. Also, mean absolute error (MAE) values 0.22 and 0.21 during training and testing respectively.

Fuzzy Logic Model 4 for Banaskantha district

The Model 4 is combination of annual rainfall, average temperature and Potential evapotranspiration as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.121 shows the steps implicated in a fuzzy based system. The triangular membership function is selected for input and output parameters. The rainfall range is divided into seven linguistic variables, similar for other parameters viz., average temperature and PET is divided into three linguistic variables Also, the ranges of input and output variables is also shown in below Table 5.183.





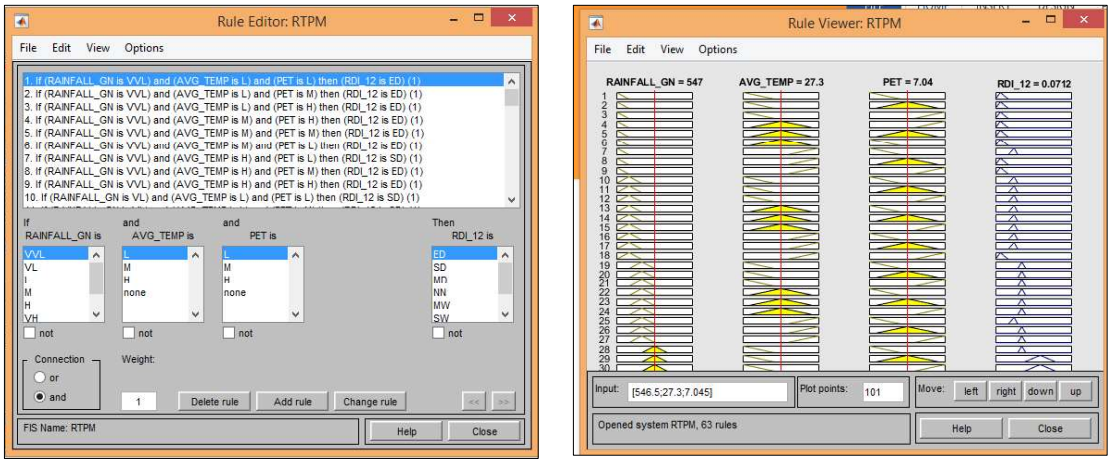


Figure 5.121: Fuzzy Logic structure of Model 4 for Banaskantha district

The linguistic expressions for fuzzy logic Model 4 is shown in below Table 5.183.

Table 5.183: Linguistic variable for different parameters for Model 4

(A) Annual Rainfall ranges

Variables	**Ranges**
Very-very low	[-155.5 20.0 195.5]
Very low	[20.00 195.5 371.1]
Low	[195.5 371.1 546.3]
Medium	[371.1 546.3 722.6]
High	[546.3 722.6 898.0]
Very high	[722.6 898.0 1073]
Very-very high	[898.0 1073 1247]

(B) Average Temperature ranges

Variables	**Ranges**
Low Temp	[25.09 26.1 27.11]
Medium Temp	[26.29 27.3 28.31]
High Temp	[27.49 28.5 29.51]

(C) Potential Evapotranspiration ranges

Variables	**Ranges**
Low PET	[6.85 6.94 7.02]
Medium PET	[6.95 7.04 7.13]
High PET	[7.06 7.15 7.23]

(D) SPI12 / RDI 12 ranges

Variables	**Ranges**

Extreme dry	[-2.35 -2.08 -1.65]
Severe dry	[-1.65 -1.33 -1.14]
Moderate dry	[-1.14 -0.92 -0.70]
Near Normal	[-0.78 0.07 0.92]
Moderate wet	[0.84 1.06 1.27]
Severe wet	[1.27 1.48 1.70]
Extreme wet	[1.71 1.75 1.80]

The performance of developed model for rainfall, average temperature, PET and RDI 12 (BK-R-T-P-RDI), rainfall, average temperature, PET and SPI 12(BK-R-T-P-SPI) is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.184.

Table 5.184: Performance Indices of FL Model 4 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-T-P-RDI		BK-R-T-P-SPI	
	70%	30%	70%	30%
R	0.9635	0.9412	0.9754	0.9709
R^2	0.9284	0.8859	0.9515	0.9426
RMSE	0.2896	0.3523	0.2514	0.2612
MAE	0.2272	0.2337	0.2046	0.2031

It is observed from Table 5.184 that root mean squared error (RMSE) values vary from 0.24 to 0.29 and 0.25 to 0.35 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.95 to 0.98 and 0.93 to 0.97 respectively. Also, mean absolute error (MAE) values vary from 0.20 to 0.22 and 0.20 to 0.24 during training and testing respectively.

Fuzzy Logic Model 5 for Banaskantha district

The Model 5 is combination of RDI 9, RDI 10 and RDI 11 previous time steps (t-1) data as input data and output as RDI 12. Similarly, for SPI 9, SPI 10 and SPI 11 previous time steps (t-1) data as input and SPI 12 separately. Below Figure 5.122 shows the steps implicated in a fuzzy based system. The triangular membership function is selected for input and output parameters which is shown below.

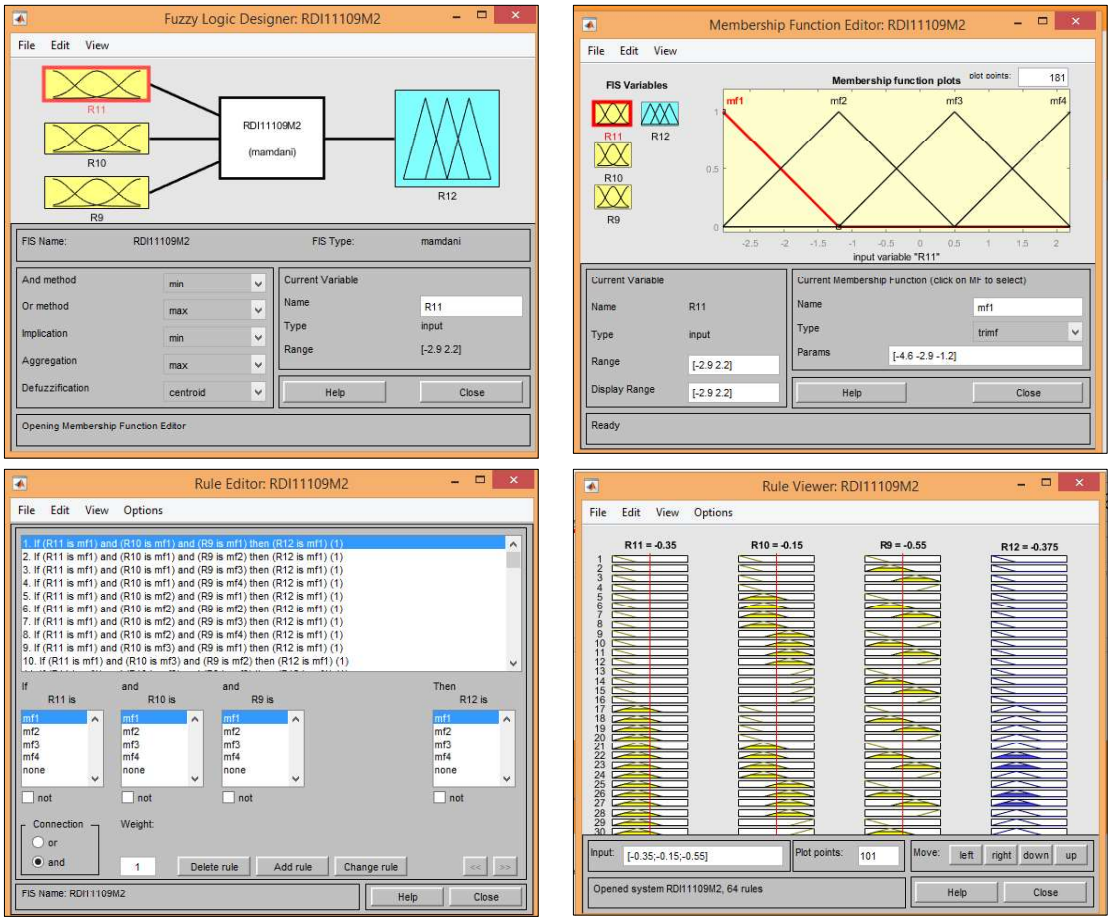


Figure 5.122: Fuzzy Logic structure of Model 5 for Banaskantha district

The performance of developed model for RDI9, RDI 10 RDI 11 and RDI 12, SPI 9, SPI 10, SPI 11 and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.185.

Table 5.185: Performance Indices of FL Model 5 for RDI and SPI for Banaskantha district

Performance Indices	BK - RDI 9 10 11 - RDI		BK - SPI 9 10 11 - SPI	
	70%	30%	70%	30%
R	0.9016	0.9498	0.9015	0.9390
R^2	0.8129	0.9022	0.8127	0.8817
RMSE	0.4389	0.3380	0.4454	0.3640
MAE	0.3550	0.2901	0.3576	0.3048

It is observed from Table 5.185 that root mean squared error (RMSE) values vary from 0.42 to 0.46 and 0.32 to 0.37 during training and testing respectively. During training and testing, values of correlation coefficient (r) 0.90 respectively. Also, mean absolute error (MAE) values vary from 0.34 to 0.36 and 0.28 to 0.30 during training and testing respectively.

Below Figures 5.123, 5.124 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Banaskantha district.

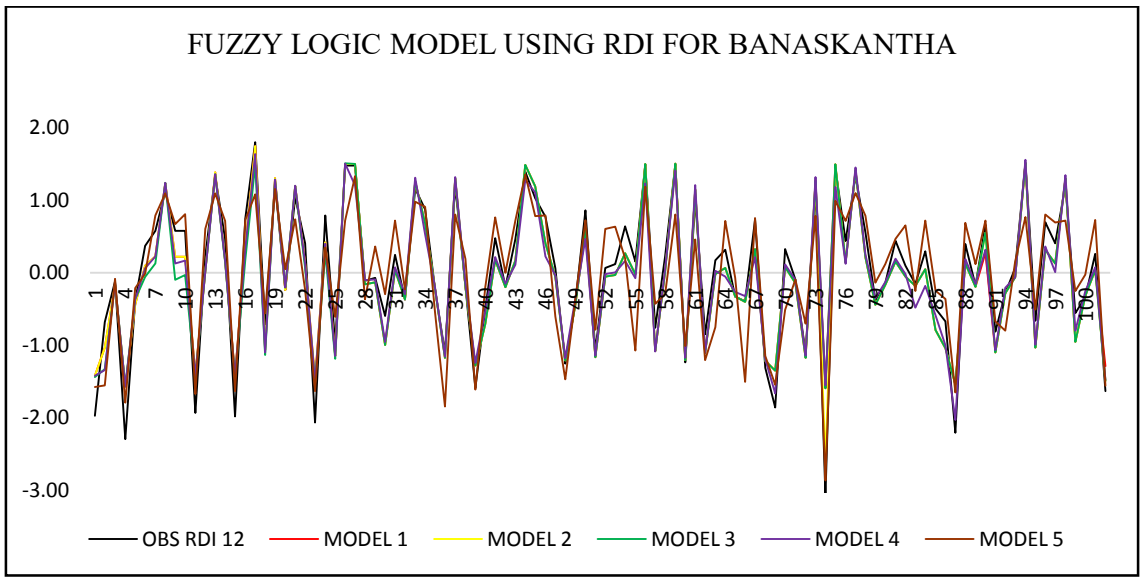


Figure 5.123: Graphical representation of Fuzzy Logic Models using RDI for Banaskantha

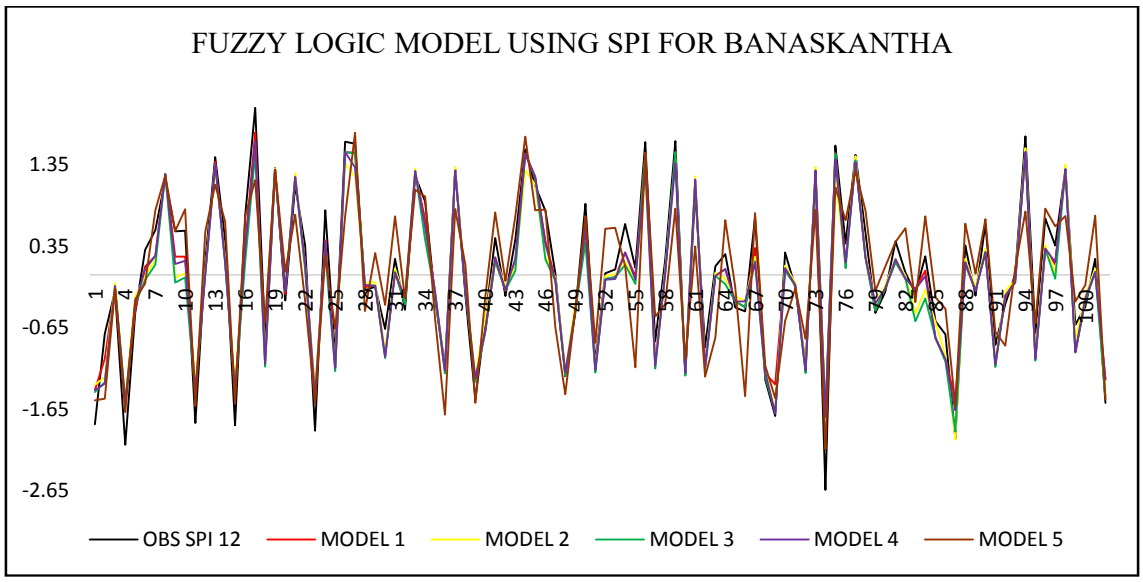


Figure 5.124: Graphical representation of Fuzzy Logic Models using SPI for Banaskantha

The above different models was developed with combinations of different meteorological variables (Rainfall, Max. temperature, Min. temperature, Avg. temperature, Potential evapotranspiration), SPI 9, SPI 10, SPI 11 and RDI 9, RDI 10, RDI 11 were used as input data for estimating the drought severity estimation. The

results of the predictability of fuzzy logic models are compared with those of derived values of SPI and RDI which are obtain from DrinC tool.

Five Fuzzy Logic Models i.e., FL Model 1, FL Model 2, FL Model 3, FL Model 4 and FL Model 5 have been developed considering data set of 70%-30%. All Fuzzy Logic Model developed with different numbers of linguistic variables for each input and output and for different models. To identify the most appropriate model, different models were formulated and tested using different performance measures the best Fuzzy Logic Model has been analyzed on basis of various performance indices, i.e., the Root Mean Squared Error, Co-efficient of correlation, Co-efficient of determination and Mean Absolute Error.

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 2 with the RMSE of 0.0002 by training and 0.2548 by validation of the model, and co efficient of determination by training of the model is 0.9364 and by validation of the model is 0.9452 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall and temperature given. For estimation of RDI both rainfall and PET needed so here Model 2 is developed using combination of both rainfall and temperature data which gives accurate results.

Amongst all five models, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2241 by training and 0.2664 by validation of the model, and co-efficient of determination by training of the model is 0.9610 and by validation of the model is 0.9389 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given. For estimation of SPI only rainfall is required and developed model is also giving same results.

Finally, the developed models were found to be suitable to make effective extreme point predictions.

Fuzzy Logic Models for Gandhinagar district

The following Tables 5.186, 5.187, 5.188, 5.189 and 5.189 shows the results of Gandhinagar district for development of drought forecasting models for RDI and SPI.

Table 5.186: Performance Indices of FL Model 1 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-RDI		GN-R-SPI	
	70%	30%	70%	30%
R	0.9770	0.9806	0.9828	0.9833
R^2	0.9546	0.9616	0.9659	0.9669

RMSE	0.2434	0.2379	0.2436	0.2533
MAE	0.2009	0.1889	0.1780	0.2038

Table 5.187: Performance Indices of FL Model 2 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-T-RDI		GN-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9651	0.9822	0.9695	0.9835
R^2	0.9315	0.9647	0.9400	0.9673
RMSE	0.0000	0.2372	0.2640	0.2404
MAE	0.2399	0.1903	0.2062	0.1871

Table 5.188: Performance Indices of FL Model 3 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-RDI		GN-R-T-SPI	
	70%	30%	70%	30%
R	0.9618	0.9748	0.9692	0.9780
R^2	0.9250	0.9503	0.9393	0.9565
RMSE	0.3042	0.2629	0.2822	0.2703
MAE	0.2562	0.2100	0.2277	0.2161

Table 5.189 Performance Indices of FL Model 4 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-P -RDI		GN-R-T-P -SPI	
	70%	30%	70%	30%
R	0.9677	0.9770	0.9707	0.9805
R^2	0.9365	0.9545	0.9422	0.9613
RMSE	0.2852	0.2651	0.2655	0.2531
MAE	0.2337	0.2097	0.2029	0.1946

Table 5.190: Performance Indices of FL Model 5 for RDI and SPI for Gandhinagar district

Performance Indices	GN - RDI 9 10 11 - RDI		GN - SPI 9 10 11 - SPI	
	70%	30%	70%	30%
R	0.8795	0.9139	0.8736	0.9096
R^2	0.7734	0.8352	0.7632	0.8273
RMSE	0.4839	0.4335	0.4996	0.4193
MAE	0.3937	0.3584	0.3941	0.3204

Below Figure shows 5.125 and 5.126 the graphical representation of comparisons between developed model and observed values for RDI and SPI for Gandhinagar district.

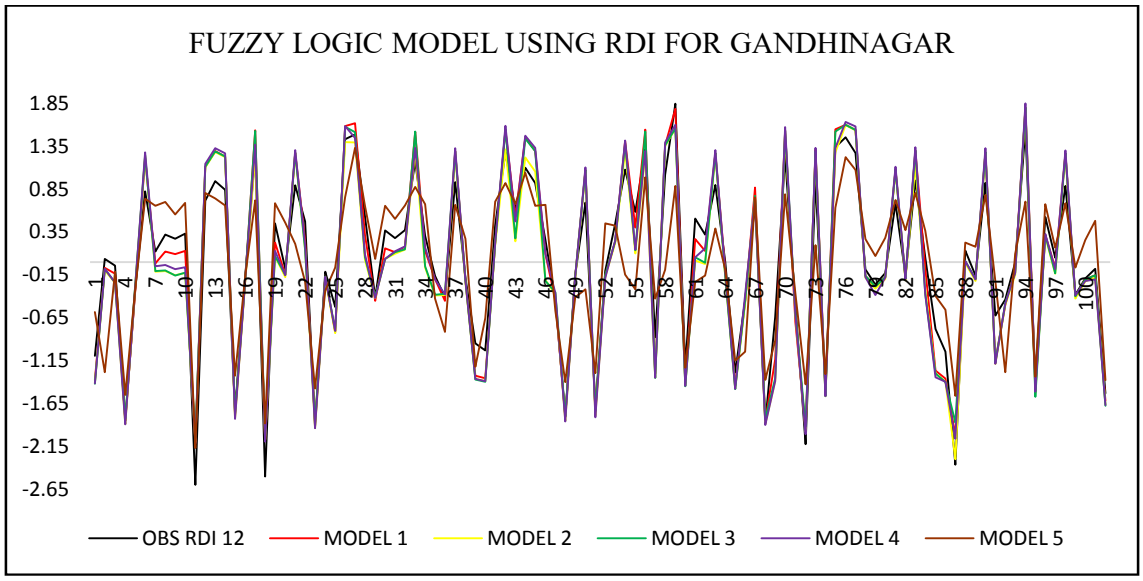


Figure 5.125: Graphical representation of Fuzzy Logic Models using RDI for Gandhinagar

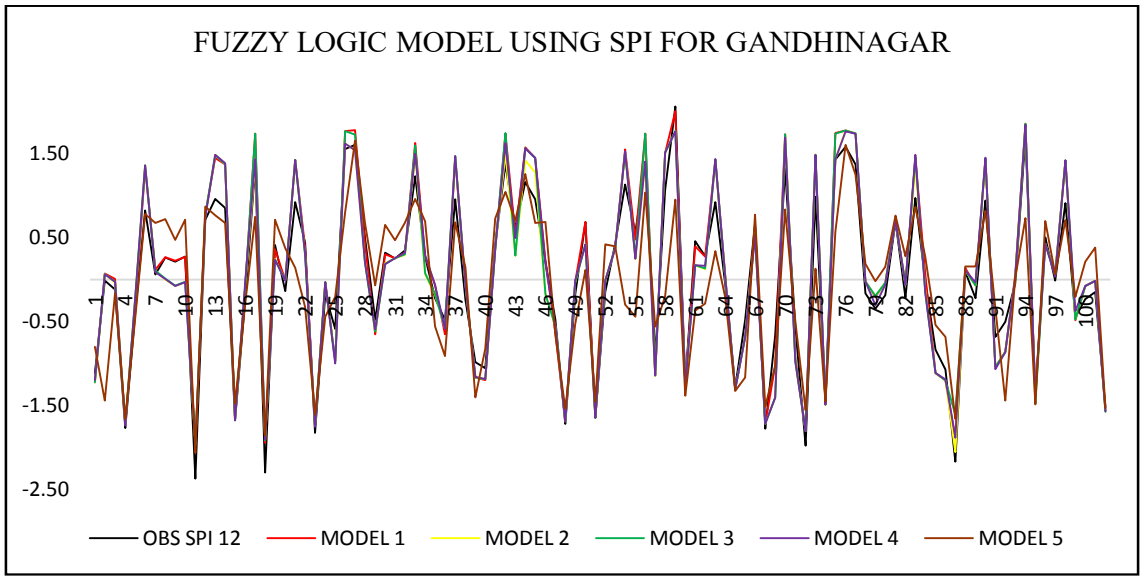


Figure 5.126: Graphical representation of Fuzzy Logic Models using SPI for Gandhinagar

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2434 by training and 0.2379 by validation of the model, and co efficient of determination by training of the model is 0.9546 and by validation of the model is 0.9616 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models of Gandhinagar district, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2436 by training and 0.2533 by

validation of the model, and co efficient of determination by training of the model is 0.9659 and by validation of the model is 0.9669 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given. Finally, the developed models were found to be suitable to make effective extreme point predictions.

Fuzzy Logic Models for Mehsana district

The following Tables 5.191, 5.192, 5.193, 5.194 and 5.195 shows the results of Mehsana district for development of drought forecasting models for RDI and SPI.

Table 5.191: Performance Indices of FL Model 1 for RDI and SPI for Mehsana district

Performance Indices	ME-R-RDI		ME-R-SPI	
	70%	30%	70%	30%
R	0.9781	0.9785	0.9849	0.9879
R^2	0.9567	0.9574	0.9700	0.9760
RMSE	0.2698	0.2658	0.2658	0.2699
MAE	0.2421	0.2348	0.1907	0.2073

Table 5.192: Performance Indices of FL Model 2 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-T-RDI		ME-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9676	0.9751	0.9745	0.9834
R^2	0.9363	0.9509	0.9496	0.9670
RMSE	0.0000	0.2820	0.2560	0.2608
MAE	0.2771	0.2422	0.1985	0.2046

Table 5.193: Performance Indices of FL Model 3 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-RDI		ME-R-T-SPI	
	70%	30%	70%	30%
R	0.9664	0.9693	0.9727	0.9696
R^2	0.9339	0.9395	0.9461	0.9402
RMSE	0.2893	0.2788	0.2773	0.3156
MAE	0.2425	0.2123	0.2160	0.2366

Table 5.194: Performance Indices of FL Model 4 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-P -RDI		ME-R-T-P -SPI	
	70%	30%	70%	30%
R	0.9717	0.9707	0.9785	0.9851

R^2	0.9442	0.9422	0.9575	0.9704
RMSE	0.2684	0.2707	0.2636	0.2712
MAE	0.2192	0.2096	0.1928	0.2072

Table 5.195: Performance Indices of FL Model 5 for RDI and SPI for Mehsana district

Performance Indices	ME - RDI 9 10 11 - RDI		ME - SPI 9 10 11 - SPI	
	70%	30%	70%	30%
R	0.8694	0.9004	0.8776	0.9086
R^2	0.7559	0.8108	0.7701	0.8255
RMSE	0.5527	0.4466	0.4864	0.4453
MAE	0.4384	0.3348	0.3940	0.3669

Below Figure 5.127 and 5.128 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Mehsana district.

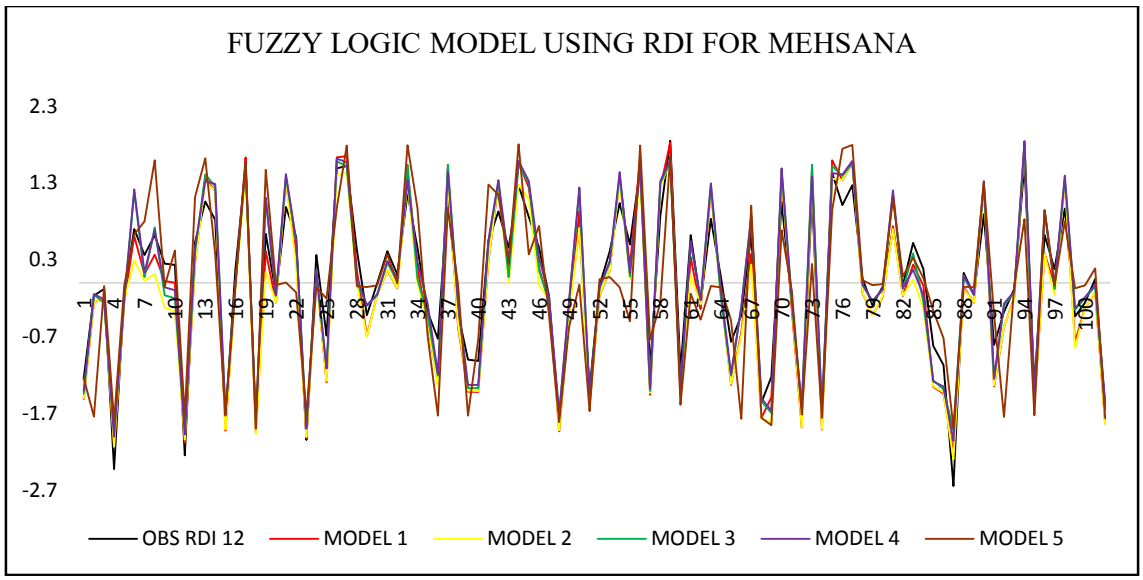


Figure 5.127: Graphical representation of Fuzzy Logic Models using RDI for Mehsana

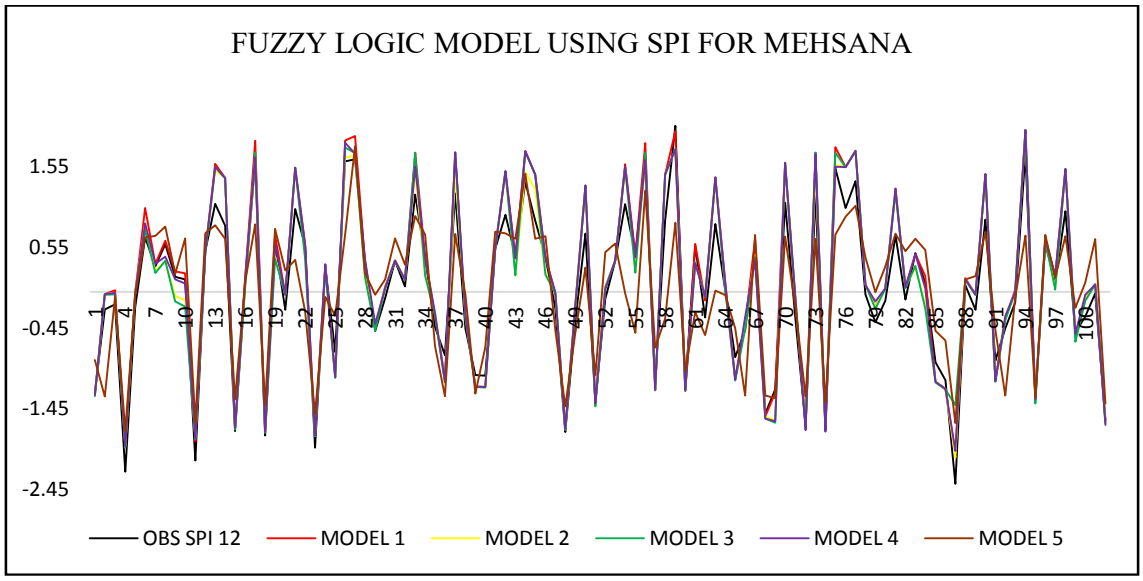


Figure 5.128: Graphical representation of Fuzzy Logic Models using SPI for Mehsana

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2698 by training and 0.2658 by validation of the model, and co efficient of determination by training of the model is 0.9567 and by validation of the model is 0.9574 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2658 by training and 0.2699 by validation of the model, and co efficient of determination by training of the model is 0.9700 and by validation of the model is 0.9760 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Fuzzy Logic Models for Patan district

The following Tables 5.196, 5.197, 5.198, 5.199 and 5.200 shows the results of Patan district for development of drought forecasting models for RDI and SPI.

Table 5.196: Performance Indices of FL Model 1 for RDI and SPI for Patan district

Performance Indices	PA-R-RDI		PA -R-SPI	
	70%	30%	70%	30%
R	0.9753	0.9671	0.9828	0.9847
R^2	0.9513	0.9353	0.9659	0.9697
RMSE	0.2763	0.2682	0.2456	0.2061
MAE	0.2416	0.2255	0.1828	0.1605

Table 5.197: Performance Indices of FL Model 2 for RDI and SPI for Patan district

Performance Indices	PA -R-T-T-RDI		PA -R-T-T-SPI	
	70%	30%	70%	30%
R	0.9683	0.9687	0.9750	0.9837
R^2	0.9375	0.9384	0.9507	0.9677
RMSE	0.0000	0.2667	0.2326	0.1866
MAE	0.2303	0.2167	0.1916	0.1582

Table 5.198: Performance Indices of FL Model 3 for RDI and SPI for Patan district

Performance Indices	PA -R-T-RDI		PA -R-T-SPI	
	70%	30%	70%	30%
R	0.9672	0.9602	0.9753	0.9793
R^2	0.9354	0.9219	0.9512	0.9589
RMSE	0.2980	0.2960	0.2423	0.2151
MAE	0.2500	0.2470	0.2014	0.1735

Table 5.199: Performance Indices of FL Model 4 for RDI and SPI for Patan district

Performance Indices	PA -R-T-P -RDI		PA -R-T-P -SPI	
	70%	30%	70%	30%
R	0.9742	0.9675	0.9806	0.9849
R^2	0.9491	0.9361	0.9616	0.9700
RMSE	0.2749	0.2647	0.2289	0.1992
MAE	0.2267	0.2172	0.1771	0.1582

Table 5.200: Performance Indices of FL Model 5 for RDI and SPI for Patan district

Performance Indices	PA - RDI 9 10 11 - RDI		PA - SPI 9 10 11 - SPI	
	70%	30%	70%	30%
R	0.9072	0.9532	0.9043	0.9390
R^2	0.8231	0.9085	0.8178	0.8817
RMSE	0.4279	0.3400	0.4412	0.3622
MAE	0.3370	0.2974	0.3440	0.3087

Below Figure 5.129 and 5.130 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Patan district.

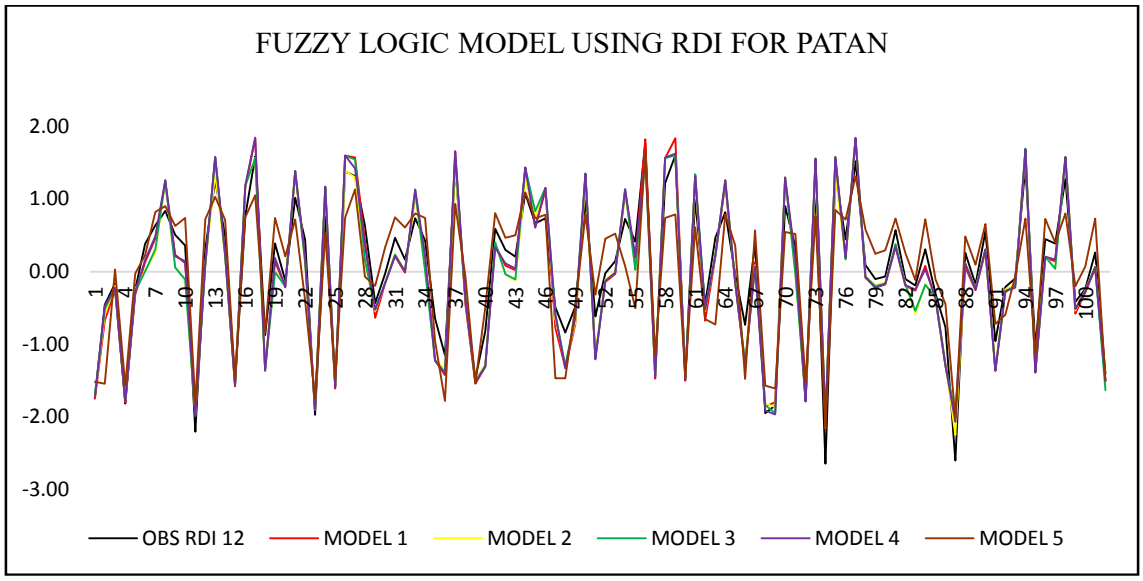


Figure 5.129: Graphical representation of Fuzzy Logic Models using RDI for Patan

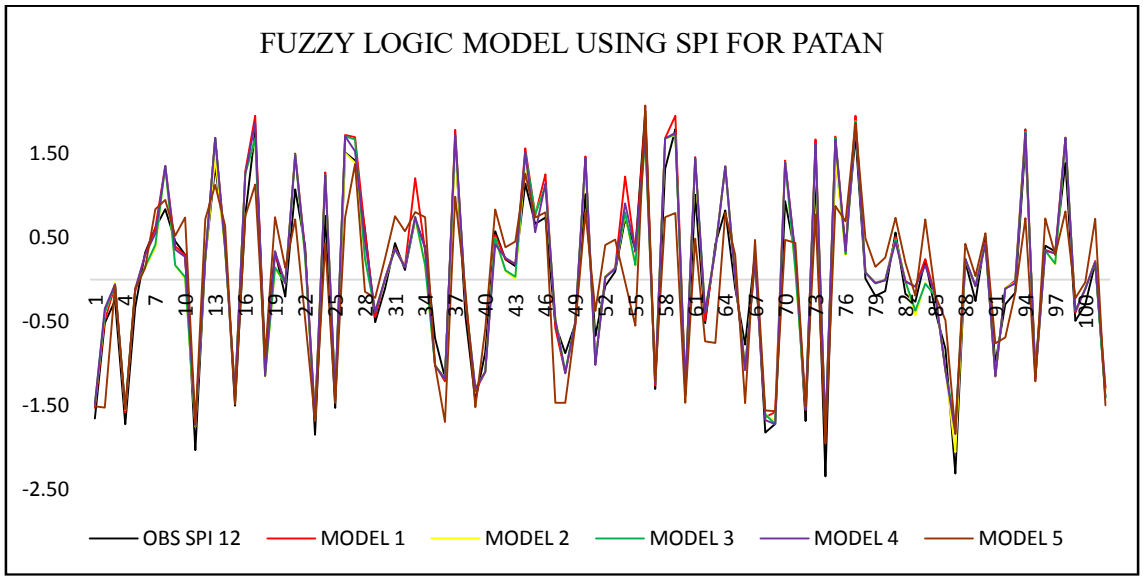


Figure 5.130: Graphical representation of Fuzzy Logic Models using SPI for Patan

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 4 with the RMSE of 0.2749 by training and 0.2647 by validation of the model, and co efficient of determination by training of the model is 0.9491 and by validation of the model is 0.9361 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall, average temp and PET data given.

Amongst all five models, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 4 with the RMSE of 0.2289 by training and 0.1992 by validation of the model, and co efficient of determination by training of the model is 0.9616 and by validation of the model is 0.9700 which are nearer to 1, which may be used for prediction of

future drought conditions for the area considered under study for any amount of rainfall, average temp and PET data given.

Fuzzy Logic Models for Sabarkantha district

The following Tables 5.201, 5.202, 5.203, 5.204 and 5.205 shows the results of Sabarkantha district for development of drought forecasting models for RDI and SPI.

Table 5.201: Performance Indices of FL Model 1 for RDI and SPI for Sabarkantha district

Performance Indices	SK-R-RDI		SK -R-SPI	
	70%	30%	70%	30%
R	0.9768	0.9748	0.9795	0.9755
R^2	0.9540	0.9503	0.9594	0.9516
RMSE	0.3637	0.3505	0.2762	0.2819
MAE	0.2938	0.2796	0.2219	0.2197

Table 5.202: Performance Indices of FL Model 2 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-T-RDI		SK -R-T-T-SPI	
	70%	30%	70%	30%
R	0.9683	0.9723	0.9730	0.9726
R^2	0.9376	0.9453	0.9467	0.9460
RMSE	0.0000	0.3265	0.2864	0.2899
MAE	0.2781	0.2659	0.2319	0.2219

Table 5.203: Performance Indices of FL Model 3 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-RDI		SK -R-T-SPI	
	70%	30%	70%	30%
R	0.9634	0.9737	0.9684	0.9738
R^2	0.9282	0.9481	0.9378	0.9483
RMSE	0.3586	0.3160	0.3144	0.2904
MAE	0.2863	0.2582	0.2720	0.2248

Table 5.204: Performance Indices of FL Model 4 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-P -RDI		SK -R-T-P -SPI	
	70%	30%	70%	30%
R	0.9705	0.9729	0.9736	0.9730
R^2	0.9418	0.9465	0.9480	0.9467
RMSE	0.3353	0.3113	0.2822	0.2825
MAE	0.2546	0.2501	0.2274	0.2192

Table 5.205: Performance Indices of FL Model 5 for RDI and SPI for Sabarkantha district

Performance Indices	SK - RDI 9 10 11 - RDI		SK - SPI 9 10 11 - SPI	
	70%	30%	70%	30%
R	0.8913	0.9209	0.8854	0.9177
R^2	0.7945	0.8480	0.7840	0.8421
RMSE	0.4676	0.3865	0.4829	0.3862
MAE	0.3629	0.3261	0.3777	0.3221

Below Figure 5.131 and 5.132 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Sabarkantha district.

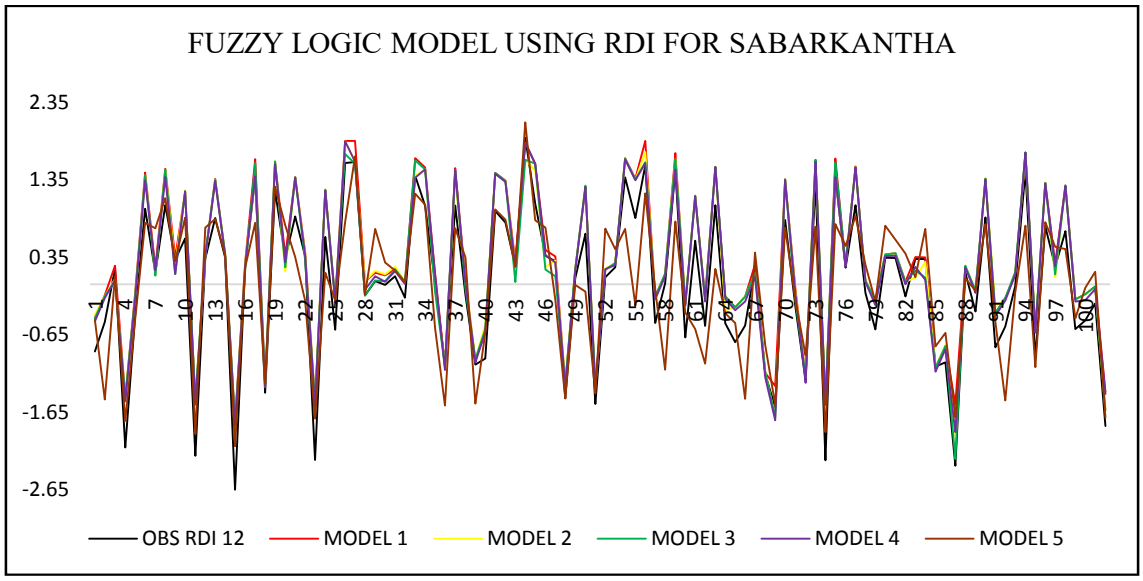


Figure 5.131: Graphical representation of Fuzzy Logic Models using RDI for Sabarkantha

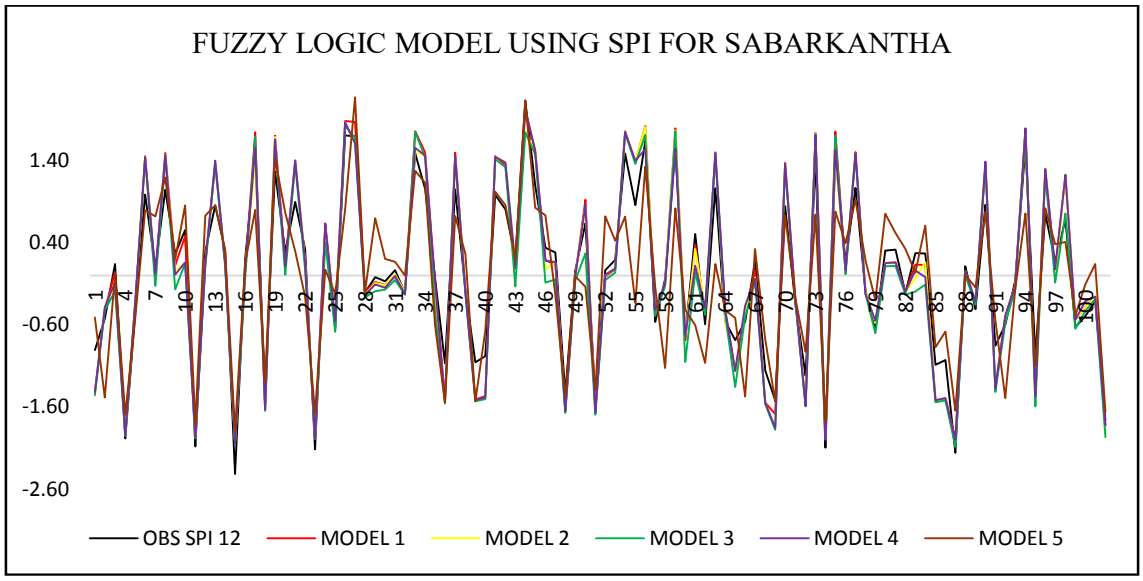


Figure 5.132: Graphical representation of Fuzzy Logic Models using RDI for Sabarkantha

Amongst all five models, the best Fuzzy Logic model for RDI is Fuzzy Logic (FL) Model 4 with the RMSE of 0.3353 by training and 0.3113 by validation of the model, and co-efficient of determination by training of the model is 0.9418 and by validation of the model is 0.9465 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall, average temp and PET data given.

Amongst all five models of Sabarkantha district, the best Fuzzy Logic model for SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2762 by training and 0.2819 by validation of the model, and co efficient of determination by training of the model is 0.9594 and by validation of the model is 0.9516 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

ANFIS approach for RDI and SPI

There are no fixed rules for developing an ANFIS, even though a general framework can be followed based on previous successful applications in engineering. The selection of proper input and output data possess the prime importance and needs to be selected carefully. Here the development of drought forecasting model was done using rainfall and other data as input and drought indices data as output.

ANFIS Architecture Mamdani (1974) documented that the fuzzy inference system (FIS) consists of four major components. This study aimed to establish a new soft computing model for drought monitoring and assessment. ANFIS has been effectively utilized for modelling and predicting complex hydrologic systems and

processes. This model combines the learning skills of ANNs and the inference system of FL models.

ANFIS Model 1 for Banaskantha district

The Model 1 is combination of annual rainfall as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.133 shows a simplified adaptive neuro-fuzzy inference system for Model 1. The developed architecture includes one input membership functions, one output membership functions, and 7 fuzzy rules.

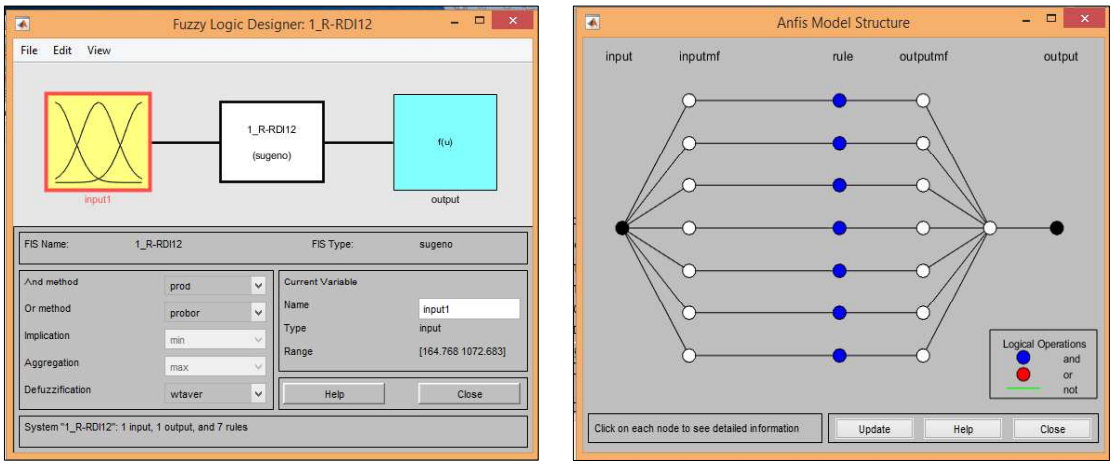


Figure 5.133: ANFIS structure of Model 1 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.206.

Table 5.206: Performance Indices of ANFIS Model 1 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-RDI		BK-R-SPI	
	70%	30%	70%	30%
R	0.9730	0.9905	1.0000	0.9952
R^2	0.9467	0.9810	0.9999	0.9904
RMSE	0.2336	0.1534	0.0096	0.1061
MAE	0.0398	0.0392	0.0058	0.0240

It is observed from Table 5.206 that root mean squared error (RMSE) values vary from 0.23 to 0.0096 and 0.1534 to 0.1061 during training and testing respectively. During training and testing, values of correlation coefficient (r) vary from 0.9730 to 1.00 and 0.9905 to 1.00 respectively. Also, mean absolute error (MAE) values vary from 0.0398 to 0.006 and 0.035 to 0.024 during training and testing respectively.

ANFIS Model 2 for Banaskantha district

The Model 2 is combination of annual rainfall, maximum temperature, minimum temperature as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.134 shows a simplified adaptive neuro-fuzzy inference system for model 2. The ANFIS model includes one input and an output. The developed architecture includes one input membership functions, one output membership functions, and 27 fuzzy rules.

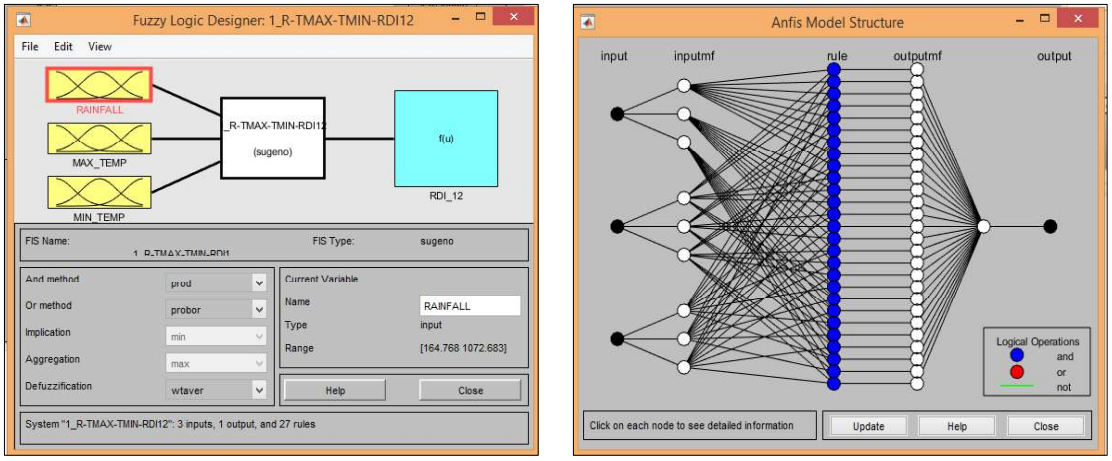


Figure 5.134: ANFIS structure of Model 2 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table5.207.

Table 5.207: Performance Indices of ANFIS Model 2 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-T-T-RDI		BK-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9940	0.9834	0.9976	0.9919
R^2	0.9881	0.9670	0.9951	0.9839
RMSE	0.0000	0.1824	0.0705	0.1253
MAE	0.0839	0.1357	0.0554	0.0919

ANFIS Model 3 for Banaskantha district

The Model 3 is combination of annual rainfall, average temperature as input data and output as RDI 12 and SPI 12 separately. Below Figure 12.18 shows a simplified adaptive neuro-fuzzy inference system for model 3. The ANFIS model includes one input and an output. The simplified ANFIS model includes two input data and one output data. The developed architecture includes two input membership functions, one output membership functions, and 9 fuzzy rules.

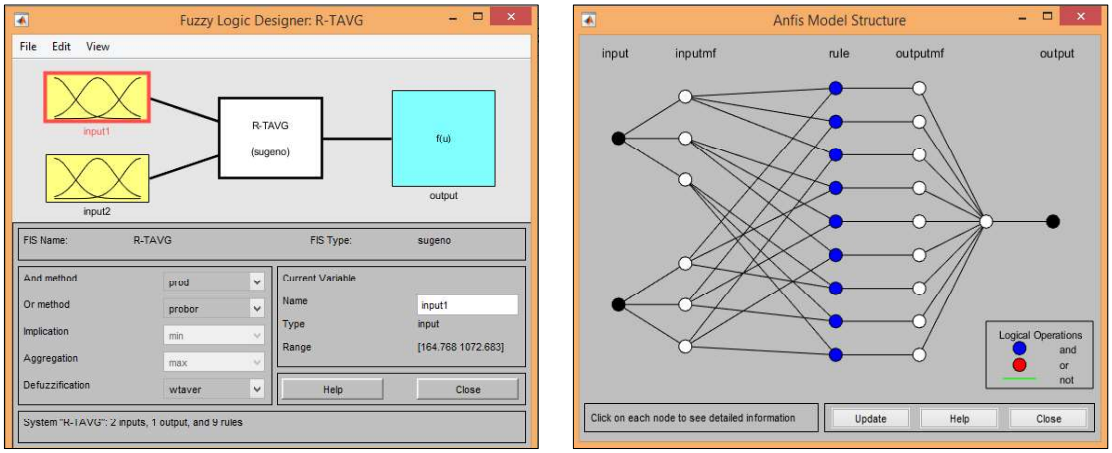


Figure 5.135: ANFIS structure of Model 3 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.208.

Table 5.208: Performance Indices of ANFIS Model 3 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-T-RDI		BK - R - T - SPI	
	70%	30%	70%	30%
R	0.9998	0.8946	0.9972	0.9862
R^2	0.9997	0.8003	0.9945	0.9726
RMSE	0.0176	0.4550	0.0750	0.1647
MAE	0.0101	0.2177	0.0573	0.0988

ANFIS Model 4 for Banaskantha district

The Model 4 is combination of annual rainfall, average temperature, potential evapotranspiration as input data and output as RDI 12 and SPI 12 separately. Below Figure 5.136 shows a simplified adaptive neuro-fuzzy inference system for model 4. The ANFIS model includes one input and an output. The simplified ANFIS model includes three input data and one output data. The developed architecture includes one input membership functions, one output membership functions, and 27 fuzzy rules.

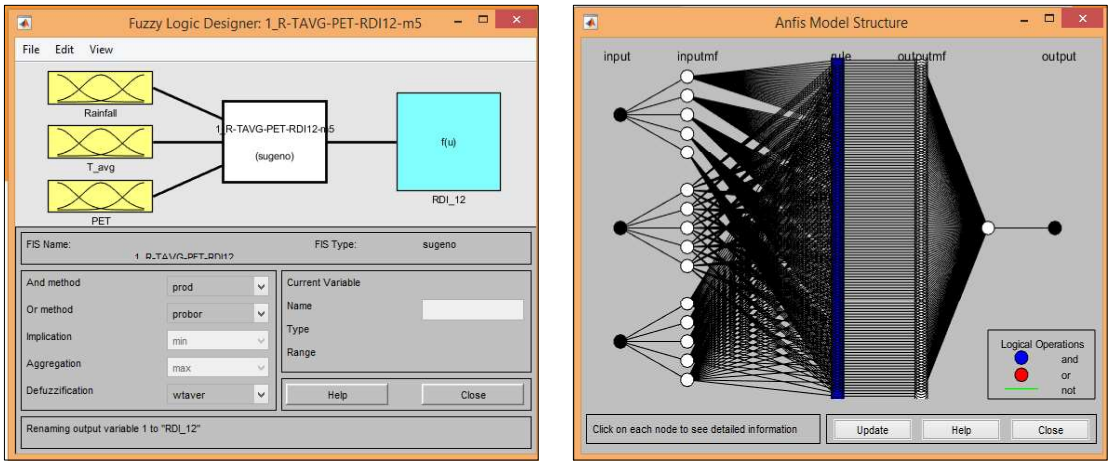


Figure 5.136: ANFIS structure of Model 4 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table 5.209.

Table 5.209: Performance Indices of ANFIS Model 4 for RDI and SPI for Banaskantha district

Performance Indices	BK-R-T-P-RDI		BK - R-T-P - SPI	
	70%	30%	70%	30%
R	0.9950	0.8431	0.9982	0.9661
R^2	0.9899	0.7108	0.9964	0.9333
RMSE	0.1004	0.5673	0.0602	0.2527
MAE	0.0727	0.2803	0.0432	0.1459

ANFIS Model 5 for Banaskantha district

The Model 5 is combination of RDI 9, RDI10 and RDI 11 as input data and output as RDI 12 & SPI 9, SPI 10 and SPI 11 as input data and output as SPI 12. Below Figure 5.137 shows a simplified adaptive neuro-fuzzy inference system for model 5. The simplified ANFIS model includes three input data and one output data. The developed architecture includes three input membership functions, one output membership functions, and 27 fuzzy rules.

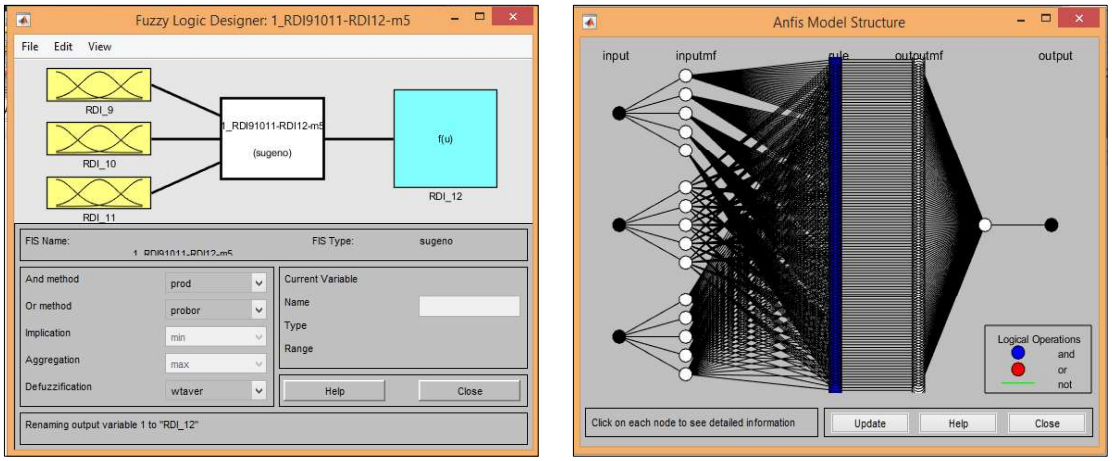


Figure 5.137: ANFIS structure of Model 5 for Banaskantha district

The performance of developed model for rainfall and RDI 12, rainfall and SPI 12 is evaluated by applying various statistical indices as explained and the results is presented in below Table5.210.

Table 5.210: Performance Indices of ANFIS Model 5 for RDI and SPI for Banaskantha district

Performance Indices	BK - RDI 9 10 11 - RDI 12		BK - SPI 9 10 11 - SPI 12	
	70%	30%	70%	30%
R	0.9388	0.5909	0.9461	0.5789
R^2	0.8813	0.3491	0.8950	0.3352
RMSE	0.3446	0.8701	0.3273	1.0040
MAE	0.2595	0.4951	0.2570	0.5500

Below Figure 5.138 and 5.139 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Banaskantha district.

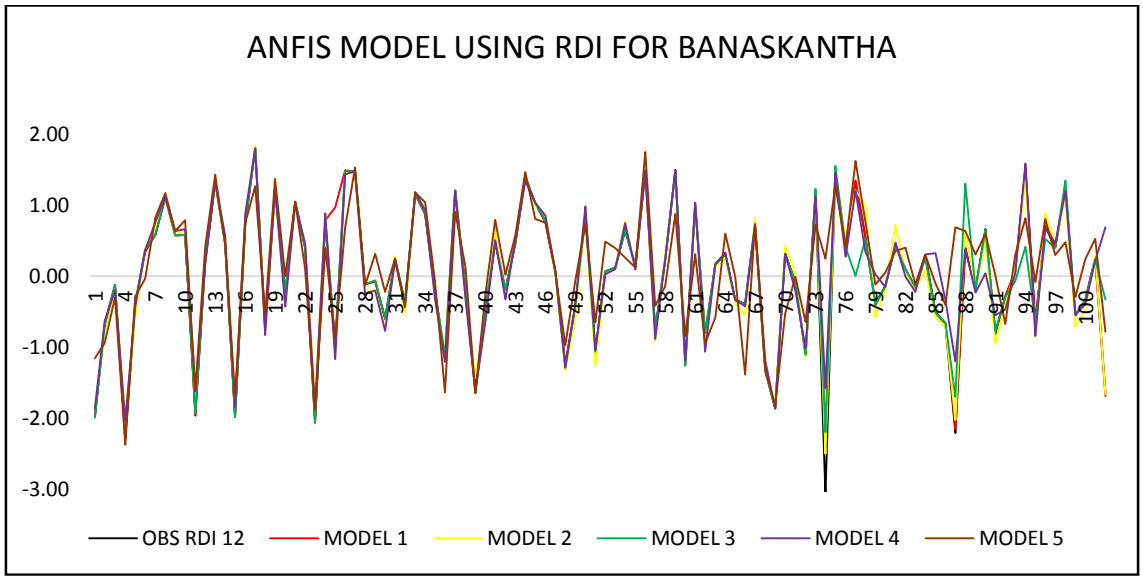


Figure 5.138: Graphical representation of ANFIS Models using RDI for Banaskantha

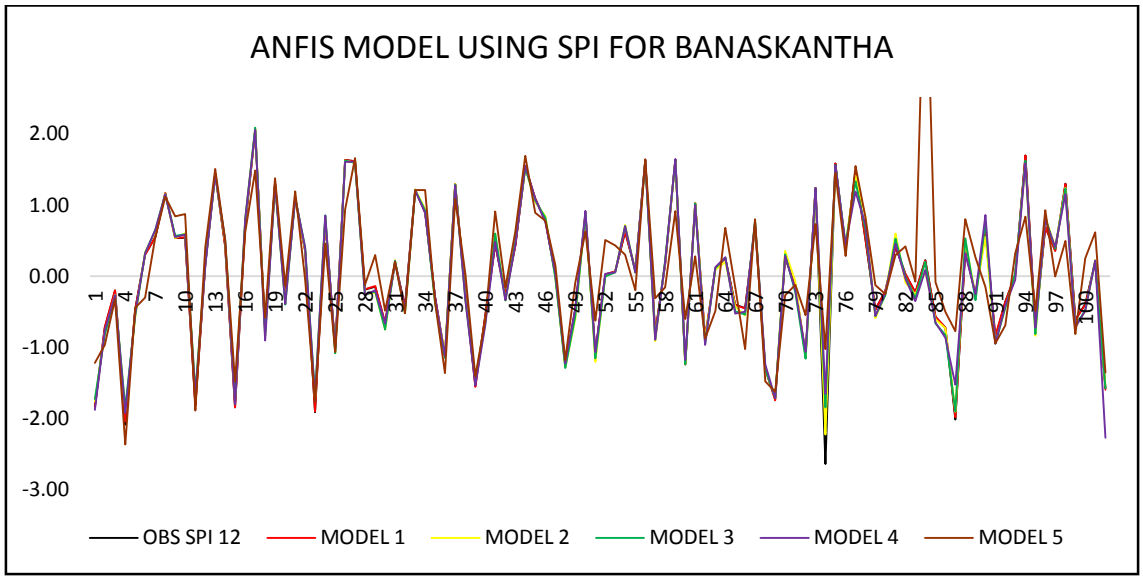


Figure 5.139: Graphical representation of ANFIS Models using SPI for Banaskantha

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.2336 by training and 0.1534 by validation of the model, and co efficient of determination by training of the model is 0.9467 and by validation of the model is 0.9810 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.0096 by training and 0.1061 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 0.9904 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

ANFIS Models for Gandhinagar district

The following Tables 5.211, 5.212, 5.213, 5.214 and 5.215 shows the results of Gandhinagar district for development of drought forecasting models for RDI and SPI.

Table 5.211: Performance Indices of ANFIS Model 1 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-RDI		GN-R-SPI	
	70%	30%	70%	30%
R	0.9998	0.9999	1.0000	1.0000
R^2	0.9997	0.9997	0.9999	1.0000
RMSE	0.0188	0.0163	0.0100	0.0060
MAE	0.0143	0.0126	0.0062	0.0045

Table 5.212: Performance Indices of ANFIS Model 2 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-T-RDI		GN-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9965	0.9781	0.9982	0.9957
R^2	0.9930	0.9568	0.9965	0.9915
RMSE	0.0000	0.2121	0.0592	0.0930
MAE	0.0609	0.1491	0.0436	0.0764

Table 5.213: Performance Indices of ANFIS Model 3 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-RDI		GN-R-T-SPI	
	70%	30%	70%	30%
R	0.9950	0.9936	0.9979	0.9975
R^2	0.9901	0.9872	0.9958	0.9950
RMSE	0.0996	0.1155	0.0645	0.0728
MAE	0.0736	0.0918	0.0488	0.0548

Table 5.214: Performance Indices of ANFIS Model 4 for RDI and SPI for Gandhinagar district

Performance Indices	GN-R-T-P -RDI		GN-R-T-P -SPI	
	70%	30%	70%	30%
R	1.0000	0.8928	0.9985	0.9344
R^2	1.0000	0.7971	0.9969	0.8731
RMSE	0.0061	0.4846	0.0556	0.3631
MAE	0.0046	0.2449	0.0377	0.1774

Table 5.215: Performance Indices of ANFIS Model 5 for RDI and SPI for Gandhinagar district

Performance Indices	GN - RDI 9 10 11 - RDI 12		GN - SPI 9 10 11 - SPI 12	
	70%	30%	70%	30%
R	0.9373	0.8746	0.9277	0.8123
R^2	0.8785	0.7649	0.8606	0.6599
RMSE	0.3494	0.5064	0.3731	0.7103
MAE	0.2629	0.3982	0.2902	0.4927

Below Figure 5.140 and 5.141 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Gandhinagar district.

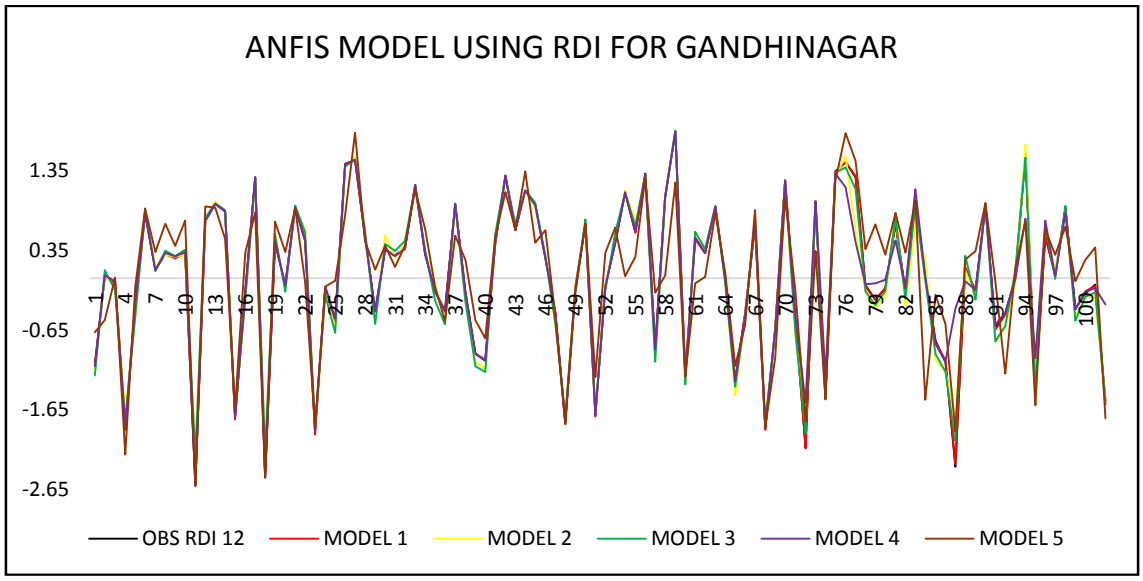


Figure 5.140: Graphical representation of ANFIS Models using RDI for Gandhinagar

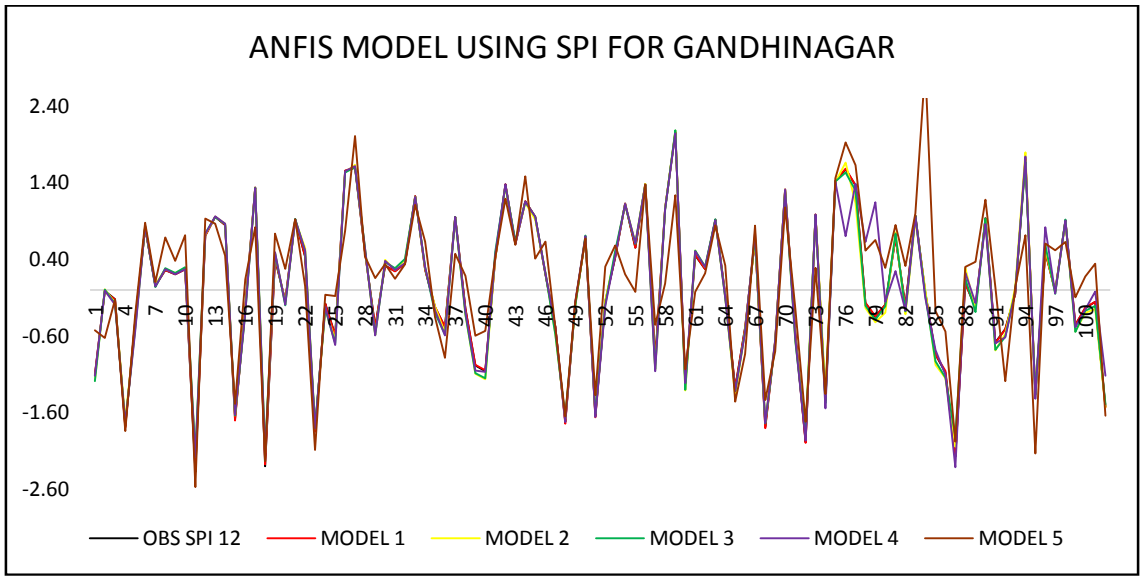


Figure 5.141: Graphical representation of ANFIS Models using SPI for Gandhinagar

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.0188 by training and 0.0163 by validation of the model, and co efficient of determination by training of the model is 0.9997 and by validation of the model is 0.9997 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.010 by training and 0.0060 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 1.0000 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

ANFIS Models for Mehsana district

The following Tables 5.216, 5.217, 5.218, 5.219 and 5.220 shows the results of Mehsana district for development of drought forecasting models for RDI and SPI.

Table 5.216: Performance Indices of ANFIS Model 1 for RDI and SPI for Mehsana district

Performance Indices	ME-R-RDI		ME-R-SPI	
	70%	30%	70%	30%
R	0.9996	0.9980	1.0000	0.9994
R^2	0.9992	0.9959	0.9999	0.9989
RMSE	0.0287	0.0653	0.0087	0.0351
MAE	0.0210	0.0280	0.0057	0.0118

Table 5.217: Performance Indices of ANFIS Model 2 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-T-RDI		ME-R-T-T-SPI	
	70%	30%	70%	30%
R	0.9966	0.9869	0.9985	0.9939
R^2	0.9933	0.9740	0.9970	0.9879
RMSE	0.0000	0.1673	0.0552	0.1104
MAE	0.0622	0.1316	0.0438	0.0818

Table 5.218: Performance Indices of ANFIS Model 3 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-RDI		ME-R-T-SPI	
	70%	30%	70%	30%
R	0.9954	0.9892	0.9981	0.9954
R^2	0.9908	0.9785	0.9961	0.9907
RMSE	0.0958	0.1514	0.0624	0.0985
MAE	0.0729	0.0964	0.0488	0.0613

Table 5.219: Performance Indices of ANFIS Model 4 for RDI and SPI for Mehsana district

Performance Indices	ME-R-T-P -RDI		ME-R-T-P -SPI	
	70%	30%	70%	30%
R	1.0000	0.8371	1.0000	0.8661
R^2	1.0000	0.7008	1.0000	0.7502
RMSE	0.0057	0.6096	0.0040	0.5365
MAE	0.0023	0.3666	0.0017	0.2780

Table 5.220: Performance Indices of ANFIS Model 5 for RDI and SPI for Mehsana district

Performance Indices	ME - RDI 9 10 11 - RDI 12		ME - SPI 9 10 11 - SPI 12	
	70%	30%	70%	30%
R	0.9317	0.7666	0.9325	0.8729
R^2	0.8680	0.5877	0.8696	0.7620
RMSE	0.3628	0.7399	0.3613	0.5084
MAE	0.2908	0.4976	0.2772	0.4390

Below Figure 5.142 and 5.143 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Mehsana district.

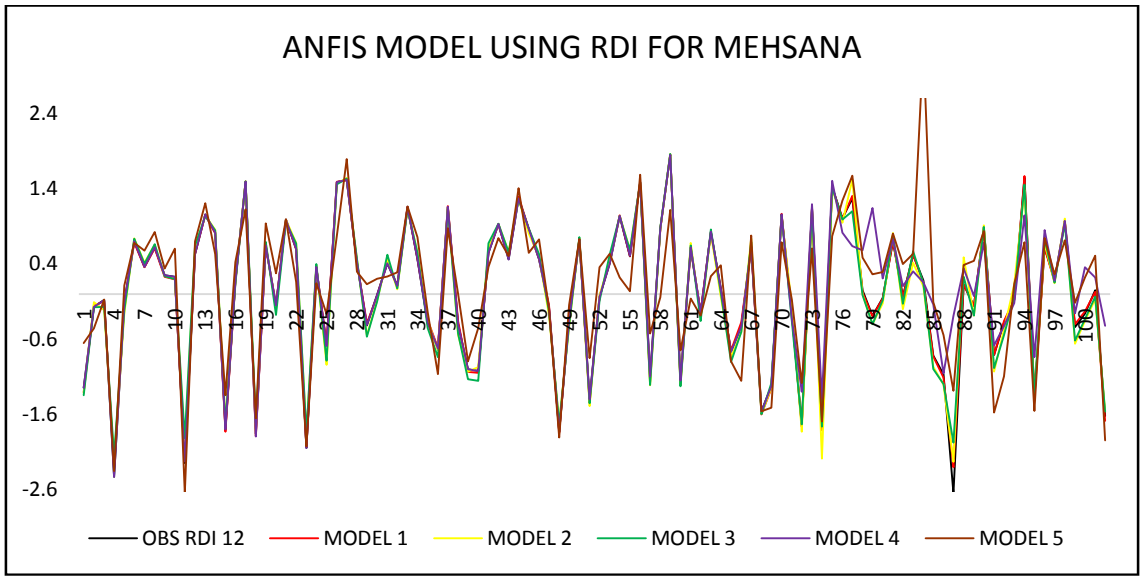


Figure 5.142: Graphical representation of ANFIS Models using RDI for Mehsana

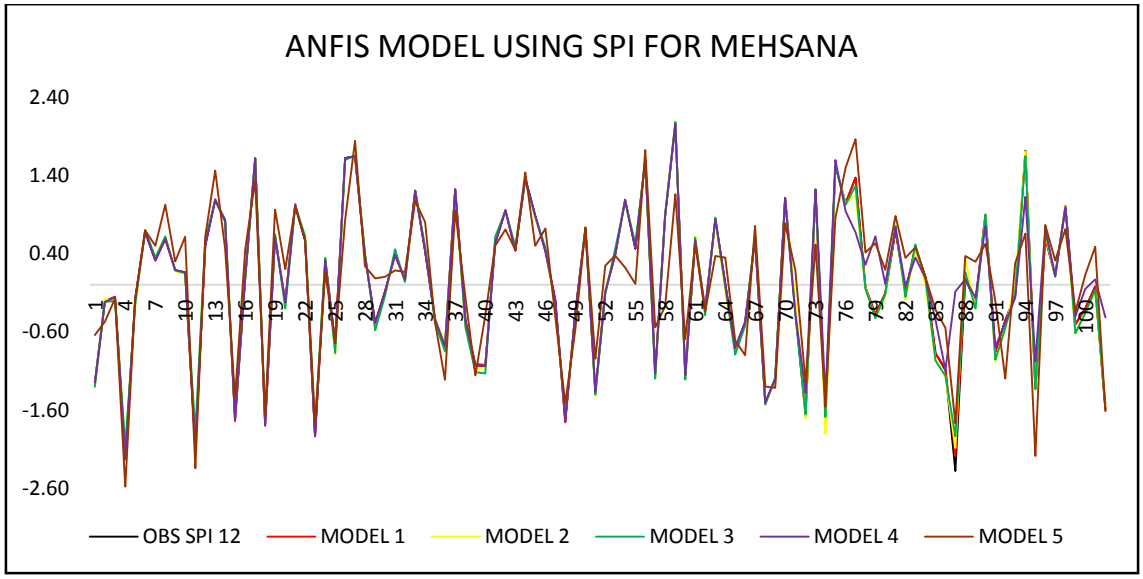


Figure 5.143: Graphical representation of ANFIS Models using SPI for Mehsana

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.0287 by training and 0.0653 by validation of the model, and co efficient of determination by training of the model is 0.9992 and by validation of the model is 0.9959 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.0087 by training and 0.0351 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 0.9989 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

ANFIS Models for Patan district

The following Tables 5.221, 5.222, 5.223, 5.224 and 5.225 shows the results of Patan district for development of drought forecasting models for RDI and SPI.

Table 5.221: Performance Indices of ANFIS Model 1 for RDI and SPI for Patan district

Performance Indices	PA-R-RDI		PA -R-SPI	
	70%	30%	70%	30%
R	0.9994	0.9925	0.9999	0.9973
R^2	0.9988	0.9850	0.9999	0.9946
RMSE	0.0348	0.1426	0.0107	0.0867
MAE	0.0228	0.0550	0.0066	0.0262

Table 5.222: Performance Indices of ANFIS Model 2 for RDI and SPI for Patan district

Performance Indices	PA -R-T-T-RDI		PA -R-T-T-SPI	
	70%	30%	70%	30%
R	0.9998	0.8589	0.9999	0.9575
R^2	0.9996	0.7378	0.9998	0.9167
RMSE	0.0000	0.5275	0.0150	0.3035
MAE	0.0110	0.2388	0.0098	0.1192

Table 5.223: Performance Indices of ANFIS Model 3 for RDI and SPI for Patan district

Performance Indices	PA -R-T-RDI		PA -R-T-SPI	
	70%	30%	70%	30%
R	0.9995	0.9812	0.9998	0.9861
R^2	0.9990	0.9629	0.9996	0.9723
RMSE	0.0307	0.2148	0.0196	0.1869
MAE	0.0203	0.0918	0.0132	0.0711

Table 5.224: Performance Indices of ANFIS Model 4 for RDI and SPI for Patan district

Performance Indices	PA -R-T-P -RDI		PA -R-T-P -SPI	
	70%	30%	70%	30%
R	0.9960	0.9407	0.9999	0.9972
R^2	0.9921	0.8849	0.9999	0.9944
RMSE	0.0885	0.3465	0.0107	0.0892
MAE	0.0590	0.2134	0.0083	0.0357

Table 5.225: Performance Indices of ANFIS Model 5 for RDI and SPI for Patan district

Performance Indices	PA - RDI 9 10 11 - RDI 12		PA - SPI 9 10 11 - SPI 12	
	70%	30%	70%	30%
R	0.9495	0.8052	0.9432	0.9240
R^2	0.9015	0.6483	0.8896	0.8537
RMSE	0.3119	0.6498	0.3332	0.4159
MAE	0.2279	0.3744	0.2527	0.3279

Below Figure 5.144 and 5.145 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Patan district.

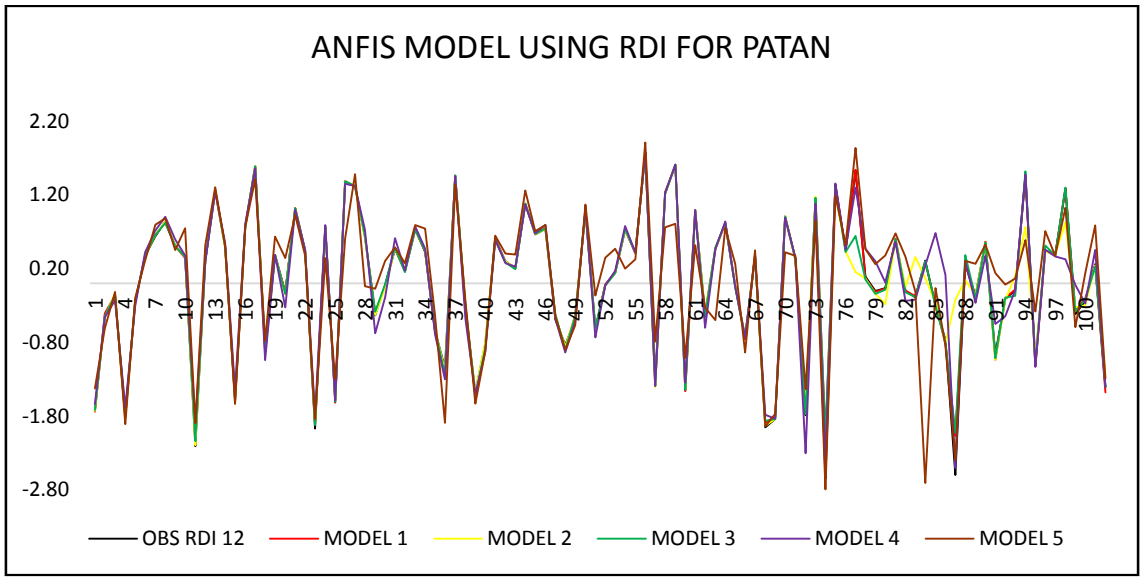


Figure 5.144: Graphical representation of ANFIS Models using RDI for Patan

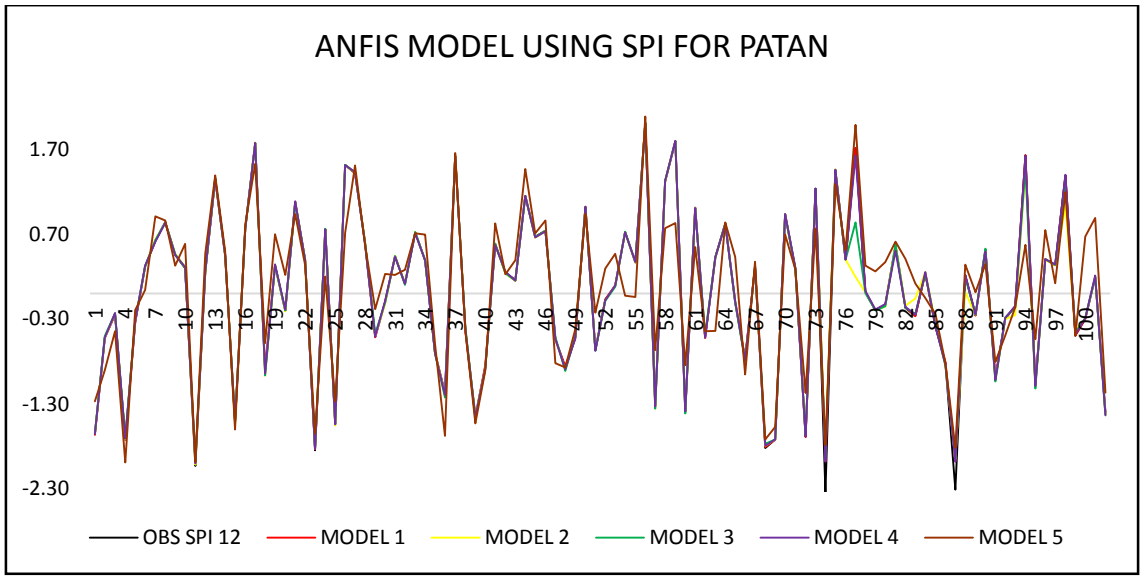


Figure 5.145: Graphical representation of ANFIS Models using SPI for Patan

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.0348 by training and 0.1426 by validation of the model, and co efficient of determination by training of the model is 0.9988 and by validation of the model is 0.9850 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.0107 by training and 0.0867 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 0.9946 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Results of ANFIS Models for Sabarkantha district

The following Tables 5.226, 5.227, 5.228, 5.229 and 5.230 shows the results of Sabarkantha district for development of drought forecasting models for RDI and SPI.

Table 5.226: Performance Indices of ANFIS Model 1 for RDI and SPI for Sabarkantha district

Performance Indices	SK-R-RDI		SK -R-SPI	
	70%	30%	70%	30%
R	0.9996	0.9997	1.0000	1.0000
R^2	0.9993	0.9994	1.0000	0.9999
RMSE	0.0277	0.0241	0.0064	0.0081
MAE	0.0189	0.0190	0.0042	0.0057

Table 5.227: Performance Indices of ANFIS Model 2 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-T-RDI		SK -R-T-T-SPI	
	70%	30%	70%	30%
R	0.9979	0.9714	0.9987	0.9934
R^2	0.9958	0.9437	0.9975	0.9868
RMSE	0.0000	0.2771	0.0508	0.1158
MAE	0.0438	0.1793	0.0384	0.0801

Table 5.228: Performance Indices of ANFIS Model 3 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-RDI		SK -R-T-SPI	
	70%	30%	70%	30%
R	0.9966	0.9927	0.9986	0.9968
R^2	0.9933	0.9855	0.9972	0.9935
RMSE	0.0828	0.1179	0.0538	0.0773
MAE	0.0606	0.1010	0.0392	0.0667

Table 5.229: Performance Indices of ANFIS Model 4 for RDI and SPI for Sabarkantha district

Performance Indices	SK -R-T-P -RDI		SK -R-T-P -SPI	
	70%	30%	70%	30%
R	0.9982	0.8715	0.9993	0.9574
R^2	0.9965	0.7596	0.9985	0.9166
RMSE	0.0602	0.6060	0.0387	0.3064
MAE	0.0452	0.3274	0.0295	0.1689

Table 5.230: Performance Indices of ANFIS Model 5 for RDI and SPI for Sabarkantha district

Performance Indices	SK - RDI 9 10 11 - RDI 12		SK - SPI 9 10 11 - SPI 12	
	70%	30%	70%	30%
R	0.9354	0.8549	0.9254	0.7547
R^2	0.8749	0.7309	0.8563	0.5696
RMSE	0.3579	0.5281	0.3850	0.6452
MAE	0.2756	0.4326	0.2999	0.4394

Below Figure 5.146 and 5.147 shows the graphical representation of comparisons between developed model and observed values for RDI and SPI for Sabarkantha district.

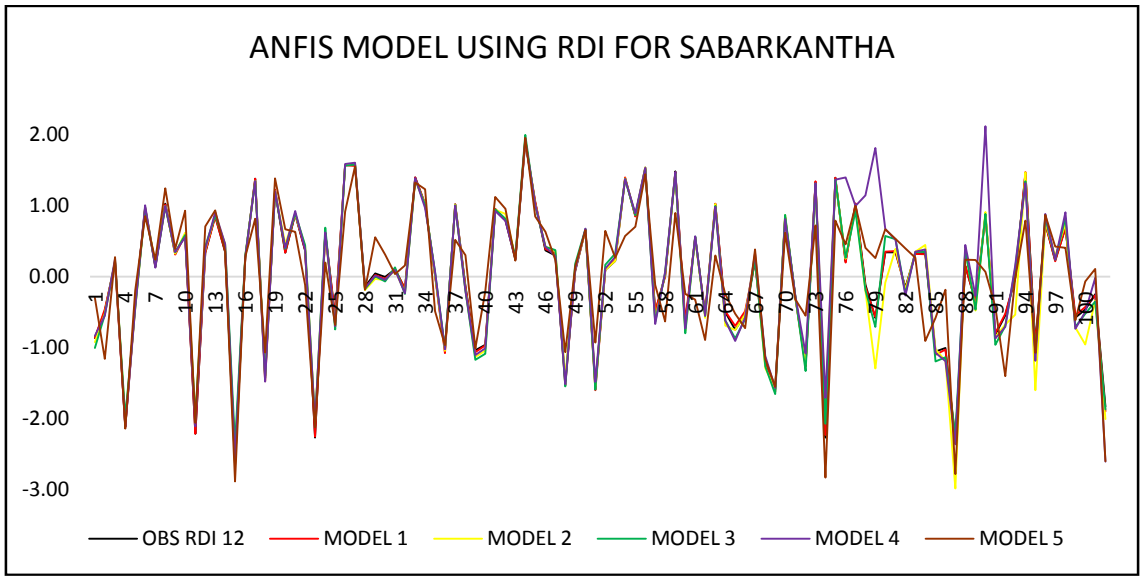


Figure 5.146: Graphical representation of ANFIS Models using RDI for Sabarkantha

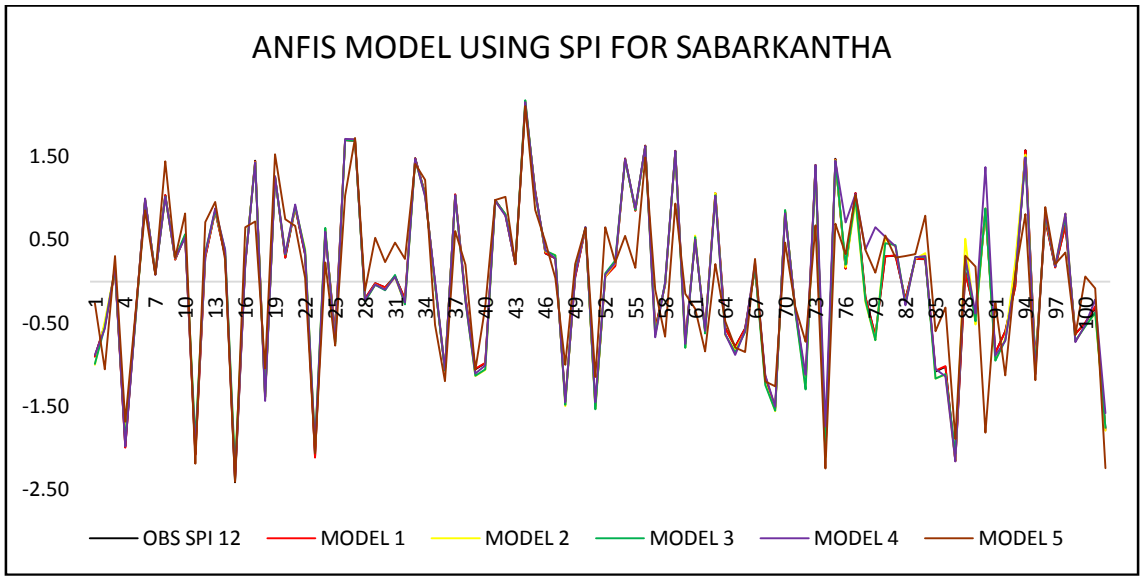


Figure 5.147: Graphical representation of ANFIS Models using SPI for Sabarkantha

Amongst all five models, the best ANFIS model for RDI is Model 1 with the RMSE of 0.0348 by training and 0.1426 by validation of the model, and co efficient of determination by training of the model is 0.9988 and by validation of the model is 0.9850 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

Amongst all five models, the best ANFIS model for SPI is Model 1 with the RMSE of 0.0107 by training and 0.0867 by validation of the model, and co efficient of determination by training of the model is 0.9999 and by validation of the model is 0.9946 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.

5.12.3 Comparative analysis of drought forecasting models in North Gujarat region

Drought prediction is a real problem for local administrations and water resources planners. So in the present study different models were developed using different combinations of input data. Almost all the models were found to be suitable to make effective extreme point predictions. Continuous monitoring and validation of the model against real-world data are essential to improve its accuracy and reliability in drought forecasting. Amongst all developed five models, the best Fuzzy and ANFIS model for RDI and SPI is Model 1 and 2 with the RMSE ranges between 0.03 to 0.015 for training and 0.0867 to 0.15 for validation period, and co efficient of determination value for training period is 0.9999 and for validation period is 0.9946 which are nearer to 1, which may be used for prediction of future drought conditions for the area considered under study for any amount of rainfall given.