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# Monthly, Annual and Seasonal Changes in Temperature by Using Mann Kendall and Sen's Slope Estimator in Karnataka, India

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*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

The mean annual minimum temperature during the period 1979-2019 has increased significantly in Eastern dry zone, Southern dry zone and Southern transition zone to a cumulative of total of 0.010°C, 0.013°C and 0.08 °C respectively while it has decreased significantly in Hilly zone with a magnitude of -0.032°C. The annual maximum temperature significantly increased in North eastern transition zone (0.018°C), North eastern dry zone (0.017°C), Northern dry zone (0.014°C), Central dry zone (0.010°C), Eastern dry zone (0.011°C), Southern dry zone (0.013°C), Southern transition zone (0.016°), Northern transition zone (0.016°C) and Coastal zone (0.018°C). The hilly zone experienced a decrease in annual maximum temperature by-0.055°C. Therefore, it is evidential that, Karnataka is getting raised over the years. Researchers should develop crop varieties that are insensitive to temperature changes and scientist should develop packages of practices which will reduce adverse effect of fluctuations in climate parameters on crop productivity.

*Keywords: Climate change; agro-climatic zones; temperature; Karnataka.*

## 1. INTRODUCTION

The emission of green house gases disturbs the established energy balance of atmosphere which result in rising in temperature and increased erraticity of climatic parameters. The global annual mean surface temperature has increased by more than 1.5°C above the pre industrial level (IPCC, 2018). This increase in temperature has caused unprecedented changes across the human and natural systems. In the process of gradual warming, the mean temperature shifted upward which amounts to climate change [1-5]. At global level, though total precipitation has decreased across the African continent with increasing length of consecutive dry days and decreasing length of consecutive wet days, average rainfall intensity and extreme rainfall events have decreased in western central Africa [6]. In India, the last five decades experienced an increase in the frequency and magnitude of extreme rain events over central India, western India, north-eastern India, and southern India whereas, an increase in the frequency of severe droughts have been observed over south India, central Maharashtra, the Indo-Gangetic plains, north, and northwest India (Sharma and Majumdar, 2017). The vulnerability of a system is determined by concepts of exposure, sensitivity and adaptive capacity towards climate change [7,8].

Semi- arid region of peninsular India are vulnerable to drought and water stress due to uneven distribution of monsoon rainfall. The delay in monsoon or dry spells adds pressure on available water resources. Even in such situations farmers in semi arid India continue to grow water intensive crops. Karnataka ranks second among drought effected states after Rajasthan with frequent occurrence of droughts once in five years [9-11]. The impact of climate shock creates unequal access to resources, food insecurity and incidence of poverty in country. The risk associated with climate change calls for a broad spectrum of policy responses and strategies at the local, regional, national and global level to mitigate the effect of the same [12-16]. It is, therefore, important to examine the extent of change and extremes in temperature across ten agro climatic zones of Karnataka.

## 2. MATERIALS AND METHODS

There are 10 agro climatic zones in Karnataka which is classified by Department of Agriculture along with University of Agricultural sciences, Bangalore during the year 2010 summarised in Table 1.

**Source of Secondary Data**: The daily observed data for minimum temperature (Min Temp) and maximum temperature (Max Temp) of 30 districts of Karnataka for a period of 1979 to 2019 were collected from the AICRPAM, CRIDA, Hyderabad based on the availability of Data.

The daily weather data is aggregated for 12 months, 4 climatic seasons namely, Winter (January-February), Summer (March –May), South west monsoon (SWM) (June-September) and north east monsoon (NEM) (October – December) and annual by taking simple averages for analysis. Total 34 data sets i.e., 12 months, 4 seasons and 1 annual data set of temperature were computed for each agro climatic zones. Thus, 340 data sets were obtained for 10 agro climatic zones of Karnataka to analyse Mann Kendall analysis.

**Table 1. Agro-climatic zones (ACZ) of Karnataka**

| Dry Zones | Transition Zones | Hilly and Coastal Zones |
|---|---|---|
| North Eastern Dry Zone (II) | North Eastern Transition Zone (I) | Hilly Zone (IX) |
| Northern Dry Zone (III) | Southern Transition Zone (VII) | Coastal Zone (X) |
| Central Dry Zone (IV) | Northern Transition Zone (VIII) | |
| Eastern Dry Zone (V) | | |
| Southern Dry Zone (VI) | | |

*Source: Department of Agriculture &University of Agricultural Sciences, Bangalore 2010*

## 2.1 Mann Kendall (MK) Test

Mann Kendall test is one of the most widely used methods to statistically assess the presence of significance of trend in the climatic data (Lanzante, 1996). This test compares only the relative values of sample data rather than absolute value (Modarres & Silva, 2007). In Mann Kendall test, the null hypothesis (Ho) assumes that there is no trend in the data against alternative hypothesis ($H_1$) which assumes that there is a trend. Software XL Stata is used for analysing the data.

Null hypothesis Ho: There is no trend in the data

Alternate hypothesis $H_1$: There is trend in the data

Mann Kendall S Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{i+1}^{n} \text{sign}(Tj - Tj) \quad \text{.....} \quad (1)$$

Where n represents the number of data points, and represents the data values in time series Tj and Ti such that (i>j), respectively and sign ( ) is the sign function as;

$$\text{sign}(Tj - Ti) = \begin{cases} 1 \text{ if } Tj > Ti \\ 0 \text{ if } Tj = Ti \\ -1 \text{ if } Tj < Ti \end{cases} \quad \text{.....} \quad .(2)$$

Where $T_j$ and $T_i$ are the annual values in year j and i , j > I, respectively. It assumes a linear trend in the time series. The variance is computed as:

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

Where n represents the number of data set, m is the number of ties group (sample data having the same value) and '$t_i$' represents the number of ties to extent 'i'. The standardized test statistic Zs is computed using following equation:

$$Z_s = \left\{ \begin{array}{c} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0 \quad , if\ S = 0 \\ \frac{S+1}{\sqrt{Var\ (S)}}, if\ S < 0 \end{array} \right\} \text{.....} \quad (4)$$

Zs value indicates the nature of trend. Negative value of Zs indicate decreasing trend while positive values indicate increasing trend [17]. Zs is used to measure the significance of trend. Null hypothesis is tested using the test statistic Zs values. If | Zs| > Zα/2, where α represent the chosen significance level then the null hypothesis is rejected indicating that the trend is significant [18]. In this study null hypothesis was tested at 1%, 5% and 10% significance level. Asgher *et al.,* [19] examined in detail the temperature of Bhaderwah meteorological station from 1980 to 2017 by applying Mann Kendall test on mean monthly maximum temperature data. The Zs statistic value reveals the trend of mean monthly maximum temperature for individual months from January to December which are -0.243, 0.016, 1.364, -0.130, 0.535, - 1.867, -0.138, -2.306, -1.494, -0.325, -1.379 and -0.746, respectively

## 2.2 Sen's Slope Estimator

Sen's slope estimator is a non-parametric procedure which is used for estimating the magnitude of trend in the sample of N pairs of data [20].

$$Q_i = \frac{x_k - x_j}{k-j} \ for\ i = 1 \ldots . N \quad \text{.....} \quad (5)$$

Where $X_k$ and Xj represents the data values at times j and k such that j >k, respectively. The median of N values of $Q_i$ is Sen's estimator of slope which is computed as:

$$Q = \left\{ \begin{array}{c} Q_{\frac{N+1}{2}},\ if\ N\ is\ Odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}\right) if\ N\ is\ even \end{array} \right\} \text{.....} \quad (6)$$

Positive value of Q indicates increasing trend while negative value of Q indicates decreasing trend. Q value indicates the steepness of trend. Sen's slope estimator has been widely used for calculating the magnitude of trend in hydro meteorological time series [21].

## 3. RESULTS AND DISCUSSION

### 3.1 Trend of Temperature in North Eastern Transition Zone (NETZ) during 1979-2019

*North Eastern Transition Zone* consists of Bidar and Gulbarga districts with 7 talukas (Map 1). The total geographical area of the region is about 0.87Mha. The annual rainfall in this region varies from 700 to 890 mm. Bidar and Gulbarga have highest maximum temperature with 33°C

The results reveal that, monthy mean minimum temperature (MTmin) of August is increasing significantly with a magnitude of 0.012°C for the total forty years period from 1979 to 2019 (Table 2). The maximum temperature has increased significantly in January, August, November and December with a magnitude of 0.030°C, 0.019°C, 0.045°C and 0.045°C, respectively. The seasonal significant trends are detected for maximum temperature during North east monsoon, Annual with magnitude of 0.035 and 0.018°C respectively.

### 3.2 Trend in Temperature of North Eastern Dry Zone (NEDZ) during 1979-2019

*North Eastern Dry Zone* consists of three districts Gulbarga, Yadgir and Raichur (Map 2) with 11 talukas. The geographical area of this zone is 1.76 Mha The results reveal that, the mean minimum temperature of August has significantly increased (Table 3) with a magnitude of 0.010°C and has decreased in winter with magnitude of -0.022°C for the study period 1979 to 2019. The mean monthly maximum temperature significantly increased in January, August and November with magnitude of slope of 0.036, 0.023 and 0.041°C, respectively. The analysis of seasonal temperature trends revealed that warming trends were more pronounced in Winter and North east monsoon. The average annual warming for the last forty years was calculated to be 0.017°C.

**Table 2. Mann-Kendall test results of minimum and maximum temperatures of NETZ, 1979-2019**

| Month/Season | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| | T | S | þ | β | T | S | Þ | B |
| January | -0.25 | -206 | 0.021 | -0.029** | 0.30 | 252 | 0.005 | 0.030* |
| February | -0.11 | -96 | 0.286 | -0.015 | 0.18 | 150 | 0.094 | 0.023 |
| March | -0.04 | -38 | 0.678 | 0.005 | 0.15 | 125 | 0.164 | 0.020 |
| April | 0.02 | 16 | 0.866 | 0.001 | 0.07 | 58 | 0.522 | 0.011 |
| May | 0.16 | 138 | 0.124 | 0.018 | 0.07 | 58 | 0.522 | 0.001 |
| June | 0.11 | 94 | 0.296 | 0.009 | 0.01 | 8 | 0.937 | 0.003 |
| July | 0.20 | 166 | 0.064 | 0.011 | 0.00 | 2 | 0.991 | 0.000 |
| August | 0.33 | 276 | 0.002 | 0.012* | 0.27 | 226 | 0.011 | 0.019* |
| September | 0.05 | 48 | 0.598 | 0.002 | -0.03 | -28 | 0.762 | 0.003 |
| October | 0.01 | 10 | 0.919 | 0.001 | 0.09 | 78 | 0.387 | 0.014 |
| November | 0.02 | 16 | 0.866 | 0.004 | 0.42 | 350 | <0.0001 | 0.045* |
| December | -0.04 | -38 | 0.678 | -0.007 | 0.37 | 310 | 0.001 | 0.045* |
| *Winter* | -0.19 | -156 | 0.082 | -0.021 | 0.27 | 224 | 0.012 | 0.024* |
| *Summer* | 0.05 | 48 | 0.598 | 0.005 | 0.13 | 114 | 0.204 | 0.014 |
| *SWM* | 0.20 | 164 | 0.067 | 0.008 | 0.06 | 54 | 0.552 | 0.004 |
| *NEM* | 0.10 | -4 | 0.973 | 0.000 | 0.36 | 296 | 0.001 | 0.035* |
| *Annual* | 0.03 | 28 | 0.762 | 0.002 | 0.39 | 326 | 0.000 | 0.018* |

*Note: T indicates Kendell's rank correlation coefficient, S indicates Kendell score, p indicates Level of significance, β indicates Sen's slope; *,** &*** indicates 1%, 5% and 10% level of significance, respectively*

**Table 3. Mann-Kendall test results of minimum and maximum temperatures of NEDZ, 1979-2019**

| Month/season | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| | T | S | þ | β | T | S | þ | B |
| January | -0.22 | -182 | 0.042 | -0.025 | 0.44 | 364 | <0.0001 | 0.036* |
| February | -0.13 | -112 | 0.212 | -0.019 | 0.15 | 124 | 0.160 | 0.017 |
| March | -0.03 | -28 | 0.762 | -0.003 | 0.16 | 132 | 0.141 | 0.019 |
| April | -0.02 | -24 | 0.796 | -0.001 | 0.06 | 52 | 0.567 | 0.008 |
| May | 0.13 | 108 | 0.229 | 0.012 | 0.03 | 30 | 0.745 | 0.005 |
| June | 0.15 | 102 | 0.132 | 0.012 | 0.01 | 8 | 0.937 | 0.002 |
| July | 0.2 | 164 | 0.067 | 0.008 | 0.06 | 52 | 0.567 | 0.006 |
| August | 0.29 | 242 | 0.007 | 0.010* | 0.3 | 248 | 0.006 | 0.023* |
| September | 0.04 | 34 | 0.711 | 0.001 | -0.03 | -26 | 0.779 | -0.003 |
| October | 0.01 | 10 | 0.919 | 0.001 | 0.09 | 80 | 0.375 | 0.013 |
| November | 0.01 | 8 | 0.937 | 0.001 | 0.4 | 332 | 0.000 | 0.041* |
| December | -0.1 | -82 | 0.363 | -0.014 | 0.2 | 286 | 0.750 | 0.041 |
| *Winter* | -0.24 | -202 | 0.024 | -0.022** | 0.3 | 250 | 0.005 | 0.026* |
| *Summer* | 0.04 | 34 | 0.711 | 0.003 | 0.13 | 114 | 0.204 | 0.012 |
| *SWM* | 0.18 | 154 | 0.086 | 0.007 | 0.11 | 92 | 0.307 | 0.008 |
| *NEM* | -0.04 | -36 | 0.694 | -0.004 | 0.36 | 302 | 0.001 | 0.033* |
| *Annual* | -0.05 | -42 | 0.645 | -0.002 | 0.39 | 322 | 0.000 | 0.017* |

*Note: T indicates Kendell's rank correlation coefficient, S indicates Kendell score, p indicates Level of significance, β indicates Sen's slope; *,** &*** indicates 1%,5% and 10% level of significance, respectively*

**Table 4. Mann-Kendall test results for minimum and maximum temperatures of NDZ, 1979-2019**

| NDZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| Month/Season | τ | S | þ | β | τ | S | Þ | B |
| January | -0.22 | -182 | 0.042 | -0.018** | 0.38 | 316 | 0.000 | 0.024* |
| February | -0.09 | -74 | 0.412 | -0.011 | 0.29 | 242 | 0.007 | 0.027* |
| March | -0.01 | -10 | 0.919 | -0.001 | 0.22 | 182 | 0.042 | 0.018** |
| April | 0.05 | 42 | 0.645 | 0.005 | 0.08 | 66 | 0.465 | 0.010 |
| May | 0.09 | 74 | 0.412 | 0.006 | -0.03 | -30 | 0.745 | -0.003 |
| June | 0.10 | 86 | 0.34 | 0.004 | 0.02 | 18 | 0.849 | 0.003 |
| July | 0.18 | 152 | 0.09 | 0.008*** | 0.05 | 48 | 0.598 | 0.005 |
| August | 0.26 | 206 | 0.017 | 0.009* | 0.42 | 348 | <0.0001 | 0.023* |
| September | 0.05 | 44 | 0.629 | 0.002 | 0.03 | 30 | 0.745 | 0.003 |
| October | 0.01 | 10 | 0.919 | 0.001 | 0.09 | 78 | 0.387 | 0.010 |
| November | 0.01 | 14 | 0.884 | 0.002 | 0.39 | 320 | 0.000 | 0.031* |
| December | -0.05 | -44 | 0.629 | 0.002 | 0.35 | 290 | 0.001 | 0.031* |
| *Winter* | -0.20 | -168 | 0.061 | -0.016*** | 0.4 | 332 | 0.000 | 0.026* |
| *Summer* | 0.06 | 54 | 0.552 | 0.00 | 0.07 | 58 | 0.522 | 0.005 |
| *SWM* | 0.18 | 150 | 0.094 | 0.004*** | 0.12 | 98 | 0.276 | 0.011 |
| *NEM* | -0.01 | -14 | 0.884 | -0.001 | 0.31 | 254 | 0.004 | 0.023* |
| *Annual* | 0.00 | 2 | 0.991 | 0.000 | 0.43 | 360 | <0.0001 | 0.014* |

*Note: τ indicates Kendall's rank correlation coefficient, S indicates Kendall score, p indicates level of significance, β indicates Sen's slope; *, ** & *** indicates 1%, 5% and 10% level of significance, respectively*

### 3.3 Trend of Temperature in Northern Dry Zone (NDZ) during 1979-2019

Northern Dry Zone consists of seven districts (Map 3) Koppal, Bagalkot, Bijapur, Davangere, Bellary, Belagum and Gadag with 18 talukas with area of 5.04 Mha. The magnitude of trend observed in November & December was 0.031°C for the study period of 1979-2019. The seasonal maximum temperature (Tmax) increased significantly in winter (0.026°C) and North East monsoon (0.023°C) for the

whole of the study period 1979-2019 as shown in Table 4.

### 3.4 Trend in Temperature of Central Dry Zone (CDZ) during 1979-2019

Central Dry zone consists of three districts (Map 4) Chitradurga, Davanagere and Tumkur with 17 taluks. Total geographical area of this zone is 1.98 Mha. The highest magnitude of slope was recorded for the mean temperature of the month of August with 0.015°C as shown in Table 5. While the mean maximum temperature of the months of January, February, July, August and November recorded significant increase which has replicated for the temperatures of winter, South west monsoon and north east monsoon. The trend of annual mean maximum temperature increased with magnitude of 0.01°C for the study period 1979 to 2019.

**Table 5. Mann-Kendall test results of minimum and maximum temperatures of CDZ, 1979-2019**

| CDZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/Season** | **τ** | **S** | **þ** | **B** | **τ** | **S** | **Þ** | **B** |
| January | -0.07 | -64 | 0.479 | -0.009 | 0.36 | 296 | 0.001 | 0.032* |
| February | -0.10 | -82 | 0.363 | -0.011 | 0.22 | 182 | 0.042 | 0.020** |
| March | 0.04 | 38 | 0.678 | 0.003 | 0.15 | 128 | 0.154 | 0.014 |
| April | 0.13 | 111 | 0.217 | 0.008 | 0.00 | 0 | 1.000 | 0.000 |
| May | 0.11 | 94 | 0.296 | 0.008 | -0.17 | -142 | 0.113 | -0.018 |
| June | 0.19 | 160 | 0.074 | 0.010*** | 0.09 | 78 | 0.387 | 0.009 |
| July | 0.32 | 262 | 0.003 | 0.013* | 0.19 | 158 | 0.078 | 0.013*** |
| August | 0.36 | 298 | 0.001 | 0.015* | 0.30 | 246 | 0.006 | 0.018* |
| September | 0.26 | 214 | 0.017 | 0.010* | 0.06 | 54 | 0.552 | 0.005 |
| October | 0.18 | 152 | 0.090 | 0.012*** | 0.14 | 122 | 0.174 | 0.011 |
| November | 0.09 | 80 | 0.375 | 0.011 | 0.24 | 198 | 0.027 | 0.017** |
| December | 0.07 | 64 | 0.479 | 0.009 | 0.17 | 144 | 0.108 | 0.016 |
| *Winter* | -0.10 | -82 | 0.363 | -0.011 | 0.35 | 292 | 0.001 | 0.021* |
| *Summer* | 0.12 | 98 | 0.276 | 0.007 | -0.03 | -26 | 0.779 | -0.003 |
| *SWM* | 0.31 | 254 | 0.004 | 0.012* | 0.19 | 160 | 0.074 | 0.011*** |
| *NEM* | 0.09 | 80 | 0.375 | 0.007 | 0.27 | 224 | 0.012 | 0.015* |
| *Annual* | 0.17 | 138 | 0.124 | 0.006 | 0.26 | 210 | 0.019 | 0.010* |

*Note: τ indicates Kendall's rank correlation coefficient, S indicates Kendall score, p indicates level of significance, β indicates Sen's slope; *, ** & *** indicates 1%, 5% and 10% level of significance, respectively*

**Table 6. Mann-Kendall test results of minimum and maximum temperatures of EDZ, 1979-2019**

| EDZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/season** | **T** | **S** | **þ** | **β** | **τ** | **S** | **Þ** | **B** |
| January | -0.02 | -20 | 0.831 | -0.003 | 0.29 | 242 | 0.007 | 0.021* |
| February | -0.06 | -56 | 0.537 | -0.009 | 0.15 | 128 | 0.154 | 0.015 |
| March | 0.69 | 568 | <0.0001 | 0.012* | 0.16 | 134 | 0.135 | 0.016 |
| April | 0.12 | 106 | 0.238 | 0.008 | 0.03 | 28 | 0.762 | 0.003 |
| May | 0.14 | 116 | 0.196 | 0.007 | -0.14 | -122 | 0.174 | -0.014 |
| June | 0.24 | 200 | 0.025 | 0.010** | 0.06 | 50 | 0.582 | 0.006 |
| July | 0.35 | 294 | 0.001 | 0.015* | 0.12 | 104 | 0.247 | 0.009 |
| August | 0.44 | 362 | <0.0001 | 0.018* | 0.27 | 228 | 0.011 | 0.018* |
| September | 0.46 | 380 | <0.0001 | 0.016* | 0.01 | 12 | 0.902 | 0.001 |
| October | 0.27 | 228 | 0.011 | 0.017* | 0.12 | 104 | 0.247 | 0.012 |
| November | 0.17 | 144 | 0.108 | 0.016 | 0.26 | 101 | 0.143 | 0.019 |
| December | 0.15 | 124 | 0.167 | 0.016 | 0.26 | 218 | 0.015 | 0.010* |
| Winter | -0.02 | -16 | 0.866 | -0.001 | 0.27 | 224 | 0.012 | 0.011* |
| Summer | 0.26 | 214 | 0.017 | 0.007* | 0.01 | 10 | 0.919 | 0.000 |
| SWM | 0.44 | 366 | <0.0001 | 0.014* | 0.18 | 152 | 0.090 | 0.090 |
| NEM | 0.25 | 212 | 0.018 | 0.016* | 0.24 | 204 | 0.023 | 0.016** |
| Annual | 0.30 | 246 | 0.006 | 0.010* | 0.29 | 244 | 0.006 | 0.011* |

*Note: τ indicates Kendall's rank correlation coefficient, S indicates Kendall score, p indicates level of significance, β indicates Sen's slope, *, ** & *** indicates 1%, 5% and 10% level of significance, respectively*

### 3.5 Trend of Temperature in Eastern Dry Zone (EDZ) during 1979-2019

Eastern Dry Zone consists of five districts (Map 5) Benguluru, Tumkur, Ramanagar, Kolar and Chikballapur with 24 taluks. The geographical area of this zone is 1.80 Mha. The magnitude of average monthly minimum temperature of August was recorded to be highest with 0.018°C as shown in Table 6. The change in minimum temperature was recorded in summer, south west monsoon, north east monsoon and annual. The monthly mean maximum temperature has increased significantly in the months of January, August and December with magnitude of 0.021, 0.018, and 0.010°C, respectively.

### 3.6 Trend in temperature of Southern Dry zone (SDZ) during 1979-2019

Southern dry zone consists of Mysuru, Mandya, Chamarajanaga and Hassan (Map 6) with 18 taluks with area coverage of 1.56 Mha. The annual rainfall ranges from 650 to 760 mm. It was observed that (Table 7) minimum temperature has increased significantly in April, June, July, August, September, October with magnitude of 0.013,0.011, 0.015, 0.019, 0.014 and 0.016°C respectively during the period from 1969 to 2019. The maximum temperature increased significantly in January, February, August and November. The highest monthly magnitude was recorded in February with 0.025°C. The trend of minimum and maximum temperatures occurred in all seasons except summer. The magnitude of annual temperature trend was recorded with 0.013°C in this zone during forty years.

### 3.7 Trend in Temperature of *Southern Transition Zone (STZ)* during 1979-2019

The southern transition zone consists of (Map 7) Mysore, Hassan and Shimoga districts comprising of 11 taluks with area of 1.66 Mha. The analysis showed that the average minimum temperature of the months of April and July increased with same magnitude of 0.012°C (Table 8) during the period 1979 to 2019. The average monthly maximum temperature of the January, February, March, August, November and December increased significantly. The magnitude of noticed increase in average maximum temperature in February was 0.033°C. The seasonal temperature of winter, South west monsoon, North east monsoon recorded with magnitude of 0.030, 0.014 and 0.020°C. The annual minimum and maximum temperature increased with magnitude values of 0.008°C and 0.016°C, respectively.

**Table 7. Mann-Kendall test results of minimum and maximum temperatures of SDZ, 1979-2019**

| SDZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/Season** | **τ** | **S** | **Þ** | **β** | **τ** | **S** | **þ** | **β** |
| January | 0.03 | 32 | 0.728 | 0.003 | 0.40 | 330 | 0.000 | 0.022* |
| February | 0.03 | 26 | 0.779 | 0.003 | 0.31 | 260 | 0.004 | 0.025* |
| March | 0.17 | 146 | 0.103 | 0.011 | 0.19 | 160 | 0.074 | 0.017 |
| April | 0.23 | 194 | 0.030 | 0.013** | 0.05 | 44 | 0.629 | 0.005 |
| May | 0.17 | 146 | 0.103 | 0.009 | -0.14 | -118 | 0.189 | -0.015 |
| June | 0.23 | 196 | 0.029 | 0.011** | 0.11 | 96 | 0.286 | 0.011 |
| July | 0.37 | 310 | 0.001 | 0.015* | 0.19 | 160 | 0.074 | 0.013 |
| August | 0.45 | 374 | <0.0001 | 0.019* | 0.31 | 254 | 0.004 | 0.019* |
| September | 0.36 | 299 | 0.001 | 0.014* | 0.10 | 84 | 0.351 | 0.008 |
| October | 0.30 | 252 | 0.005 | 0.016* | 0.17 | 142 | 0.113 | 0.013 |
| November | 0.20 | 166 | 0.064 | 0.016 | 0.26 | 21 | 0.016 | 0.018** |
| December | 0.13 | 108 | 0.229 | 0.017 | 0.19 | 160 | 0.074 | 0.019 |
| *Winter* | *0.02* | *18* | *0.849* | *0.002* | *0.40* | *334* | *0.000* | *0.023** |
| *Summer* | *0.17* | *144* | *0.108* | *0.009* | *0.00* | *2* | *0.991* | *0.000* |
| *SWM* | *0.42* | *344* | *0.000* | *0.016** | *0.28* | *230* | *0.010* | *0.014*** |
| *NEM* | *0.26* | *216* | *0.016* | *0.014*** | *0.30* | *252* | *0.005* | *0.017** |
| *Annual* | *0.31* | *258* | *0.004* | *0.013** | *0.34* | *280* | *0.002* | *0.013** |

*Note : T indicates Kendell's rank correlation coefficient, S indicates Kendell score, p indicates Level of significance, β indicates Sen's slope; *, ** & *** indicates 1%, 5% and 10% level of significance, respectively*

**Table 8. Mann-Kendall test results of minimum and maximum temperatures of STZ, 1979-2019**

| STZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/season** | **T** | **S** | **Þ** | **β** | **T** | **S** | **þ** | **β** |
| January | -0.05 | -46 | 0.613 | -0.006 | 0.49 | 402 | <0.0001 | 0.027* |
| February | -0.03 | -32 | 0.728 | -0.003 | 0.41 | 342 | 0.000 | 0.033* |
| March | 0.10 | 88 | 0.328 | 0.006 | 0.33 | 274 | 0.002 | 0.022* |
| April | 0.21 | 176 | 0.049 | 0.012** | 0.11 | 94 | 0.296 | 0.009 |
| May | 0.10 | 86 | 0.340 | 0.006 | 0.10 | 84 | 0.194 | 0.001 |
| June | 0.14 | 116 | 0.196 | 0.008 | -0.10 | -88 | 0.328 | 0.028 |
| July | 0.26 | 218 | 0.015 | 0.012* | 0.12 | 102 | 0.257 | 0.008 |
| August | 0.31 | 258 | 0.004 | 0.016* | 0.36 | 302 | 0.001 | 0.022* |
| September | 0.19 | 162 | 0.071 | 0.010 | 0.12 | 98 | 0.276 | 0.007 |
| October | 0.20 | 170 | 0.058 | 0.012 | 0.16 | 134 | 0.135 | 0.013 |
| November | 0.12 | 106 | 0.238 | 0.013 | 0.34 | 282 | 0.002 | 0.025* |
| December | 0.09 | 76 | 0.400 | 0.011 | 0.28 | 232 | 0.009 | 0.021* |
| Winter | -0.05 | -48 | 0.598 | -0.006 | 0.52 | 426 | <0.0001 | 0.030* |
| Summer | 0.18 | 150 | 0.094 | 0.009*** | 0.10 | 88 | 0.328 | 0.006 |
| SWM | 0.26 | 220 | 0.014 | 0.011* | 0.25 | 208 | 0.020 | 0.014** |
| NEM | 0.16 | 136 | 0.129 | 0.011 | 0.36 | 296 | 0.001 | 0.020* |
| Annual | 0.20 | 170 | 0.058 | 0.008*** | 0.46 | 382 | <0.0001 | 0.016* |

*Note: T indicates Kendell's rank correlation coefficient,S indicates Kendell score,p indicates Level of significance ,β indicates Sen's slope *,** &*** indicates 1%,5% and 10% significance respectively*

**Table 9. Mann-Kendall test results of minimum and maximum temperatures of NTZ 1979-2019**

| | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| **Month/season** | **T** | **S** | **þ** | **β** | **T** | **S** | **þ** | **β** |
| January | -0.23 | -192 | 0.032 | -0.022** | 0.35 | 286 | 0.001 | 0.023* |
| February | -0.02 | -22 | 0.814 | -0.004 | 0.34 | 280 | 0.002 | 0.031* |
| March | 0.01 | 12 | 0.902 | 0.001 | 0.24 | 196 | 0.029 | 0.022** |
| April | 0.11 | 92 | 0.307 | 0.009 | 0.21 | 174 | 0.052 | 0.016** |
| May | 0.05 | 46 | 0.613 | 0.003 | 0.05 | 40 | 0.661 | 0.003 |
| June | 0.08 | 72 | 0.425 | 0.004 | 0.02 | 12 | 0.902 | 0.003 |
| July | 0.15 | 130 | 0.147 | 0.006 | 0.05 | 40 | 0.661 | 0.004 |
| August | 0.12 | 8 | 0.12 | 0.000 | 0.46 | 378 | <0.0001 | 0.025* |
| September | 0.05 | 46 | 0.613 | 0.003 | 0.08 | 64 | 0.479 | 0.005 |
| October | 0.03 | 29 | 0.753 | 0.002 | 0.08 | 64 | 0.479 | 0.011 |
| November | 0.01 | 10 | 0.919 | 0.003 | 0.40 | 328 | 0.000 | 0.030* |
| December | -0.04 | -36 | 0.694 | -0.004 | 0.37 | 302 | 0.001 | 0.029* |
| Winter | -0.16 | -138 | 0.124 | -0.010 | 0.42 | 348 | <0.0001 | 0.026* |
| Summer | 0.08 | 70 | 0.438 | 0.005 | 0.18 | 146 | 0.103 | 0.011 |
| SWM | 0.18 | 148 | 0.099 | 0.006*** | 0.18 | 150 | 0.094 | 0.012*** |
| NEM | 0.00 | 6 | 0.955 | 0.000 | 0.33 | 274 | 0.002 | 0.022* |
| Annual | 0.01 | 14 | 0.884 | 0.001 | 0.52 | 426 | <0.0001 | 0.016* |

*Note : T indicates Kendell's rank correlation coefficient,S indicates Kendell score,p indicates Level of significance ,β indicates Sen's slope *,** &*** indicates 1%,5% and 10% significance respectively*

### 3.8 Trend in Temperature of North Transition Zone (NTZ) during 1979-2019

The zone consists (Map 8) of Belagavi, Dharwad and Haveri districts with 14 taluks. It has an area of about 1.13 Mha. The annual rainfall is > 850mm. The results (Table 9) revealed that, minimum temperature has decreased in January but increased in South west monsoon with magnitude of -0.022 and 0.006°C, respectively. The maximum temperature increased significantly in January, February, March, April, August, November and December during 1969 to 2019. The highest magnitude of maximum temperature recorded in 0.031° C in February. The seasonal maximum temperature increased in winter, South west monsoon, North east

monsoon with magnitude of 0.026, 0.012 and 0.022°C, respectively. The annual maximum temperature increased by 0.016°C in NTZ during forty years.

### 3.9 Trend of Temperature in Hilly Zone (HZ) during 1979-2019

The hilly zone consists (Map 9) of Uttara Kannada, Chikmagalur, Kodagu and Belagum. The geographical area is 2.27 Mha. The results of Mann Kendall analysis test (Table 10) revealed a marked decrease in the mean minimum and maximum temperature. The decrease in temperature was recorded in all months and seasons. The magnitude of monthly mean minimum temperature ranges from -0.023 to 0.038°C. The monthly mean maximum temperature decreased with magnitude ranging from -0.037 to -0.070°C. The annual maximum temperature recorded a decrease by -0.05°C in Hilly zone.

### 3.10 Trend of Temperature in Coastal Zone (CZ) during 1979-2019

This zone consists two districts (Map 10) Uttar Kannada and Dakshina Kannada with 13 Taluks. The geographical area of this zone is 0.98 Mha. The results revealed that the magnitude of mean minimum temperature of July and August increased by 0.010 and 0.015°C, respectively (Table 11). In south west monsoon the mean minimum temperature increased by 0.01°C during 1979 to 2019. The maximum temperature during the same period increased significantly in January, February, March, August, November, and December with magnitude of 0.027, 0.038, 0.022, 0.024, 0.027, 0.024 and 0.032°C, respectively. The mean maximum temperature of South west monsoon and north east monsoon recorded an increase of 0.014 °C and 0.021°C, respectively. The annual maximum temperature of coastal zone increased with magnitude of 0.018°C.

### 3.11 Comparative Analysis of Seasonal trends of Minimum and maximum temperature for Agro Climatic Zones of Karnataka 1978-79 to 2018-19

The significant increase in trend of monthly minimum temperature was more often found in EDZ, SDZ and STZ when compared to other agro climatic zones. The magnitude of monthly minimum temperature ranged 0.01 to 0.19°C. The highest magnitude of change in monthly mean minimum temperature noticed in August (Table 12). The positive magnitude of 0.019°C recorded in EDZ and SDZ but STZ recorded with 0.016°C in minimum temperature of August. The change in mean monthly maximum temperature found in all agro climatic zones. The highest magnitude of maximum temperature

**Table 10. Mann-Kendall test results of minimum and maximum temperatures of HZ, 1979- 2019**

| HZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| Month/Season | T | S | þ | β | T | S | þ | β |
| January | -0.35 | -288 | 0.001 | -0.032* | -0.75 | -618 | <0.0001 | -0.053* |
| February | -0.41 | -338 | 0.000 | -0.030* | -0.68 | -562 | <0.0001 | -0.056* |
| March | -0.56 | -462 | <0.0001 | -0.035* | -0.7 | -576 | <0.0001 | -0.070* |
| April | -0.57 | -472 | <0.0001 | -0.038* | -0.66 | -548 | <0.0001 | -0.074* |
| May | -0.65 | -538 | <0.0001 | -0.041* | -0.68 | -560 | <0.0001 | -0.083* |
| June | -0.61 | -504 | <0.0001 | -0.036* | -0.48 | -394 | <0.0001 | -0.053* |
| July | -0.64 | -526 | <0.0001 | -0.031* | -0.48 | -398 | <0.0001 | -0.042* |
| August | -0.52 | -442 | <0.0001 | -0.029* | -0.37 | -308 | 0.001 | -0.037* |
| September | -0.53 | -442 | <0.0001 | -0.031* | -0.46 | -384 | <0.0001 | -0.046* |
| October | -0.52 | -428 | <0.0001 | -0.031* | -0.55 | -452 | <0.0001 | -0.052* |
| November | -0.30 | -248 | 0.006 | -0.027* | -0.56 | -462 | <0.0001 | -0.044* |
| December | -0.26 | -220 | 0.014 | -0.023* | -0.68 | -562 | <0.0001 | -0.049* |
| Winter | -0.41 | -340 | 0.000 | -0.030* | -0.78 | -644 | <0.0001 | -0.054* |
| Summer | -0.64 | -526 | <0.0001 | -0.039* | -0.74 | -610 | <0.0001 | -0.076* |
| SWM | -0.60 | -494 | <0.0001 | -0.031* | -0.53 | -436 | <0.0001 | -0.043* |
| NEM | -0.46 | -380 | <0.0001 | -0.029* | -0.64 | -526 | <0.0001 | -0.049* |
| Annual | -0.66 | -546 | <0.0001 | -0.032* | -0.79 | -650 | <0.0001 | -0.055* |

*Note: T indicates Kendell's rank correlation coefficient,S indicates Kendell score,p indicates Level of significance ,β indicates Sen's slope *,** &*** indicates 1%,5% and 10% level of significance respectively*

**Table 11. Mann-Kendall test results of minimum and maximum temperatures of, CZ 1979 to 2019**

| CZ | Minimum Temperature | | | | Maximum temperature | | | |
|---|---|---|---|---|---|---|---|---|
| Month/Season | T | S | þ | β | T | S | þ | β |
| January | -0.14 | -122 | 0.174 | -0.016 | 0.46 | 384 | <0.0001 | 0.027* |
| February | 0.00 | 6 | 0.955 | 0.001 | 0.44 | 366 | <0.0001 | 0.038* |
| March | 0.09 | 78 | 0.387 | 0.002 | 0.33 | 276 | 0.002 | 0.022* |
| April | 0.21 | 174 | 0.052 | 0.013 | 0.16 | 138 | 0.124 | 0.013 |
| May | 0.11 | 90 | 0.317 | 0.006 | -0.04 | -36 | 0.694 | -0.004 |
| June | 0.12 | 98 | 0.276 | 0.006 | 0.08 | 68 | 0.452 | 0.010 |
| July | 0.23 | 192 | 0.032 | 0.010* | 0.12 | 98 | 0.276 | 0.008 |
| August | 0.30 | 249 | 0.005 | 0.015* | 0.41 | 340 | 0.000 | 0.024* |
| September | 0.18 | 148 | 0.099 | 0.009 | 0.11 | 96 | 0.286 | 0.007 |
| October | 0.17 | 142 | 0.113 | 0.009 | 0.15 | 124 | 0.167 | 0.012 |
| November | 0.10 | 86 | 0.34 | 0.011 | 0.38 | 314 | 0.000 | 0.027* |
| December | 0.05 | 48 | 0.598 | 0.008 | 0.36 | 300 | 0.001 | 0.024* |
| *Winter* | -0.07 | -62 | 0.493 | -0.010 | 0.52 | 432 | <0.0001 | 0.032* |
| *Summer* | 0.16 | 134 | 0.135 | 0.009 | 0.15 | 128 | 0.154 | 0.009 |
| *SWM* | 0.26 | 218 | 0.015 | 0.014* | 0.27 | 222 | 0.013 | 0.014* |
| ***NEM*** | 0.12 | 102 | 0.257 | 0.009 | 0.36 | 300 | 0.001 | 0.021* |
| ***Annual*** | 0.14 | 116 | 0.196 | 0.005 | 0.52 | 426 | <0.0001 | 0.018* |

*Note : T indicates Kendell's rank correlation coefficient, S indicates Kendell score, p indicates Level of significance, β indicates Sen's slope *,** & *** indicates 1%, 5% and 10% level of significance, respectively*

**Table 12. Trend and Magnitude of Minimum Temperature in Agro climatic zones of Karnataka**

| Month /Season | Minimum Temperature | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NETZ | NEDZ | NDZ | CDZ | EDZ | SDZ | STZ | NTZ | HZ | CZ |
| Jan | -0.029** | - | -0.018** | - | - | - | - | - | -0.032* | - |
| Feb | - | - | - | - | - | - | - | - | -0.030* | - |
| Mar | - | - | - | - | 0.01* | - | - | - | -0.035* | - |
| Apr | - | - | - | - | - | 0.013** | 0.012*** | - | -0.038* | - |
| May | - | - | - | - | - | | | - | -0.041* | |
| June | - | - | - | 0.010*** | 0.01* | 0.011** | | - | -0.036* | |
| July | | | 0.008*** | 0.013* | 0.01* | 0.015* | 0.012** | - | -0.031* | 0.010* |

| Month /Season | Minimum Temperature | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NETZ | NEDZ | NDZ | CDZ | EDZ | SDZ | STZ | NTZ | HZ | CZ |
| Aug | 0.012* | 0.010* | 0.009* | 0.015* | 0.01* | 0.019* | 0.016* | - | -0.039* | 0.015* |
| Sept | - | - | - | 0.010* | 0.01* | 0.014* | - | - | -0.031* | 0.00* |
| Oct | - | - | - | 0.012* | 0.01* | 0.016* | - | - | -0.031* | - |
| Nov | - | - | - | - | - | - | - | - | -0.027* | - |
| Dec | - | - | - | - | - | - | - | - | -0.023* | - |
| Winter | -0.02* | -0.022** | -0.016*** | - | - | - | - | - | -0.030* | - |
| Summer | - | - | - | | 0.00*** | 0.00 | 0.009* | | -0.039* | - |
| SWM | 0.00** | 0.00* | 0.006** | 0.012* | 0.01*** | 0.016* | 0.011*** | 0.006*** | -0.031* | 0.011* |
| NEM | - | - | - | -- | 0.01*** | 0.014** | - | - | -0.029* | - |
| Annual | - | - | - | - | 0.010*** | 0.013* | 0.003*** | - | -0.032* | - |

****,** and * indicates 1%,5% and 19% level of significance respectively*

**Table 13. Trend and magnitude of Maximum Temperature in Agro climatic zones of Karnataka**

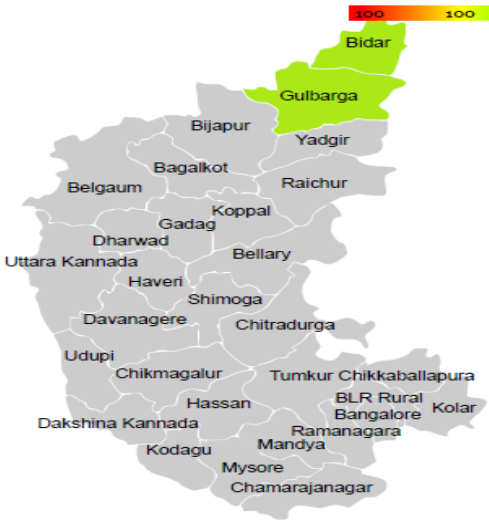
| Month/ Season | Maximum Temperature | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NETZ | NEDZ | NDZ | CDZ | EDZ | SDZ | STZ | NTZ | HZ | CZ |
| Jan | 0.030* | 0.036* | 0.024* | 0.023* | 0.02* | 0.022* | 0.027* | 0.023* | -0.053* | 0.027* |
| Feb | - | - | 0.027* | 0.020** | - | 0.025* | 0.033* | 0.031* | -0.056* | 0.038* |
| Mar | - | - | 0.018** | - | - | - | 0.022* | 0.022** | -0.070* | 0.022* |
| April | - | - | - | - | - | - | - | 0.016** | -0.074* | - |
| May | - | - | - | - | - | - | - | - | -0.083* | - |
| June | - | - | - | - | - | - | - | - | -0.053* | - |
| July | - | - | - | 0.013*** | - | - | - | - | -0.042* | - |
| Aug | 0.019* | 0.023* | 0.023** | 0.018* | 0.01* | 0.019* | 0.022* | 0.025* | -0.037* | 0.024* |
| Sept | - | - | - | - | - | - | - | - | -0.046* | - |
| Oct | - | - | - | | - | - | - | - | -0.052* | - |
| Nov | 0.045* | 0.041* | 0.031* | 0.017** | - | 0.018** | 0.025* | 0.030* | -0.044* | 0.027* |
| Dec | 0.045* | | 0.031* | - | 0.01* | | 0.021* | 0.029* | -0.049* | 0.024* |
| Winter | 0.024** | 0.026* | 0.026* | 0.021** | 0.01*** | 0.023* | 0.030** | 0.026** | -0.054* | 0.032* |
| Summer | - | - | - | - | - | - | - | - | -0.076* | - |
| SWM | - | - | - | 0.011*** | 0.09* | 0.014** | 0.014** | 0.012*** | -0.043* | 0.014* |
| NEM | 0.035*** | 0.033* | 0.023* | 0.015* | 0.01** | 0.017* | 0.020* | 0.022* | -0.049* | 0.021* |
| Annual | 0.018*** | 0.017* | 0.014* | 0.01*** | 0.010* | 0.013* | 0.016* | 0.016* | -0.055* | 0.018* |

****,** and * indicates 1%,5% and 10% level of significance respectively*

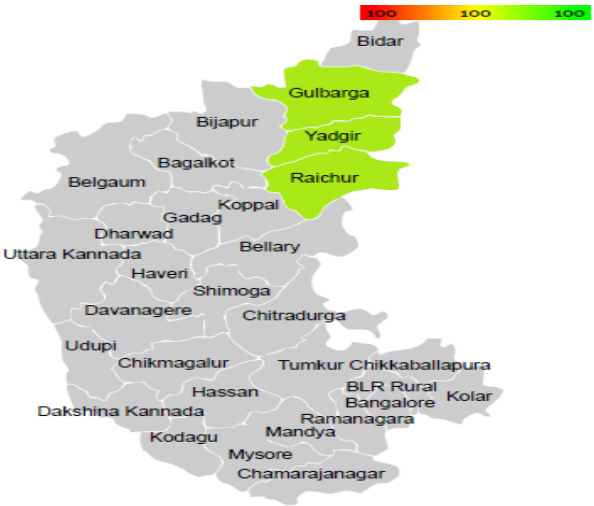
recorded in NEDZ and EDZ is in January with 0.036 & 0.021°C respectively. Similarly, magnitude noticed in NDZ & NETZ is in November with 0.031 & 0.045°C respectively. The magnitude in agro climatic zones like CDZ, SDZ, NTZ, STZ &CZ is in February with 0.020, 0.025, 0.031, 0.033 & 0.038°C respectively.

The HZ noticed with negative magnitude slope in both maximum and minimum temperature with -0.041 & -0.083°C respectively in month of May. The change in maximum temperature in majority of the zones noticed in February. The change in the seasonal minimum temperature occurred in South west monsoon across NDZ, CDZ, EDZ, SDZ, NTZ, STZ and CZ. The highest magnitude noticed in SDZ with 0.016 and lowest in HZ with -0.031. The annual minimum temperature noticed in EDZ, SDZ and STZ with magnitude slope of 0.010, 0.0.013 and 0.08°C respectively. The change in the seasonal maximum temperature (Table 13) occurred during winter, NEM and annual across all ten agro climatic zones. The highest annual maximum temperature for 40 years occurred in NETZ and CZ with magnitude of 0.018°C. To sum up, the change in annual mean minimum and maximum temperature across agro climatic zones lies between 0.010 to 0.018°C for forty years.

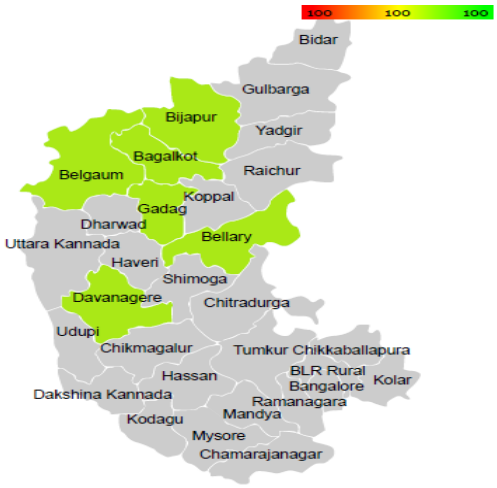
**Map showing different Agro Climatic Zones of Karnataka state**



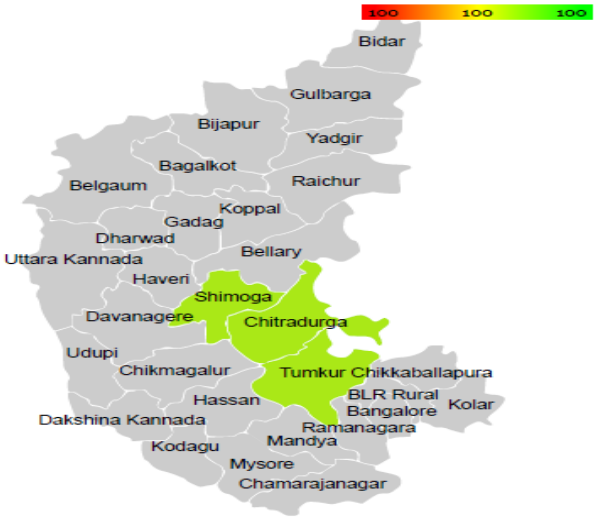

**Map 1. ACZ-I -NETZ**



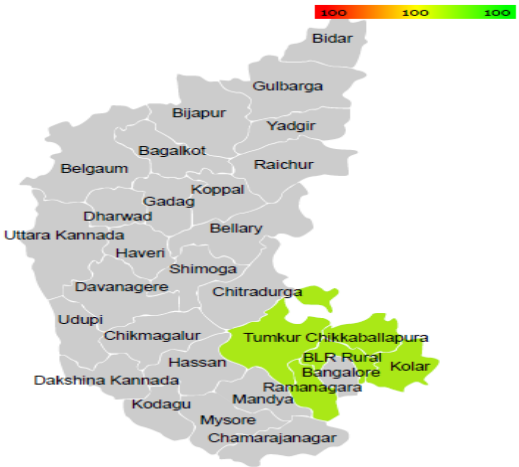

**Map 2. ACZ-II -NEDZ**



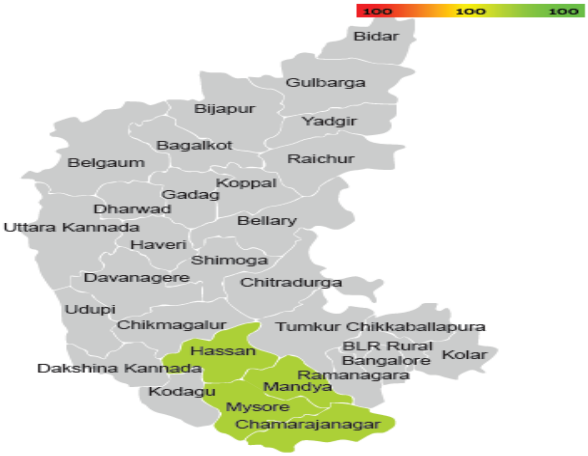

**Map 3. ACZ-III -NDZ**



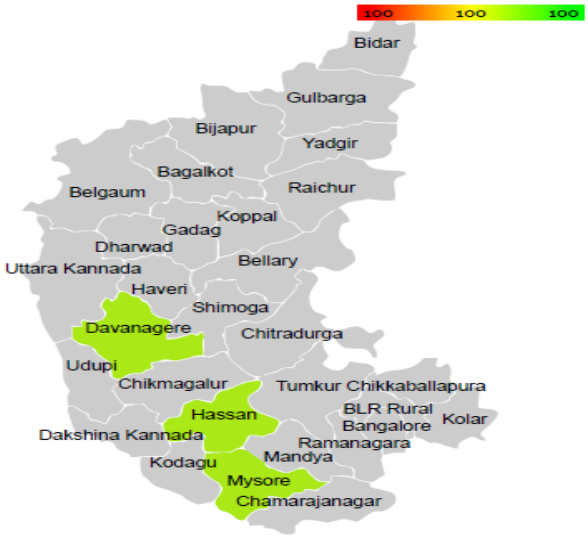

**Map 4. ACZ-IV -CDZ**



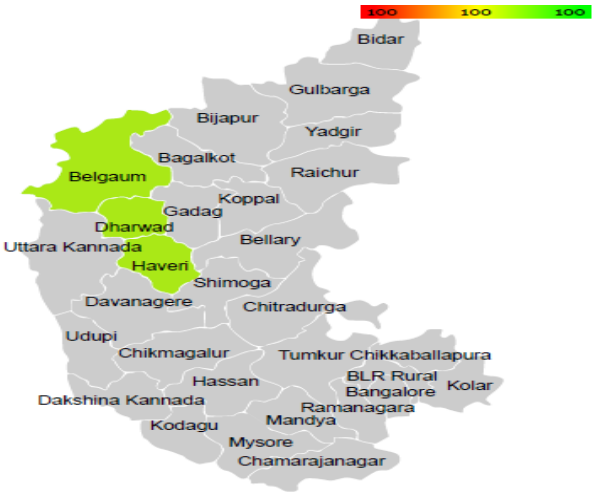

**Map 5. ACZ-V -EDZ**



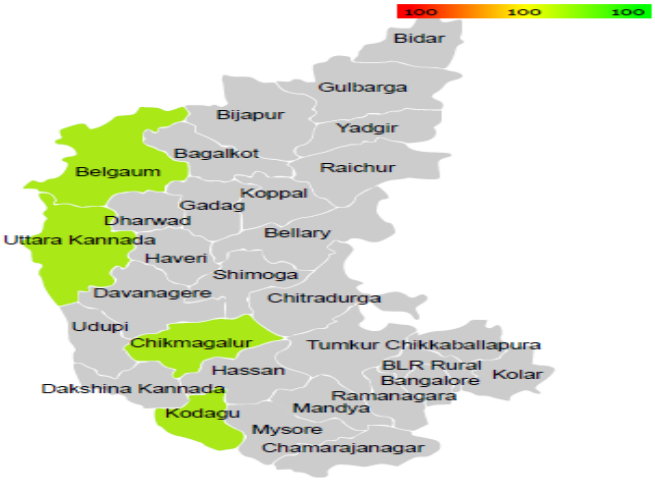

**Map 6. ACZ-VI -SDZ**



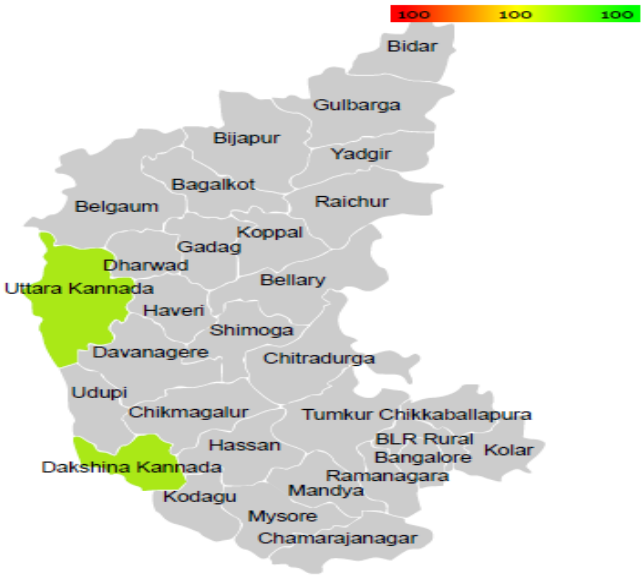

**Map 7. ACZ-VII -STZ**




**Map 8. ACZ-VIII- NTZ**




**Map 9. ACZ-IX -HZ**




**Map 10. ACZ-X -CZ**

## 4. CONCLUSION

Through Mann Kendall trend analysis (MKT), it is clearly found that, there is a significant increase and shifts in both minimum and maximum temperature across climatic zones. The Kendall rank measures strength and direction between variables. The positive sign indicates increase of temperature and negative sign indicates decrease of temperature. The Sen's slope further measure the change in magnitude of slope in temperature at 1, 5 & 10% level of significance. The annual minimum temperature noticed in EDZ, SDZ and STZ with magnitude slope of 0.010, 0.0.013 and 0.08°C respectively. The change in the seasonal maximum temperature occurred during winter, NEM and annual across all ten agro climatic zones. The highest annual maximum temperature for 40 years occurred in NETZ and CZ with magnitude of 0.018°C. To sum up, the change in annual mean minimum and maximum temperature across agro climatic zones lies between 0.010 to 0.018°C for forty years. Therefore, there is a need for government programs to educate farmers and provide them with more localized information on climate forecasts, climate change and droughts. Further, an implementation of meteorological departments in large number for better weather information which helps in improving the reliability of drought predictions.

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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