

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL

The conclusions derived from the overall results of North Gujarat districts using Meteorological drought indices, Hydrological drought indices and Agricultural drought indices are discussed. Also, the trend analysis of drought indices (SPI, RDI, and SPEI) and the conclusions from developed drought forecasting models are discussed. The derived conclusions for various districts, considering the above said drought indices are discussed hereafter.

6.2 BANASKANTHA DISTRICT

The monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 67, 73, 81, 55, 68, 81, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation. From the annual rainfall and different meteorological drought indices it is observed that extreme drought 1901, 1904, 1911, 1915, 1923, 1939, 1969, 1974, 1987, and 2002. The severe drought condition occurred during 1903, 1905, 1920, 1928, 1932, 1935, 1938, 1942, 1949, 1965, 1966, 1979, 1980, 1983, 1989, 1992, and 2000. Also, Moderate drought condition occurred during 1902, 1918, 1925, 1930, 1936, 1940, 1948, 1951, 1957, 1960, 1962, 1968, 1972, 1985, 1986, 1991, 1995, and 1999. The results of PN, PD, RAI, SPI 12, RDI12 and SPEI 12 shows that Banaskantha district having 32% of drought condition during study period. The annual rainfall shows a significant negative trend with Z value as -0.307 and its corresponding Sen's slope value is -0.245. For summer season rainfall shows a significant negative trend with Z value as -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. By comparing results of SPI, RDI and SPEI indices for MK test and Sen's slope estimator shows that there is an increasing trend as time scales is increased.

The results of PCI shows that summer season having 23.5% uniform precipitation, 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 comparative study of different aridity index shows that 5 to 18% of the year is arid while 35% area is humid. This data analysis and results will be a good predictor for agricultural scientist, agronomist and hydrologist to plan according the climate of the region.

The results obtain using Hydrological drought indices shows that average water spread area using NDWI index 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 and NDSI index shows that average 3027.60 sqkm area which is around 28.5% districts having moderate saline characteristics during 1992 to 2019 years. 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 sqkm area in 2012, 91.59 Sq.km area in 2019 observed. Also, the average water spread area in the district is 287.93 sqkm area in Banaskantha district during the period of study.

Agricultural drought assessment is carried out using various RS and GIS approaches the results of NDVI 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 using NDVI deviation. Similarly, 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. The results of LST shows that 7877.60 Sq.km area of the district under high temperature. The minimum temperature was 22.80°C and maximum temperature was 45.09°C during study period. The average percentage of dry area was 60.7% in Banaskantha district using TCI, VHI indices.

The best Fuzzy Logic model for SPI and RDI using Fuzzy Logic (FL) Model 1 with the RMSE of 0.2241 by training and 0.2664 by validation of the model, and coefficient 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.

6.3 GANDHINAGAR DISTRICT

The monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 72, 76, 82, 70, 63, 80, 81 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From the annual rainfall data and various meteorological drought indices the years 1911, 1918, 1987 as extreme dry. Severe dry years as 1904, 1915, 1923, 1948, 1951, 1960, 1965, 1968, 1972, 1974, 1995, 2002. The moderate dry year as 1901, 1925, 1929, 1936, 1939, 1940, 1947, 1957, 1966, 1969, 1971, 1985, 1986, 1991,

1992, 1999 Similar results were obtained using climatic drought index 1904, 1911, 1918, 1923, 1968, 1972 and 1987 years as very extreme drought and 1915, 1948, 1951, 1960, 1965, 1974, and 2002 as drought years. The study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Gandhinagar district. The frequency analysis reveals that 7%, 15% and 16% of extreme dry years, severe dry years and moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years. The PCI index 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 annual rainfall of 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. Similar trend analysis of SPI 12 as Z is -0.06 with Sen's slope value as 0.03. For RDI the value of Z is -0.07 with Sen's slope value as 0.09 and for SPEI the 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 SPEI. Also, maximum trend value of Z statistics for RDI indices is obtained.

The average water spread using NDWI index 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%. From the analysis of NDSI it was observed that average 321.97 Sq.km area which is around 11.80% having moderate saline characteristics. 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 of 1992 to 2019. The results of hydrological drought indices shows that the water ratio index in Gandhinagar district the medium dry condition and medium water condition varies from 27% to 33% and 65% to 72% respectively.

The results of 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. 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 of 1992 to 2019. Similarly, 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 results of LST shows that average 835.20 Sq.km area or 48.43% of the district under high temperature 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.

The results of best Fuzzy Logic model for RDI 12 and SPI 12 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.

6.4 MEHSANA DISTRICT

The monthly rainfall of Mehsana district of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 72, 75, 85, 70, 64, 78, 81 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From this results of meteorological drought indices 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. The results of Mehsana district for climatic index show 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 PCI index 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 frequency analysis reveals that 8%, 14% and 16% of extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years using SPI12, RDI 12, and SPEI 12.

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 results of meteorological drought indices trend analysis shows that the SPI 12 the value of Z is -0.21 with Sen's slope value as 0.14. For RDI 12 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.

The results of NDWI index shows that average water spread area 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. 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 sqkm 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 results of hydrological drought indices shows that the water ratio index in Mehsana district the medium dry condition and medium water condition varies from 21% to 30% and 65% to 78% respectively.

The results Agricultural drought indices 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 of data set. 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.

LST results shows that 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 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. The average

percentage of dry using TCI area was 35.02% in Mehsana district with annual average rainfall 672.70 mm during study period.

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.

6.5 PATAN DISTRICT

The monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 72, 75, 82, 80, 70, 77, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From the meteorological drought indices the result shows 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, severe 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.

The results of climatic index 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 PCI 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 study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Patan district.

The frequency analysis reveals that 7%, 16% and 15% of extreme dry years, severe dry years and moderate dry years occur amongst drought years considered, which means 38% years are categorized into moderate to extreme drought years out of the total drought years.

The results of NDWI index for Hydrological drought analysis shows that 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. 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 sqkm area during study period. 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 results of hydrological drought indices shows that the water ratio index in district the medium dry condition and medium water condition varies from 22% to 30% and 67% to 90% respectively.

The results of Agricultural drought indices using 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 results of NDVI-deviation shows that 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 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 results of LST shows that maximum area under 35 to 45 degree temperature was 5937.0 sq.km area which is 98%. 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 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.

The best Fuzzy Logic model for RDI and SPI 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.

6.6 SABARKANTHA DISTRICT

The monthly rainfall data of 102 years (1901-2002), analyzed and results shows that the months of January, February, March, April, May, November and December have been identified 68, 73, 78, 71, 68, 81, 79 times as drought months respectively in the 20th century, indicating that these months must be provided with assured Irrigation.

From the various meteorological drought indices 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.

The results of Sabarkantha district for various climatic indices 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 result of PCI 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. The study of aridity indices shows that 18 years identified as arid years and 34 years as semi-arid years out of 102 years in Sabarkantha district. The frequency analysis reveals that 6%, 15% and 13% of extreme dry years, severe dry years and Moderate dry years occur amongst drought years considered, which means 34% years are categorized into moderate to extreme drought years out of the total drought years.

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.

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 SPEI. Also, maximum trend value of Z statistics for RDI indices is obtained.

The results of hydrological drought indices using NDWI shows that 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 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. 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. The results of hydrological drought indices shows that the water ratio index in Sabarkantha district the medium dry condition and medium water condition varies from 22% to 30% and 54% to 70% respectively.

The results of Agricultural drought indices using 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 results of NDVI deviation shows that 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 1992 to 2019 years.

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 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 average percentage of dry area using VCI and TCI was 31.70% in Sabarkantha district with annual average rainfall 734.50 mm during study period.

The best Fuzzy Logic and ANFIS models for RDI and SPI is Fuzzy Logic (FL) Model 1 with the RMSE of 0.2762 by training and 0.2819 by validation of the model, and coefficient 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.

6.7 RECOMMENDATIONS

It has been found from the conclusions that by analysing the meteorological drought indices the considered districts of North Gujarat under the study area drought has been occurred almost nearing to 50% of the years considered therefor it is strictly recommended that the proper planning of water conservation structures and at the same time management of available water resources should be well planned.

Looking at the analysis of Hydrological drought indices, the water spread in the study area is comparatively minimum in almost all the districts the efforts are to be made towards increasing water bodies and if possible, towards river water management.

By analysing at the Agricultural drought indices the percentage of dry areas is quite high as per some of the indices considered, it is recommended to have better watershed management practices, proper selection of crops/ improvement in agricultural practices by better cropping pattern and by planning drought resistant variety of crops in drought affected areas. Even the techniques of lined ponds or farm ponds plays an important role and may act as potential game changers.

Looking at the all the three types of drought, amongst the five districts the measures are to be taken in Banaskantha and Patan at the first place followed by Gandhinagar, Mehsana and Sabarkantha.