Abstract - In this study, ETo was calculated using FAO-56 Penman Monteith method. Lag-1 autocorrelation coefficient was performed to detect the presence of serially correlation in data series. Mann-Kendall (MK) or Modified Mann Kendall (MMK) and Spearman’s rho test were applied to detect the trend in annual and monthly ETo at 8 districts over 49 years (1960–2008) in the Soenath river basin, Chhattisgarh (India). The slopes of trend lines were computed using the Theil–Sen’s slope estimator. The increasing trends in ETo were more pronounced than the decreasing trends. Annual analysis of the ETo series indicated a increasing trend in almost all the districts except Bilaspur district. The percentage change in annual ETo was maximum for Raipur (1.72%) and minimum for Bilaspur (-1.41%). On the monthly time scale increasing trends were identified in ETo data in most of the months. The significant positive trend magnitude was found for the months of September, October and November with Theil–Sen’s slope equal to 1.08, 1.15 and 1.30 mm/year. The Coefficient of Variability (CV) revealed that inter-annual variability was high in the whole river basin, with highest variability noticed for Durg district (104.31%).

Keywords – Reference Evapotranspiration, Mann-Kendall, Penman–Monteith equation Coefficient of variation, autocorrelation coefficient

I. INTRODUCTION

Now a day’s extensive concern has been shown to climate variability and its effect on the hydrological cycle and water supply (Schwartz & Randall, 2003). Many of the researchers perceive climate changes, trends and variability in various parts of the world utilizing some climate parameters such as air temperature, rainfall depth, reference evapotranspiration ETo and pan evapotranspiration ETp (Schwartz & Randall, 2003; Garbrecht et al., 2004; Hegerl et al., 2007; Fu et al., 2009; Saghravani et al., 2009; Hakan et al., 2010). Evapotranspiration is an important parameter for irrigation scheduling and regional water allocation. The changes in ETo are of great influence on agricultural water use planning, irrigation system design and management. Thus, analysis of trend and variation of ETo will help us to understand climate change and its effect on hydrology. A few studies have assessed ETo in the prospects of its temporal variation. Xu et al., 2006 analyzed the temporal trend of ETo and pan evaporation (Epan) in the Changjiang River basin and found a significant decreasing trend during 1961–2000 by statistical methods (parametric T-test and non-parametric Mann–Kendall test) for both ETo and Epan dataset. Mo et al., 2004 simulated evapotranspiration and analyzed its seasonal and annual variation from 1984 to 1997 in the Lushi basin in a mountainous region. Tong et al., 2007 analyzed the temporal variation of spring wheat evapotranspiration in the last 50 years and tested the trend of ETo by the Mann–Kendall test and linear regression analysis. Trajkovic et al., 2003 used an extended Kalman filter in conjunction with an artificial neural network to forecast ETo in time. While these studies to some extent addressed seasonal and annual variation and long term patterns of ETo. Spatial and temporal trends and variability is an important aspect of trend analysis of any hydro-meteorological parameter in any region.

Therefore, the present study is undertaken with the four objectives, which are as follows: (1) to estimate the monthly and annual ETo time series using the FAO-56 Penman Monteith (PM) method, and to detect the monotonic linear trends in the ETo time series using the MK non-parametric test and Spearman’s rho parametric methods.
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The Seonath river basin is the longest tributary of the Mahanadi basin. It rises in an undulating region with numerous small groups of hills at an elevation of about 533m near Kotgal and flows for about 383km to join the Mahanadi on its left near Kharghand in Bilaspur district of Chhattisgarh, India. The Seonath River originates near village Panabaras in the Rajnandgaon district. The Basin is located between latitude 20°16' N to 22°41' N and Longitude 80°25' E to 82°35' E. The drainage area of the Seonath river basin is 30,860 Sq km. The river traverses a length of 380 km. The main tributaries of Seonath river basin are Tandula, Kharun, Arpa, Hamp, Agar and Maniyari rivers. The mean annual rainfall in the basin varies from 1005 mm to 1255 mm. Seonath river basin comprises 25% of the catchment of the Mahanadi basin. The main soil types found in the basin are Black soil and Red soil.

The daily meteorological data of eight districts falls under entire Seonath river basin for a period of 1960 to 2008 (49 years) were collected from India Meteorological Department (IMD), Pune, and State Data Centre, Department of Water Resources, Raipur (Chhattisgarh) to examine the spatial and temporal trend and variability of ETo. The information about the stations is presented in Table 1. The geographical locations of meteorological stations are shown in Figure 1.

<table>
<thead>
<tr>
<th>Districts</th>
<th>Latitude (Degree Decimals)</th>
<th>Longitude (Degree Decimals)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raipur</td>
<td>21.25</td>
<td>81.65</td>
<td>307.0</td>
</tr>
<tr>
<td>Bilaspur</td>
<td>21.99</td>
<td>82.11</td>
<td>670.0</td>
</tr>
<tr>
<td>Durg</td>
<td>20.75</td>
<td>81.13</td>
<td>288.0</td>
</tr>
<tr>
<td>Damtari</td>
<td>20.70</td>
<td>81.55</td>
<td>305.0</td>
</tr>
<tr>
<td>Jhangir-Champa</td>
<td>20.27</td>
<td>81.49</td>
<td>402.0</td>
</tr>
<tr>
<td>Kawardha</td>
<td>22.21</td>
<td>81.20</td>
<td>353.0</td>
</tr>
<tr>
<td>Korba</td>
<td>22.35</td>
<td>82.68</td>
<td>304.8</td>
</tr>
<tr>
<td>Rajnandgaon</td>
<td>21.53</td>
<td>81.02</td>
<td>307.0</td>
</tr>
</tbody>
</table>

Figure 1. Location of the study area and distribution of meteorological station

III. METHODOLOGY ADOPTED

The FAO-56 Penman-Monteith (PM) method is recommended for determining ETo, was used in this study to compute the daily ETo of the Seonath River basin with necessary meteorological data. The Mann-Kendall trend test and Spearman’s rho test were selected to establish ETo trends; the trend magnitude was determined by Theil-
Sen’s method. The CUSUM and cumulative deviation test were used for change point detection. The coefficient of variation was used to determine monthly and annual variation patterns of ETo in sub regions of the Seonath River basin.

A. Penman-Monteith (PM) method-

The PM method has been recommended for determining ETref by FAO (Allen et al., 1998; Xu et al., 2006; Elnesr et al., 2010; Tabari et al., 2011; Wang et al., 2011) and is used in this study. The method has been selected because it is physically based and explicitly incorporates both physiological and aerodynamic parameters (Xu et al., 2006).

B. Homogeneity Test-

Monthly and annual ETo were analyzed using double mass curve to check the homogeneity of the data series.

C. Dependency Test (Autocorrelation coefficient)-

The dependency of ETo dataset was computed using lag 1 serial correlation coefficient. Presence of positive or negative autocorrelation affects the detection of trend in a series (Hamed & Rao, 1998; Yue et al., 2002, 2003; Cunderlik & Burn, 2004; Novotny & Stefan, 2007). With a positively auto-correlated series, there are more chances of a series being detected as having trend while there may be actually none. If the r1 value fall within the confidence interval, the data are assumed to be serially independent otherwise the sample data are considered to be significant serially correlated. Lag-1 autocorrelation coefficient is used to detect the presence of serially correlation in data series. In this study, almost all the series are found to be non-correlated except few of the series are correlated (Table 2).

D. Statistical Test for Trend and Variability Analysis-

a) Mann–Kendall Test (Non-parametric)

The Mann-Kendall test (Yu et al., 1993; Douglas et al., 2000; Yue et al., 2003; Burn et al., 2004, Singh et al., 2008a, b) is used to detect monocotic (increasing or decreasing) trends and is widely used for detecting trends in time series because it is simple, robust, accommodates missing values, and the data need not conform to any statistical distribution (Libiseller & Grimvall, 2002; Gilbert, 1987). Since there are chances of outliers to be present in the dataset, the non-parametric Mann–Kendall test is useful because its statistic is based on the (+ or -) signs, rather than the values of the random variable, and therefore, the trends determined are less affected by the outliers (Helsel & Hirsch, 1992; Birsan et al., 2005).

b) Spearman’s rho (Parametric)

This is a rank-based test for correlation between two variables that can be used to test for a correlation between time and the data series (Siegel & Castellan 1988).

c) Theil-Sen’s Slope Estimator

In addition to identify whether a trend exists, the magnitude of a trend was also estimated by a slope estimator β, which was extended by Hirsch et al., 1982 from that proposed by Sen (1968). β is the robust estimate of the trend magnitude. In other words, the slope estimator β is the median over all possible combinations of pairs for the whole data set Hirsch et al., 1982. A positive value of β indicates an ‘upward trend’ (increasing values with time), while a negative value of β indicates a ‘downward trend’ Xu et al. 2007; Karpozos et al., 2010.

d) Percentage Change

Some trends may not be evaluated to be statistically significant while they might be of practical interest and vice versa. For the present study, change percentage has been computed by approximating it with a linear trend. That is change percentage equals median slope multiplied by the period length divided by the corresponding mean, expressed as percentage (Pc) followed by Yue & Hashino, 2003.
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E. Shift Detection Methods-

a) Cumulative deviations

For testing the homogeneity of the dataset, the cumulative deviation test (Buishand, 1982) suggested by the World Meteorological Organization (WMO), was undertaken to verify the presence of trends in historical records. (The test is relatively powerful in comparison with other tests (e.g. Worsley likelihood ratio test; Buishand, 1982) for a change-point that occurs towards the centre.

b) CUSUM test

This non-parametric rank-based method tests whether the means in two parts of a record are different for an unknown time of change. In particular, successive observations are compared with the median of the series in order to detect a change in the mean of a time series after a number of observations (McGilchrist & Woodyer, 1975; Chiew & McMahon, 1993; Kundzewicz & Robson, 2004). The test statistic $V_k$ of a time series data is the cumulative sum (CUSUM) of the $k$ signs of the difference from the median (a series of values of -1 or +1) starting from the beginning of the series.

F. Statistical Procedure for Rainfall Variability Analysis (Coefficient of Variation)-

The coefficient of variation (CV) is a statistical measure of how the individual data points vary about the mean value. A greater value of CV is the indicator of larger spatial variability, and vice versa. In this study, annual ETo variability has been analyzed for 8 stations of the Seonath River basin using CV (Landsea & Gray, 1992).

G. Spatial Analysis-

Kriging interpolation (Singh & Chowdhury, 1986; Lebel et al., 1987) is employed to determine the spatial pattern of ETo using Arc GIS 9.3.

IV. RESULTS

The Mann-Kendall and Spearman’s rho test was applied to detect trends of reference evapotranspiration (ETo) for all the selected stations of 8 districts falls under the Seonath river basin, Chhattisgarh. As above, the ETo in the study area followed a clearly increasing trend in the period of investigation. The results of trend analysis of the ETo are presented in Table 2 and Figure 2. The results were clearly showed that Raipur and Jhanjgir-Champa with statistically significant increasing trends at 5% significance levels and rest of the districts with non significant increasing trends except for Bilaspur district. Likewise monthly ETo (mm d$^{-1}$) for most of the districts showed non significant increasing trends. In summary, the results showed that the average monthly ETo for the period of 49 years has significant increasing trend for September, October, November (Figure 3). The magnitudes of trend and percentage changes for annual and monthly ETo are also depicted in the figure 4 & 5. The trend magnitude of annual ETo was increasing for all the districts except for Bilaspur. Whereas for monthly ETo time series decreasing trend magnitude was noticed for March, April and June and rest of the districts showed increasing trend with highest magnitude for the months of September, October and November. The percentage change was highest for two districts viz., Raipur and Jhanjgir-Champa with only one district (Bilaspur) showed downward percentage change. The overall result indicates that the increase in percentage change was noticed for the whole river basin.
Table 2- Result for Trend Analysis of Annual ETo by Spearman’s rho test (at 5% level of significance) with Autocorrelation

<table>
<thead>
<tr>
<th>Districts</th>
<th>Auto corr.</th>
<th>Test Apply</th>
<th>Spearman’s rho</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raipur</td>
<td>N</td>
<td>MK</td>
<td>2.255</td>
<td>Increasing</td>
</tr>
<tr>
<td>Bilaspur</td>
<td>N</td>
<td>MK</td>
<td>-0.935</td>
<td>No Trend</td>
</tr>
<tr>
<td>Durg</td>
<td>N</td>
<td>MK</td>
<td>1.754</td>
<td>No Trend</td>
</tr>
<tr>
<td>Damtari</td>
<td>N</td>
<td>MK</td>
<td>1.634</td>
<td>No Trend</td>
</tr>
<tr>
<td>Jhanjir-Champa</td>
<td>N</td>
<td>MK</td>
<td>2.648</td>
<td>Increasing</td>
</tr>
<tr>
<td>Kawardha</td>
<td>Y</td>
<td>MMK</td>
<td>1.204</td>
<td>No Trend</td>
</tr>
<tr>
<td>Korba</td>
<td>N</td>
<td>MK</td>
<td>0.8</td>
<td>No Trend</td>
</tr>
<tr>
<td>Rajmandgaon</td>
<td>N</td>
<td>MK</td>
<td>0.261</td>
<td>No Trend</td>
</tr>
</tbody>
</table>

Figure 2. Plots of Kendall Z statistic for the annual ETo trend during 1960-2008

Figure 3. Monthly trend of ETo at Seonath river basin over 49 years (1960-2008)
Analysis of Reference Evapotranspiration Variability and Trends in the Seonath River Basin Chhattisgarh

Figure 4. Spatial distribution of annual reference evapotranspiration (ETo) for the Seonath River basin

Figure 5. Monthly ETo trend slope values over 49 years (1960–2008) for the Seonath river basin

A. Change Point Detection-

a) Cumulative Deviation test and Distribution free CUSUM

The results of change point detection for annual ETo time series using the cumulative deviations and CUSUM tests are presented in Table 3. The change points are more consistent with each other by both the test. The most probable change year is 1980 over 49 years period for the entire study area. This is also evident from the data of 2 districts of the river basin.
B. Analysis of Annual ETo Variability Pattern-

a) Assessment of ETo Variability using CV

The variation in ETo is essential from agricultural point of view for precise estimation of supplemental water requirements. The study of ETo variability pattern using CV for a period of 1960-2008 (49 years) for Seonath river basin indicates that the inter-annual variability was highest for the entire river basin (Figure 6). The lowest (29.27%) annual ETo variability is seen in Kanker and the highest (104.3%) in Durg. Overall a high variation in ETo in the Southern region of Seonath river basin is seen.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Change point (CUSUM)</th>
<th>Maximum Deviation</th>
<th>Change point (cumulative deviation test)</th>
<th>Q/n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raipur</td>
<td>1987</td>
<td>8</td>
<td>1977</td>
<td>1.124</td>
</tr>
<tr>
<td>Bilaspur</td>
<td>1980*</td>
<td>9</td>
<td>1980*</td>
<td>1.357</td>
</tr>
<tr>
<td>Durg</td>
<td>1990</td>
<td>7</td>
<td>1977</td>
<td>0.989</td>
</tr>
<tr>
<td>Damtari</td>
<td>1989</td>
<td>8</td>
<td>2007</td>
<td>0.792</td>
</tr>
<tr>
<td>Jhargir-Champa</td>
<td>1987*</td>
<td>10</td>
<td>1977</td>
<td>1.402</td>
</tr>
<tr>
<td>Kawardha</td>
<td>1990</td>
<td>7</td>
<td>1977</td>
<td>0.615</td>
</tr>
<tr>
<td>Korba</td>
<td>1993</td>
<td>6</td>
<td>1980</td>
<td>0.759</td>
</tr>
<tr>
<td>Rajnandgaon</td>
<td>1990</td>
<td>7</td>
<td>1977</td>
<td>1.029</td>
</tr>
</tbody>
</table>

Figure 6. Spatial distribution of inter-annual variability of annual ETo (CV)

V. DISCUSSION

ETo is the most important parameter for agricultural water use planning and water resource management. Historical analysis of daily ETo in the Seonath river basin was carried out using Penman Monteith equation (FAO-56) for 8 stations distributed all over Seonath basin, Chhattisgarh for the period 1960-2008 (49 years). Annual ETo time series analysis indicated a increasing trend in almost all the districts except Bilaspur district. The percentage change in annual ETo was maximum for Raipur (1.72%) and minimum for Bilaspur (-1.41%). On the monthly time
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series increasing trends were identified in ETo data in most of the months excluding March, April and June over 49 years. The positive trend magnitude was found for the months of September, October and November with Theil–Sen’s slope equal to 1.08, 1.15 and 1.30 mm/year. The spatial analysis result shows that the Southern and central region exhibits higher percentage variability over the entire Seonath river basin.

As above, the variability of ETo was determined using CV. CV shows that the variability is high for the entire river basin, with values ranging from 29% to more than 104%. A decrease in ETo and increase in its variability are seen in Southern and Central region. The highest annual variability is experiences in Durg, and lowest in Kanker. The overall results indicate the Southern and Central region have experienced higher variability than the northern part of the study area. These results are valuable for the estimation of precise supplemental irrigation water requirements for kharif crop.

VI. CONCLUSION

Trend and variability of annual and monthly ETo time series were analyzed for 8 stations falls under Seonath river basin, Chhattisgarh (India). The increasing trend has been depicted in almost all the districts for the annual ETo series except Bilaspur exhibit non significant decreasing trend. Most ETo trends showed non significantly positive changes, except for Raipur and Jhanjigar-Champa districts showing significantly increasing trends. The monthly trend analysis indicates that ETo has significant increasing trend for the September, October and November. The trend magnitude and percentage change was highest for the entire Seonath river basin except for Bilaspur district. The results of cumulative deviation test and CUSUM shows that the most probable year of change in annual ETo in the study area is 1980. The spatial distribution of CV indicates low variability for Kanker district and highest variability was noticeable for Durg district during the study period (1960-2008). Thus, the Southern and central part of Seonath river basin has greater variability in ETo than that in the other parts.

REFERENCE