**International Journal of Science Academic Research**
Vol. 02, Issue 07, pp.1907-1922, July, 2021
Available online at http://www.scienceijsar.com

**ISSN: 2582-6425**

**Research Article**

# UNDERSTANDING ETHIOPIA RAINFALL SEASONALITY, TREND AND CYCLIC NATURE FROM TRADITIONAL TIME SERIES ANALYSIS

***Melesse Lemma**

National Meteorological Agency of Ethiopia, Addis Ababa Ethiopia

**Received** 10th May 2021; **Accepted** 18th June 2021; **Published online** 30th July 2021

**Abstract**

The selection of best stations for this study is made by comparing available data set with number of missing months at each station. Stations with 20% and more than 20% missing data are discarded if they are 1st or 3rd class stations and more than 10% if they are synoptic stations. Further securitization of the data is made by looking at the nature of missing data. Stations with more than eleven months successive missing data are eliminated from the analysis even if the percentage of missing data is within the acceptance range. For this study station with less than twenty four years data period have not been considered. A total of 64 stations are selected for the study out of available stations. We have used traditional time series analysis in order to study the time fluctuations of monthly rainfall series of selected stations by decomposing the given monthly rainfall data into its trend, seasonal, cyclic and irregular components. All the sixty four stations data is decomposed into its time series components separately. Trend analysis shows that positive monthly rainfall trend is the case over some parts of central, western south-western and eastern parts while negative trend is the case over the north and south. However the slopes are very small and are not as such very significant. Seasonality is the dominate feature in monthly rainfall records. The maximum zone of seasonal index shifts from one place to the other as the year progresses. In January the maximum zone of seasonal index is located in central and southern Ethiopia where as it shows a slight east ward shift in February. With more additional new higher contours the zone of maximum seasonal index maintains its February's position in March. During April the zone of maximum values shifts to southeast. The north-western parts begin to see better values as compared to previous four months in May. The zone of maximum seasonal index values moves to Amhara region in July and August. In September the maximum is located over parts of western Ethiopia. In October the situation over the south-eastern and southern parts improved. Though there are some differences in values and location of high seasonal rainfall index values there is generally a resemblance in pattern among January, February and March, between July and August, between November and December. The strength of seasonal index is high in the country during July and August and low during January and December. In rainfall regime C all stations have peak seasonality index in April. In August the index gets more pronounced over rainfall regime A. The case when cyclic values are high and what sort of cyclic repetitions occurs have been examined. We have not found any systematic upward and downward regular and uniform cyclic movements in any of the stations. A definite cycle length cannot be defined. However some stations have more number of high cyclic indexes than others. The irregular component varies between 0 and 3 and it does not follow any well defined pattern. How we use time series analysis to forecast monthly and seasonal rainfall of a given station is discussed in the next document of this study.

**Keywords:** Cyclic nature, Seasonality.

## 1. Introduction

Ethiopia, being a tropical country and found in the zone where the rainfall pattern is highly governed by the northward and southward movement and shift of the Inter Tropical Convergence Zone (ITCZ) in association with other semi-permanent and traveling weather systems; the strength of weather generating systems are not identical from year to year and one season to the other which is in fact manifested in the spatial and temporal rainfall variability. Some years are marked by unusually excessive rains and other years are marked by unusually very low rainfall. The time fluctuations of the rains may have distinct and well-organized characteristics. So, it becomes necessary to study the time evolution of Ethiopia rainfall time series and find where and when some distinct and well organized features arise. The time evolution of the recorded rainfall can be seen as composed of different time series components. In statistics a given time series data can be decomposed into four components that arise from its inherent behavior. This method of decomposing time series data into different components are highly used in business and economic applications. They use it for describing time series data, analyzing time series data, and give forecast about the future state of economic and business situations.

***Corresponding Author:** ***Melesse Lemma,*** National Meteorological Agency of Ethiopia, Addis Ababa Ethiopia

In the same way, in the present study, we will make use of statistical traditional time series decomposition techniques to study the characteristics of rainfall time series in Ethiopia by applying it on selected stations data series. In general, the purpose of this study can be seen as separating out selected stations time series data into its four-time series components in order to understand the time evolution, characteristics of the rainfall data and by make use of this knowledge able to give forecast about its future state in advance.

## 2. Objectives

This study has the following objectives:

- Study the time evolution of rainfall in Ethiopia using selected stations data.
- Decompose the rainfall time series data in its trend, seasonal, cyclic and irregular components and quantify them.
- Observe and document the seasonal component of the rainfall data and quantify it.
- Observe and document if there is any significant upward or downward trend in the rainfall data and quantify it.
- Observe and document if there is any long year's cyclic fluctuations in the rainfall data.

- Compare and contrast the patterns of seasonal, trend, cyclic and irregular component among the stations.
- Group stations with identical time series component pattern in the same group and list identified groups.
- Extract out if there is any periodicity in the occurrence of extreme events such as drought and wet years and provide the likely time period occurrence of such cycles.
- Study if it is possible to make prediction, short or long term, based on the decomposed time series components and verifies its success.

## 3. Research questions

The main research question is to understand the time characteristics of the rainfall patterns of the stations under study and use this information in order able to forecast the future state of rainfall.

The following interrelated research questions have been identified.

- Do study of historical time series data and the ability to extract time series components create the opportunity to understand the time characteristics of the rainfall data?
- What kind of periodic, trend, seasonal, cyclic and irregular components of the time series could be derived from this study?
- Could knowledge of the time characteristics and evolution of the rainfall data would give us a reliable confidence to give forecast?

## 4. Data preparation and filling missing gaps

### *4.1 Data preparation*

This type of study needs stations with long and unbroken records. In Ethiopia, currently, NMA is administering more than 1000 meteorological stations. Though the numbers of stations are many and seem to be sufficient for undertaking various meteorological studies and research works, the record length of many of the stations are not long enough and suffer from missing data gaps. Especially over areas where there were war outbreaks it is unlikely to get stations with non-continues missing data. In order to sort out best ones among available stations we have set up a selection criterion. The selection criteria's are as follows:

1) Discard stations with 20% and more than 20% missing data if the station is 1$^{st}$ or 3$^{rd}$ class and more than 10% missing data if the station is a synoptic station. Synoptic stations are 17 in number in the country and have got relatively good data. That is why we set the limit of avoidance to be 10% unlike the 3$^{rd}$ and 1$^{st}$ class stations.

2) Discard a station data if missing data lasts more than eleven consecutive months even if the percentage of missing data is less than the set standard in one.

3) Avoid stations from the analysis if the length of the record is not believed to be sufficient enough for the analysis. In a country like Ethiopia where most meteorological stations contain lot of missing data and established at different years it is not easy to select an arbitrary record length or accept what the analysis requires. In order to get the minimum record length, it becomes necessary to calculate record length and missing data of each station. Based on what we obtained it have been decided that for any station to be considered for this study it must have at least 24 years data. Hence twenty fours years record length taken as to be the minimum. All stations with record length of less than 24 years have not been taken. We could have taken the minimum year to be more than 24 but setting the minimum record length to be more than 24 will leave us with few numbers of stations which in fact lead us to unfair spatial coverage of Ethiopia.

Data filtering task is initiated first by considering synoptic stations. Percentage of missing data is calculated by taking the ratio of number of missing months to total number of months in the given data period and multiplying the result by 100. For example, if we take a station with data period from January 1980 to December 2009, obviously the total number of months for this period is 360. The number of missing months can easily be counted in excel spread sheet. Percentage of missing data is calculated from the formula given below:

$$\% \text{ of missing data} = \frac{\text{number of missing months} \times 100}{\text{total number of months}}$$

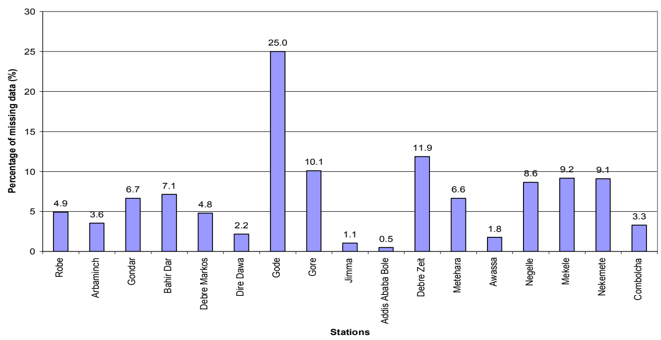



**Fig. 1. Monthly rainfall missing data as percentage of total number of months over synoptic stations**

Graphical representation of percentage of missing data versus synoptic stations is shown in figure 1. The figure shows that two of the stations have percentage of missing data more than 10% and nine of them less than 5%. The stations Addis Ababa Bole and Combolcha with the least percentage of missing data can be noted as the best stations for our purpose. According to the criteria set above, in section 5.1, Gode and Debre Zeit are eliminated from the analysis in the first run. Even if Gode and Debre Zeit happen to have less than 10% missing data they wouldn't be part of the analysis since they have got continuous missing records from 1987-1992 and1991-1993, respectively. The first criteria kicked out two stations. Then the search for stations with more than eleven months continuous missing records launched. We found Negele and Mekele with full year/s missing records in 1992 and 1989 & 1990 respectively. The first two data selection criteria reduce down the number of stations to 13. All the remaining 13 stations satisfy the third criteria. As the number of synoptic stations is not many and do not give well covered and detailed spatial coverage of the county one needs to add some more stations from existing first class stations. One hundred twenty-four first class stations which have relatively long year's records are considered and calculating missing data percentage was performed according to the formula given above. The percentage of missing data in eighty-nine of them is 20% and more.

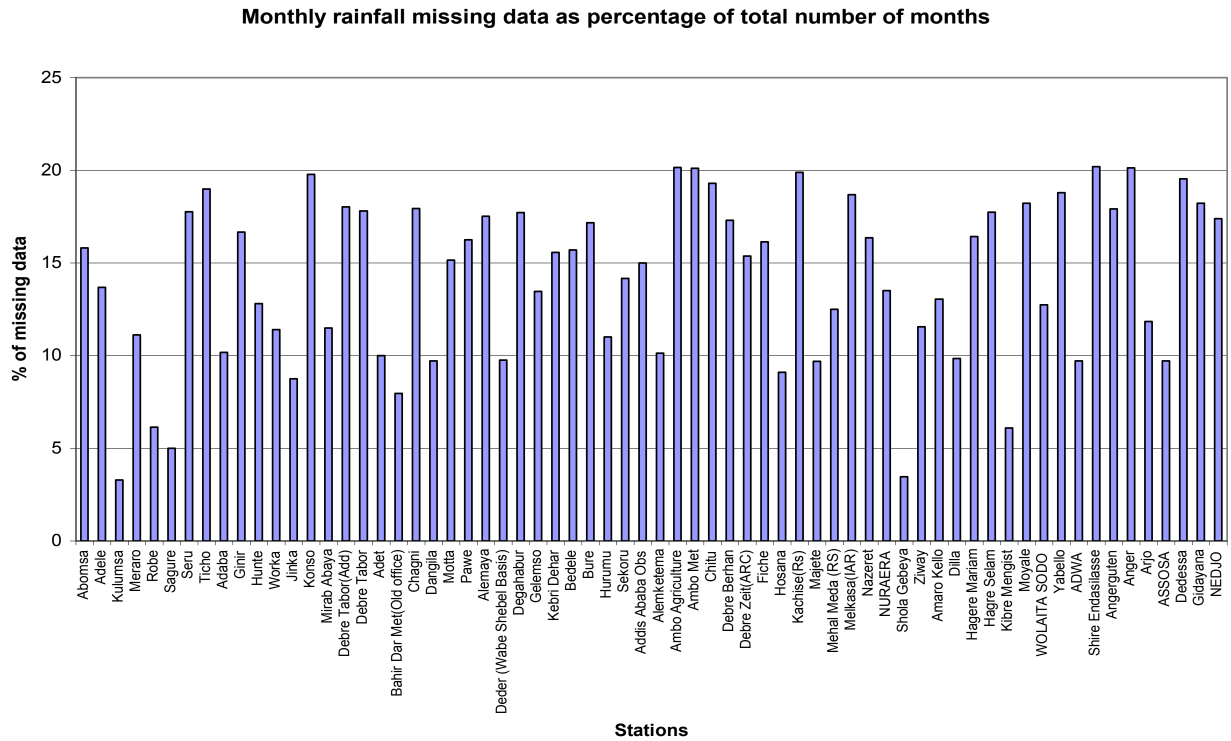



**Fig. 2 Percentage of missing data for first class stations as percentage of total number of months**

These stations are discarded immediately from the analysis since criteria one above confirmed that filling gap of this much percentage would lead to unreliable output or contaminate the natural behavior of the parameter. At this stage out of 124 stations 35 stations only remained. The percentage of missing data is shown in figure 2. Our search continued to find stations with more than eleven months continues missing data and less than 24 years data period. In the process of doing so, twelve stations are found which have full year or years missing data and we discarded them. As we have set the minimum data period length to be 24 years and our assessment results in only twenty-three 1$^{st}$ class stations, to increase number of stations and get a better spatial coverage of the country, then we look into discarded stations which may have 24 years or more data length by referring to part of their data series. The search gives thirteen additional stations. This makes up the total number of first class stations thirty-six. Ordinary stations also report rainfall data. Hence to increase the number of stations in our analysis it becomes necessary to look into third class stations and in the process, we managed to find fifteen 3$^{rd}$ class stations which meet all the criteria's. Accordingly, the total number of stations used for this analysis adds up to 64. Figure 3 shows geographical distribution of the stations used in this study. Previous study has delineated the country into three rainfall regimes (NMSA, 1996). The rainfall regimes are referred as rainfall regime A, rainfall regime B and rainfall regime C (see Appendix A). For this study 20 of the stations come from rainfall regime A, 28 of them from rainfall regime B and 16 of them from rainfall regime C. The list of meteorological stations used in this study is given in Appendix B together with their latitude, longitude coordinates, class, rain fall regime and data years. The nature of available meteorological stations data in the country forced us not to set the same data period for all the stations. For comparative interpretation and understanding of the out put of this study it is found essential to present number of available monthly rainfall records in each year (Fig. 4). For the case of complete monthly rainfall records number of available monthly rainfall data is 64.

As can be seen from Fig. 4 the number of available stations between 1960 and 1990 and 2006 & 2010 are less than the total number of stations taken for this study. For the most distant and recent past years most of the stations do not have record. The next step in data preparation is filling missing data.

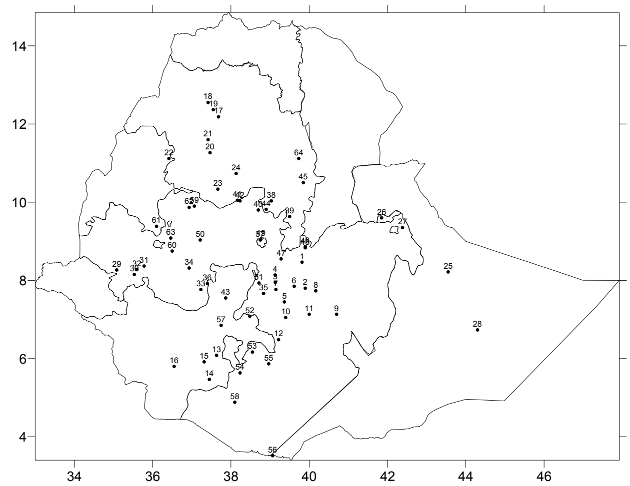


**Fig. 3 Station network used in this study**

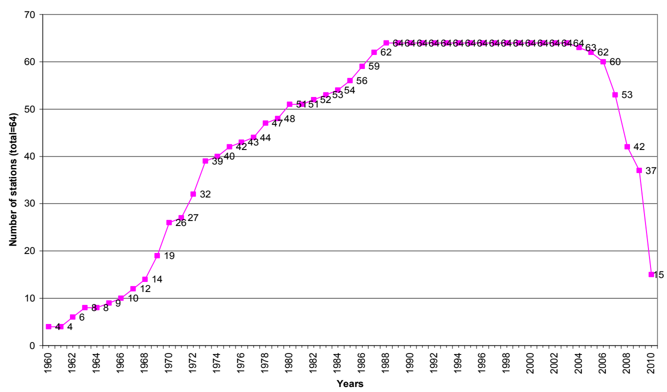



**Fig. 4 Number of available stations over the period 1960-2010**

### 4.2 Filling missing data

The Arithmetic Mean Method, the Isohyetal Linear Interpolation and Isopleth method, the Thiessen Polygon Method, the Correlation method, The Weighted Arithmetic Mean Method and many others can be used to fill missing rainfall data. Among these methods we chose the correlation method to fill missing data as past experience tell us that this method is relatively easy to apply and give reasonably good estimates. In this method, different stations are selected, and their correlation coefficients are computed in relation to the station with missing rainfall records.

The data set should have the same length and period. The correlation coefficient is computed using the relation below and the results are noted at each of the stations.

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left[\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)\right]}{\left[\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 . \frac{1}{n}\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2\right]^{\frac{1}{2}}}$$

Where $x_i$ are data values at station with missing data and $y_i$ are the corresponding data values from a nearby station with complete data. Once all the correlation coefficients have been computed, a station that depicts the highest correlation with the station having missing data is selected for use in determining the missing observations (DMC, 1999). The missing value(s) are computed from using either of the relations given below:

$$X_{periodmis\sin g} = r_{xy} . Y_{period}$$

Or $$X_{periodmis\sin g} = \frac{\overline{X}}{\overline{Y}} . Y_{period}$$

In our case each station is correlated with three or four neighboring stations. A sample of correlation done for Abomsa is presented in the table 1. Abomsa is correlated with four neighboring stations namely: Metehara, Nuraera, Merti Jeju and Guna. The correlation values are tabulated in the appropriate cell in table 1. In the table the field names entered in the second row contains the first three letters of each calendar month plus an under score and a suffix. The suffix stands for the station name. The station name is represented in two capital letters. For example, Jan_AB stands for January data for Abomsa. Similarly, Jan_Met represents January data for Metehara. January rainfall data of Abomsa is correlated with itself, other months data of Abomsa and all month's data of other stations. During selection we select the highest from other stations Jan rainfall correlation values. The station which exhibit larger correlation with the station with missing rainfall data is used to fill the gaps. Sometimes the station which exhibit larger correlation might not have data. If two stations have missed data at the same period, we cannot fill one with the other. Hence, we look for the next station which exhibit high correlation value with the station with missing data. If the second station also does not have data, we go for the next one. This process continues until we get a station with data and correlation values is 0.5 and over. If this does not happen we fill the gap with long years mean value of the station itself.

## 5. Methodology and decomposing time series data

### 5.1 Methodology

In this study the traditional time series decomposition technique is used to study and document the rainfall characteristics of selected stations rainfall data which have got relatively long year's records and less missing data.

**Table 1 Table showing correlation values between station with missing data and neighboring stations. The station with missing data is correlated with itself and four neighboring stations**

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Jan_AB | Feb_AB | Mar_AB | Apr_AB | May_AB | Jun_AB | Jul_AB | Aug_AB | Sep_AB | Oct_AB | Nov_AB | Dec_AB | Jan_Met | Feb_Met | Mar_Met | Apr_Met | May_Met | Jun_Met | Jul_Met | Aug |
| 2 | Jan_AB | 1 | | | | | | | | | | | | | | | | | | | |
| 3 | Feb_AB | -0.10978 | 1 | | | | | | | | | | | | | | | | | | |
| 4 | Mar_AB | -0.257712 | 0.245674 | 1 | | | | | | | | | | | | | | | | | |
| 5 | Apr_AB | 0.286873 | 0.46446 | -0.184678 | 1 | | | | | | | | | | | | | | | | |
| 6 | May_AB | 0.185525 | -0.124791 | -0.021297 | -0.049424 | 1 | | | | | | | | | | | | | | | |
| 7 | Jun_AB | -0.21615 | -0.231731 | 0.095903 | -0.304185 | 0.246464 | 1 | | | | | | | | | | | | | | |
| 8 | Jul_AB | -0.243696 | 0.156823 | -0.181618 | -0.261139 | -0.02208 | 0.301441 | 1 | | | | | | | | | | | | | |
| 9 | Aug_AB | -0.224502 | -0.261832 | 0.225264 | -0.319623 | 0.310154 | 0.241018 | -0.176273 | 1 | | | | | | | | | | | | |
| 10 | Sep_AB | 0.657853 | 0.073693 | -0.301118 | 0.130306 | -0.105169 | 0.18405 | 0.127211 | 0.085154 | 1 | | | | | | | | | | | |
| 11 | Oct_AB | 0.205833 | -0.220786 | -0.239403 | -0.01606 | -0.283808 | 0.007993 | 0.354347 | -0.058845 | 0.435799 | 1 | | | | | | | | | | |
| 12 | Nov_AB | -0.166792 | -0.269234 | -0.397715 | -0.05098 | 0.274137 | 0.259672 | 0.46185 | -0.253285 | -0.163858 | 0.262206 | 1 | | | | | | | | | |
| 13 | Dec_AB | -0.242436 | -0.130804 | -0.114628 | -0.098521 | -0.449949 | -0.131945 | 0.175455 | -0.127032 | -0.146847 | -0.159117 | -0.159149 | 1 | | | | | | | | |
| 14 | Jan_Met | 0.564706 | -0.182425 | -0.337886 | 0.251588 | -0.065452 | -0.212812 | -0.170484 | -0.104986 | 0.469153 | 0.1765 | -0.069768 | -0.080838 | 1 | | | | | | | |
| 15 | Feb_Met | -0.035095 | 0.969836 | 0.22418 | 0.559585 | -0.09913 | -0.322166 | 0.065877 | -0.28088 | 0.031437 | -0.215877 | -0.32785 | -0.115956 | -0.137511 | 1 | | | | | | |
| 16 | Mar_Met | -0.168439 | 0.075751 | 0.619089 | -0.146398 | 0.079119 | 0.299648 | -0.319086 | 0.389857 | -0.067765 | -0.433922 | -0.475338 | -0.111093 | -0.271111 | 0.054565 | 1 | | | | | |
| 17 | Apr_Met | 0.342631 | 0.133764 | -0.043135 | 0.752877 | -0.115307 | -0.083603 | -0.330678 | -0.133219 | 0.12608 | 0.028438 | -0.157097 | 0.05892 | 0.250434 | 0.22433 | 0.106089 | 1 | | | | |
| 18 | May_Met | 0.170559 | -0.262226 | 0.014301 | 0.024628 | 0.745009 | 0.197271 | -0.215755 | 0.15494 | -0.274631 | -0.102883 | 0.237329 | -0.452086 | 0.046298 | -0.226273 | -0.13148 | 0.063422 | 1 | | | |
| 19 | Jun_Met | -0.067269 | -0.21271 | -0.377433 | 0.157124 | -0.036931 | 0.238753 | 0.147288 | -0.221178 | 0.172096 | 0.168309 | 0.212255 | 0.348793 | 0.097226 | -0.185895 | -0.13874 | 0.256939 | -0.124333 | 1 | | |
| 20 | Jul_Met | -0.147104 | 0.031348 | -0.240421 | -0.164135 | 0.582532 | 0.452834 | 0.64365 | 0.139879 | 0.045053 | 0.083541 | 0.536442 | -0.132168 | -0.167699 | -0.040726 | -0.307311 | -0.326559 | 0.439489 | -0.157967 | 1 | |
| 21 | Aug_Met | -0.056558 | -0.253093 | -0.24214 | -0.078155 | 0.061639 | 0.002168 | -0.042937 | 0.193626 | 0.221832 | -0.121321 | -0.099666 | 0.091162 | -0.088187 | -0.14018 | -0.002035 | -0.115866 | 0.058223 | -0.05941 | 0.056775 | |
| 22 | Sep_Met | 0.084047 | 0.526555 | -0.295727 | 0.405314 | -0.063757 | 0.00281 | 0.013762 | -0.103508 | 0.458309 | -0.146115 | -0.15779 | -0.285547 | 0.08651 | 0.512009 | -0.113678 | -0.021561 | -0.271686 | -0.069353 | 0.09457 | 0 |
| 23 | Oct_Met | 0.267575 | -0.204485 | -0.187959 | -0.314497 | -0.192413 | -0.232472 | 0.131348 | 0.169683 | 0.54582 | 0.861251 | -0.063477 | -0.076556 | 0.271322 | -0.227039 | -0.329934 | -0.194772 | -0.142352 | -0.076789 | -0.069301 | 0. |
| 24 | Nov_Met | -0.196265 | -0.213281 | -0.42674 | -0.054613 | 0.273504 | -0.04069 | 0.186215 | 0.037912 | -0.037492 | 0.306823 | 0.457037 | -0.137968 | -0.091254 | -0.241784 | -0.368021 | -0.208917 | 0.340608 | -0.097893 | 0.485695 | -0. |
| 25 | Dec_Met | 0.391653 | -0.048537 | -0.108764 | 0.119791 | -0.179202 | -0.226679 | -0.026001 | -0.19207 | -0.088386 | 0.0621 | -0.211218 | 0.453186 | 0.291719 | 0.02171 | -0.27619 | 0.20833 | -0.043626 | 0.074285 | -0.03489 | -0.2 |
| 26 | Jan_Nur | 0.771132 | -0.236307 | -0.196314 | 0.210314 | 0.261702 | 0.060621 | -0.246379 | 0.000204 | 0.381543 | 0.086438 | -0.059959 | -0.241675 | 0.775339 | -0.184436 | 0.009322 | 0.17936 | 0.341145 | 0.001554 | 0.089844 | 0. |
| 27 | Feb_Nur | -0.169373 | 0.972848 | 0.331907 | 0.406121 | -0.137015 | -0.247048 | 0.228023 | -0.212807 | 0.022581 | -0.251059 | -0.263803 | -0.066729 | -0.218154 | 0.945491 | 0.154024 | 0.100062 | -0.283971 | -0.261937 | 0.046799 | -0. |
| 28 | Mar_Nur | -0.330584 | 0.141797 | 0.49336 | -0.263618 | 0.28422 | 0.412106 | 0.035737 | 0.30329 | -0.233175 | -0.528875 | -0.221694 | 0.143351 | -0.320234 | 0.129435 | 0.630303 | 0.03203 | 0.048277 | 0.01628 | 0.140018 | -0 |
| 29 | Apr_Nur | 0.135421 | 0.278325 | 0.008808 | 0.712429 | -0.064016 | 0.062298 | -0.293004 | -0.094327 | 0.281857 | -0.106533 | -0.192713 | 0.084068 | 0.101333 | 0.315643 | 0.323831 | 0.781698 | -0.107505 | 0.272577 | -0.191688 | -0.1 |
| 30 | May_Nur | 0.087226 | -0.300219 | 0.297728 | -0.016306 | 0.818184 | 0.235814 | -0.349554 | 0.267173 | -0.305078 | -0.089391 | 0.294309 | -0.445634 | -0.00457 | -0.280709 | -0.001716 | 0.019995 | 0.883692 | -0.253779 | 0.271931 | -0.( |
| 31 | Jun_Nur | -0.32263 | -0.072364 | -0.076376 | -0.074836 | 0.033077 | 0.47014 | 0.548448 | -0.374431 | 0.152979 | -0.100655 | 0.319442 | 0.445434 | -0.307222 | -0.142639 | 0.087067 | -0.052512 | -0.199208 | 0.476403 | 0.255237 | 0.2 |
| 32 | Jul_Nur | -0.222583 | 0.265034 | -0.344749 | -0.07056 | 0.284388 | 0.054831 | 0.659051 | -0.025373 | 0.089802 | 0.185986 | 0.495082 | 0.029863 | -0.151302 | 0.206791 | -0.370585 | -0.115902 | 0.147141 | -0.099314 | 0.712253 | -0 |
| 33 | Aug_Nur | -0.124379 | -0.094452 | -0.028314 | 0.047985 | -0.149869 | 0.028576 | -0.358699 | 0.237483 | 0.157326 | -0.277093 | -0.382875 | 0.231774 | -0.076018 | 0.000742 | 0.093417 | 0.002925 | -0.020108 | -0.01011 | -0.233803 | 0. |
| 34 | Sep_Nur | -0.085757 | 0.024846 | -0.156986 | -0.071532 | 0.282447 | 0.178109 | 0.176997 | 0.268138 | 0.053719 | -0.255668 | -0.238423 | 0.547235 | -0.231474 | 0.025152 | 0.167549 | -0.064387 | -0.165587 | 0.285566 | 0.268246 | 0. |
| 35 | Oct_Nur | 0.047742 | -0.241353 | -0.127463 | -0.097414 | -0.266004 | 0.040284 | 0.33647 | 0.021261 | 0.228736 | 0.898782 | 0.394524 | -0.218115 | 0.159233 | -0.275214 | -0.249652 | -0.084511 | -0.125441 | 0.000107 | 0.129662 | -0.0 |
| 36 | Nov_Nur | 0.114781 | -0.291415 | -0.1421 | -0.024778 | 0.523425 | 0.590424 | 0.127915 | 8.06E-05 | 0.296059 | -0.003508 | 0.510399 | -0.149905 | 0.422989 | -0.332403 | -0.003498 | 0.021351 | 0.455097 | 0.134501 | 0.565576 | 0. |
| 37 | Dec_Nur | -0.073667 | -0.225521 | -0.147145 | -0.234852 | -0.391255 | -0.013369 | -0.039626 | -0.274112 | -0.063239 | -0.12646 | 0.064406 | 0.863153 | -0.102627 | -0.193155 | -0.1738 | -0.167814 | -0.370334 | 0.262117 | -0.221871 | 0.0 |
| 38 | Jan_Gun | 0.874872 | -0.13567 | -0.385615 | 0.253623 | 0.217685 | -0.153649 | -0.322728 | -0.06794 | 0.679811 | 0.331871 | -0.161427 | -0.308903 | 0.645181 | -0.044571 | -0.164003 | 0.390953 | 0.247311 | 0.073235 | -0.118245 | 0.1 |
| 39 | Feb_Gun | 0.059653 | 0.94787 | 0.153442 | 0.450397 | -0.18037 | -0.331728 | 0.137598 | -0.346286 | 0.162326 | -0.056849 | -0.390966 | -0.137872 | -0.089272 | 0.946058 | -0.004653 | 0.178896 | -0.270152 | -0.132482 | -0.081729 | -0.: |
| 40 | Mar_Gun | -0.277244 | 0.113778 | 0.762259 | -0.155785 | -0.174978 | -0.00456 | -0.144213 | 0.191376 | -0.226283 | -0.411452 | -0.335695 | 0.103258 | -0.098697 | 0.056073 | 0.678235 | 0.193645 | -0.21451 | -0.345081 | -0.274287 | -0.2 |
| 41 | Apr_Gun | 0.013029 | 0.017245 | -0.244838 | 0.32705 | -0.302275 | -0.095608 | -0.228217 | -0.268172 | 0.071875 | -0.182418 | -0.003268 | 0.424155 | 0.410007 | 0.047137 | -0.031801 | 0.246782 | -0.373457 | 0.015639 | -0.16128 | -0.1 |
| 42 | May_Gun | 0.228944 | -0.2915 | 0.182517 | -0.059899 | 0.693147 | -0.033672 | -0.33927 | 0.221904 | -0.308948 | -0.302502 | 0.132327 | -0.357421 | 0.197667 | -0.291583 | 0.064422 | 0.038679 | 0.844764 | -0.18792 | 0.225973 | 0.0 |
| 43 | Jun_Gun | -0.312126 | -0.409003 | -0.069298 | -0.346136 | 0.451367 | 0.411628 | 0.437083 | 0.144269 | -0.31673 | -0.067967 | 0.569761 | 0.085015 | -0.25245 | -0.498429 | -0.010462 | -0.292819 | 0.228587 | 0.393148 | 0.421084 | -0 |
| 44 | Jul_Gun | -0.021995 | -0.100014 | -0.186403 | -0.350814 | -0.099762 | -0.152553 | 0.633799 | -0.017391 | 0.141639 | 0.152174 | 0.087413 | 0.483255 | -0.049776 | -0.107119 | -0.210293 | -0.283774 | -0.265916 | -0.071068 | 0.418871 | 0.2 |

data | corr table | Sheet2 | Sheet3

Ready NUM

The time evolution of the recorded rainfall is regarded as composed of four-time series components, i.e., trend, seasonal, cyclic and irregular components (Bowerman and O'Connell, 1987). By decomposing the time series data into the four-time series components, we can identify what sort of regularity and irregularity exists in the data set and either the data has a trend or not. Then we note the regularity, irregularity and trend the rainfall time series exhibit and use this to describe the characteristics of Ethiopian rainfall and attempt to provide time series analysis-based forecasting. This method has been used in forecasting future sales values in business applications (Arsham and Shao, 1985). We have chosen the multiplicative decomposition model to show the relation between times series data and its four components. The multiplicative model is given as follows: -

$$Y_t = TR_t \times SN_t \times CL_t \times IR_t$$

Where

$Y_t$ is the observed value of the time series in time period t
$TR_t$ is the trend component (or factor) in time period t
$SN_t$ is the seasonal component (or factor) in time period t
$CL_t$ is the cyclic component (or factor) in time period t
$IR_t$ is the irregular component (or factor) in time period t

How we selected the stations, determined the minimum length of the records and what data gaps filling techniques used in this study are discussed in the data preparation section of this document. After filling the data gaps and identify possible number of station that can be used for the study, the data of all stations are arranged in one column as shown in Table 1 from the first record until the last one. The third column in Table 2 associate the rainfall data with period numbers in increasing order. The first record linked to period one, the second to period two and the last one, i.e. July 2010 to 606. When we first confronted with the data; it is in the format months across columns and years down the row. It was x rows (years) × y columns (months) matrix data. With this format it is not easy to do all the calculations needed to separate out the different time series components. A few lines FORTRAN program converts the data into the format in which the analysis requires (Table 2).

**Table 2 Monthly rainfall data for Combolcha from January 1986-July 2009**

| Year | Month | Period (t) | Mon RF |
|---|---|---|---|
| 1960 | 1 | 1 | |
| 1960 | 2 | 2 | |
| 1960 | 3 | 3 | |
| 1960 | 4 | 4 | |
| 1960 | 5 | 5 | |
| 1960 | 6 | 6 | |
| 1960 | 7 | 7 | |
| 1960 | 8 | 8 | |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 2010 | 1 | 601 | |
| 2010 | 2 | 602 | |
| 2010 | 3 | 603 | |
| 2010 | 4 | 604 | |
| 2010 | 5 | 605 | |
| 2010 | 6 | 606 | |

In order to make sure that whether the rainfall data is composed of different components or not, we took a sample station, Combolcha, and plotted part of the series (2000-2010) on an x-y graph (Fig. 5). From the figure one can see:-

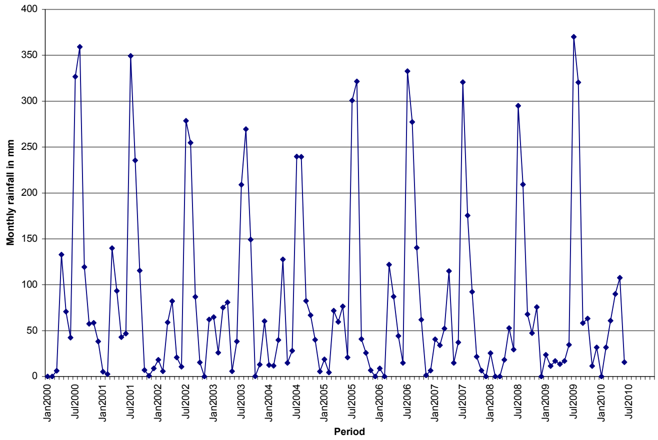



**Fig. 5. 2000-2010 Monthly rainfall plot of Combolcha, a station in north east Ethiopia**

- One small peak and another larger peak is the dominate feature of the yearly rainfall pattern of this station
- Within each year rainfall values are lower in the first five months and then it rises until it attains its peak in July or August followed by a decline.
- The years 2000, 2001 and 2009 are marked by high peak values than others.
- Even though not strong, there is a slight over all increasing trend. After 2004 more years recorded rainfall amount more that 300 mm at the peak point than before.

### *5.2 Decomposing the monthly rainfall data*

The characteristics features of the monthly rainfall data shown in Fig.5 above lead us to think of the time series data has exhibited some sort of regularity, irregularity and trend. The seasonal and trend effects are clearly observed on the plotted 2000-2010 monthly rainfall series. These effects with other hidden factors are required to be separated out from the original series to know factors that influence the data. Generally, a time series data has four components.

1) Seasonal component is regular monthly rainfall fluctuations that repeat from year to year with about the same timings and level of intensity.
2) Trend component are tendencies for monthly rainfall to increase or decrease fairly steadily over time.
3) Cyclic component are general up-and-down changes due to changes in the overall rainfall generating mechanisms
4) Irregular component is any monthly rainfall changes not categorized as one of the above (Arsham and Shao, 1985).

The steps for separating out the individual components of the rainfall data are as follows:

#### 1) Calculate 12-period moving average values

If a given station data started in 1960; the first average to be calculated contains data from January of 1960 to December of 1960. As the number of months in a year is even; the first moving average corresponds to the time period between 6 and 7. The next moving average is computed by dropping January

1960 data and adding January 1961 data and it continues in the same fashion until the last possible moving average is computed. In this calculation the first six months and the last six months do not have corresponding moving average values.

**2) Calculate centered moving average values**

The computed moving average values does not correspond to actual observation time, so we desire to compute centered moving averages to get values that correspond to actual observation time. This can be done by averaging two successive moving average values. Hence, the first moving average corresponds to period seven.

**3) From the result of step 2 calculate seasonal values and adjust them**

Taking series of moving averages of time series data removes seasonal and irregular components from the times series and leave only cyclic and trend components. Computing the ratio of original series to that of centered moving averages gives the product of seasonal and irregular components. We define the seasonal component to be 100%. Taking the average of the product of seasonal and irregular components of each month over the years separately removes the irregular component and result to the unadjusted seasonal values. It so called because due to rounding errors sum of unadjusted seasonal values is not equal to 100%. Finally, divide the unadjusted seasonal values of each month by 12 and multiply it by the sum of each month averages.

**4) Find the deseasonalized values**

Deseasonlized or seasonally adjusted values can be found by computing the ratio of the original series to that of seasonal values.

**5) From the result of step 4 using least squares method calculate the trend component**

The purpose of obtaining the deseasonalized values is to estimate the trend line. This can be done by applying least square technique on the deseasonalized values. Deseasonalized values are used instead of original series in estimating the trend line in order to get rid off the effect of seasonal variations on the trend component or to get pure trend effect on the time series. The trend equations we obtained are listed in table 6.

**6) Calculate the product of trend and seasonal components**

Multiplying the output of step three with step five give the product of trend and seasonal components (see appendix 1).

**7) From the result of step 6 calculate the product of cyclic and irregular components**

The ratio of the original monthly rainfall series to the output of step 6 gives us the product of cyclic and irregular components.

**8) Take 3 period moving average of the result of step 7 and the result will be the cyclic component**

In order to remove irregular components from cyclic components we need to take 3 period moving averages of the result of step 7.

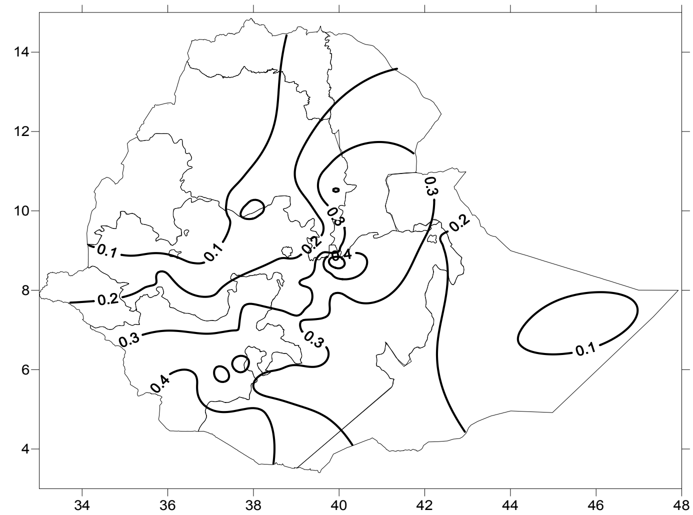
**9) Dividing the output from step 7 by the output from step 8 give us the irregular components.**

Bowerman and O'Connell (1987) have given a detailed discussion and procedures of separating out the various components of a time series data. One can refer this book for detailed explanation.

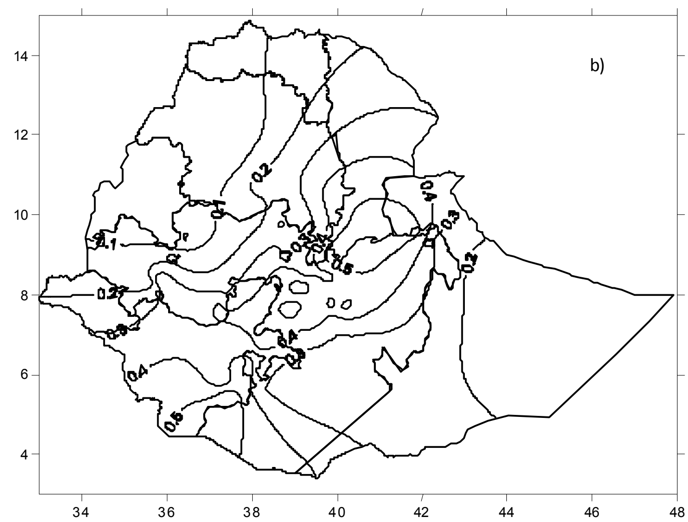
## 6. Results and Discussion

### *6.1 Seasonal component analysis*

The seasonal index values are separated out from other time series components for each station and plotted on the map of Ethiopia for each calendar month separately in order to study the characteristics of seasonality based on 64 stations data. The value of the index of seasonality in the country does not exceed 4.1 (Fig. 6 to 11).




**(a)**

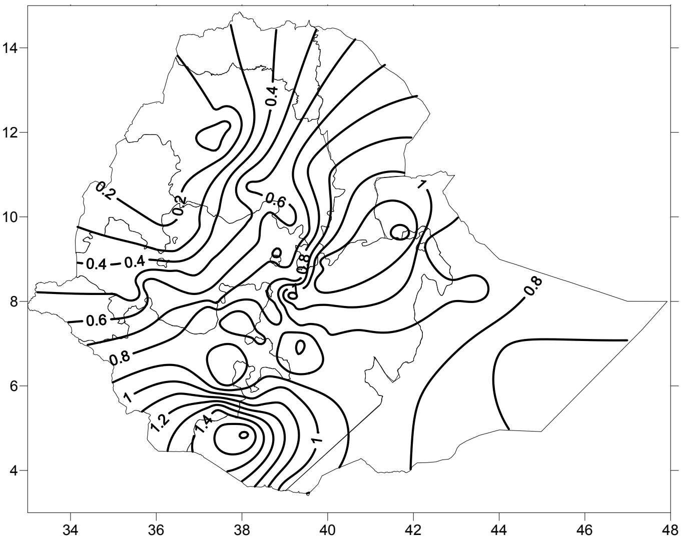



**(b)**

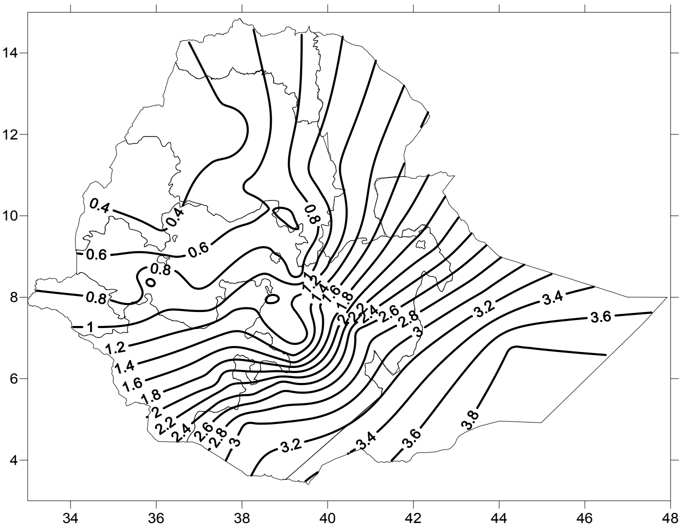
**Fig.6. The index of seasonality over Ethiopia in the month of (a) January (b) February**

In January (Fig. 6a) high values of seasonal index are located in central and southern parts of the country where the values are more than 0.4 over some places. The lowest seasonal values cover the north western and south eastern parts of the country with values less than 0.1. As the contribution of

January monthly rainfall towards the annual precipitation total is less, the seasonal index values are also less compared to other months with the exception of December. Even with in the same rainfall region the seasonal index varies. It varies between 0.1 and 0.5, exclusive, in rainfall regime A, between 0.1 and 0.4, in rainfall regime C, and between 0.1 and 0.3, in rainfall regime B. The maximum seasonality index values show an east ward location shift in comparison to January maximum values position with an additional 0.5 contour in February (Fig. 6b). The 0.4 line goes through parts of eastern, central and southern Ethiopia. The lowest index values are confined over the southeastern and northwestern parts of the country. If one draws a line through the maximum seasonality index points; the southeastern and northwestern resembles a mirror image of one to the other. Dry periods like January and February in relative terms are marked by low values.



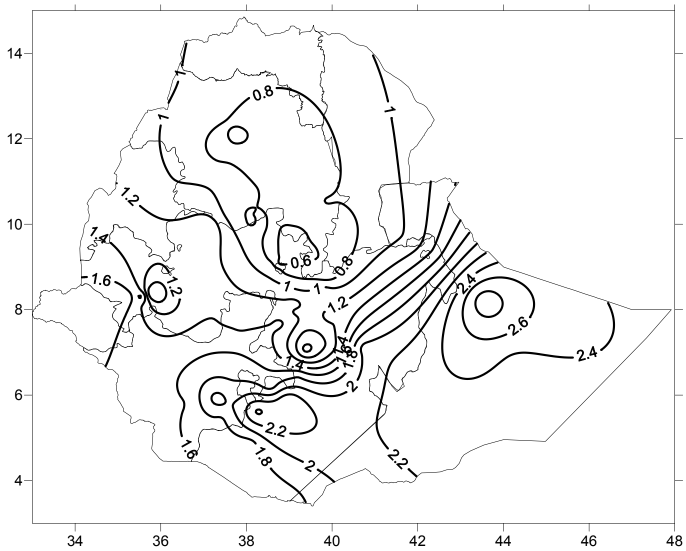

**(a)**



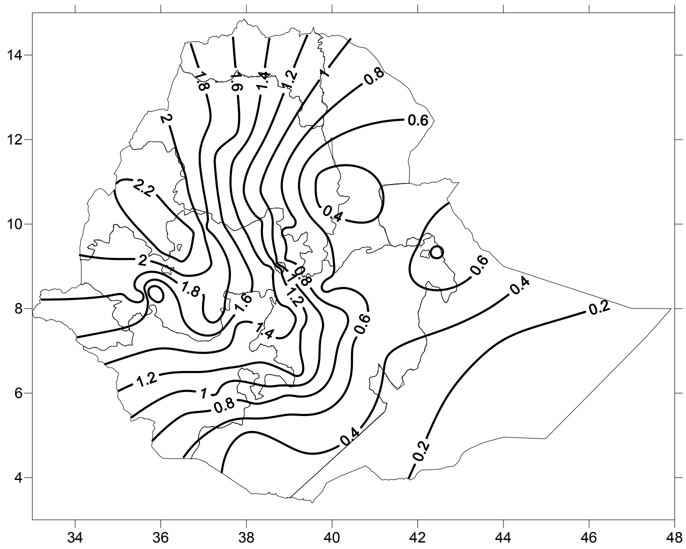

**(b)**

**Fig.7. The index of seasonality over Ethiopia in the month of (a) March (b) April**

In March (Fig. 7a) the condition of seasonal index shows a significant change in magnitude. The maximum areas more or less located where they were in February; in this month the value raised to more than 1.4 over southern and greater than 1 over parts of eastern Ethiopia. The lowest values confined over northwestern Ethiopia. The change in the magnitude of the seasonal index over southeastern is significant. At places where it was less than 0.2 in February now become 0.8. In April (Fig. 7b) the zone of maximum values shifts to southeast. In this month over the southeastern a value more than 3 is common. Even some areas got as large as 3.6 and more than 3.6. A trough extends from northwest to through central-southern parts of the country. The northwestern still enjoys low seasonal index values. A value of 0.4 and less dominate these areas.




**(a)**




**(b)**

**Fig. 8. The index of seasonality over Ethiopia in the month of (a) May (b) June**

In May (Fig. 8a) the northwestern places begin to see better values as compared to pervious four months. The zone of lowest values shifts to north. One can conclude that the northern parts are dry in long years terms compared to remaining parts of the country. A pole of seasonal index is located over the southeastern parts. A value of 2.4 and above is concentrated over eastern parts of southeastern Ethiopia. In June (Fig. 8b) the southeastern starts to enjoy low seasonal index values. On the contrary the values of seasonal index increase over parts of western and northeastern Ethiopia. The seasonal index in this month ranges form values nearly equal to 0.1 over southeastern to a value more than 2.2 over western Ethiopia. A trough of seasonality index runs from western Ethiopia to southern parts.

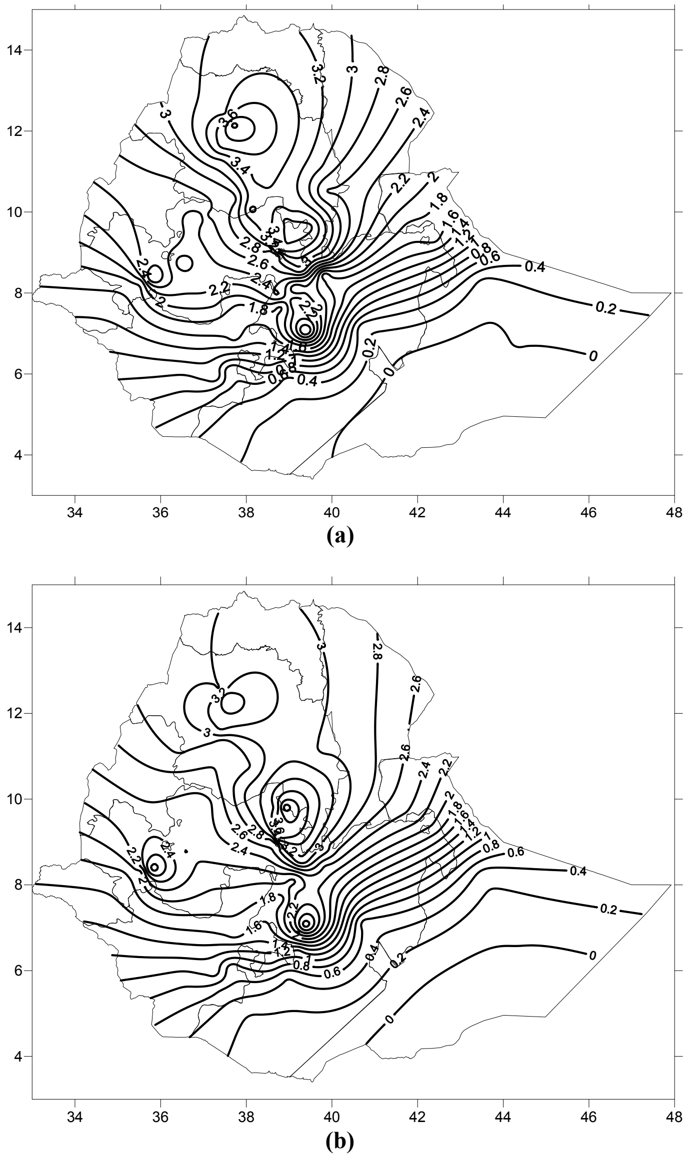



**Fig. 9. The index of seasonality over Ethiopia in the month of (a) July (b) August**

The zone of maximum seasonal index values shifts to north central Amhara in July (Fig. 9a). A value of 3.6 and above is located over these places. As we go to southern Amhara the values decrease to 3.2. Further south in much of Oromia, SNNPR and Somali the seasonal index values are less than 3.2. The lowest, in fact, observed over in Somali region. An elongated trough extends from the point of maximum to through south Ethiopia. In August (Fig. 9b) the situation looks the same as July except that the maximum seasonal index pool shifted to southern Amhara. The 3.6 closed contour now moved to over southeastern parts of Amhara. To the northwest of it another maximum is located. A similar trough line can be drawn that extends from southern Amhara to southern Ethiopia.

In September (Fig. 10a) a drastic change in seasonal index have been detected, a decrease over most parts and an increase over some parts. The maximum located over parts of western Ethiopia and is not more than 2. Now the situation over southern and southeastern Ethiopia shows an improvement compared to that of August. While a drastic reduction in seasonal index observed over much of the country places which enjoyed minimum seasonal index values in August and July now get better values. The zero line which passes through southern Somali is now replaced by 0.7 line contour. In October (Fig. 10b) the situation over the southeastern and southern parts further improved. Values of 2-2.8 are common over these areas. The northeastern are places which are characterized with low values in November (Fig. 11a). As the rainy period begin to cease over the southeastern and southern parts of the country the seasonal indexes begin to be lower. Areas where they get 2-2.8 seasonal index in October now see a value between 0.8 and 1.5. A further lowering is the case during December. The seasonal index distribution of December (Fig. 11b) is comparable to that of January though the location of maximum values is not the same. In January the maximum pool located over central parts of the country while in December it is over the southern parts.

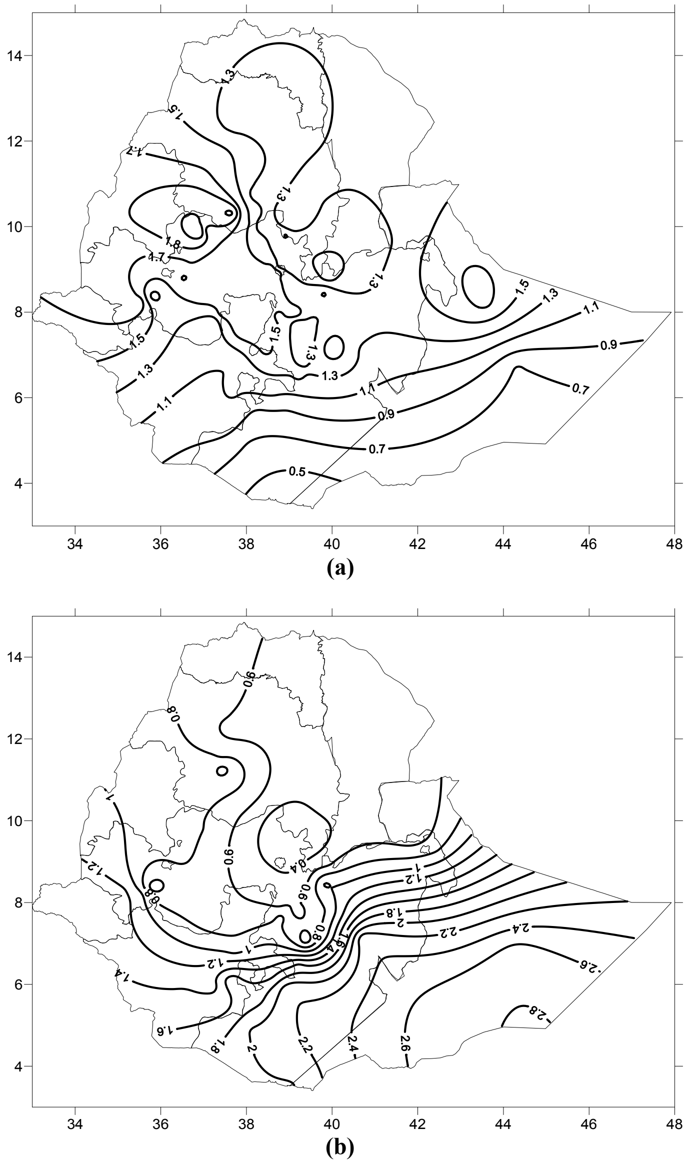
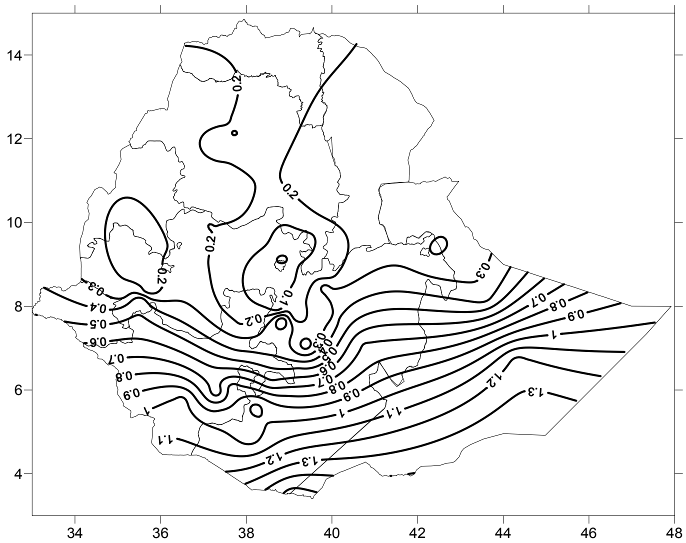
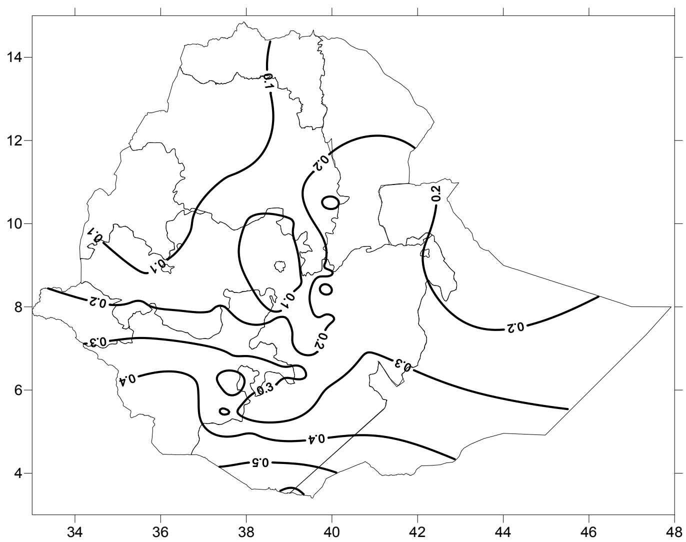



**Fig. 10. The index of seasonality over Ethiopia in the month of (a) September (b) October**

Though there are some differences in values and location of high seasonal rainfall index values there is generally a resemblance in pattern among January, February and March, between July and August, between November and December. In General, the strength of seasonal index is high in the country during July and August and low during January and December. In rainfall regime C all stations have peak seasonality index in April. In August the index gets more pronounced over rainfall regime A.




(a)




(b)

**Fig. 11. The index of seasonality over Ethiopia in the month of (a) November (b) December**

### 6.1.1 Classifying stations into different groups based on peak seasonal index values

As it was mentioned earlier in this document stations taken from rainfall regime A are 20 in number. These stations have two rainy seasons *Belg* (February-May), short rainy period, and *Kiremt* (June-September), main rainy period (NMSA, 1996). We have tried to group these stations into different groups based on the strength of their peak seasonal index value exhibited in the months of *Belg* and *Kirem*t seasons. The peak seasonal index value of *Kiremt* is categorized into four ranges and the *Bleg* into three ranges (table 3). Fifty percent of the stations have peak *Kiremt* seasonal index between 2 and 3 and peak *Belg* seasonal index between 1 and 2 (Fig. 12a). These stations are found over the Arsi zone and rift valley areas. For these stations the *Belg* season is relatively more important than for others. Seven stations have *Kiremt* peak seasonal index between 3 and 4 and Bleg between 0 and 1 (Fig. 12b). In relative terms, for these stations, *Kiremt's* rain contribution is more significant than for other stations which are considered in this study from the same rainfall regime. As we have mentioned earlier in this document stations taken from rainfall regime C are 16 in number. These stations have two rainy seasons, March-May (MAM), main rainy period, and September-November (SON) second rainy period (NMSA, 1996). As we did before we have tried to group these stations into different groups based on the strength of their peak seasonal index in the months of MAM and SON seasons. The peak seasonal index value of MAM is categorized into four ranges and the SON into three ranges (table 4). Out of sixteen stations seven of them have peak MAM seasonal index between 2 and 3 and peak seasonal SON index between 1 and 2 (Fig. 13a). Over six of them SON is as important as MAM. Both indexes are of comparable magnitude in these six stations (Fig. 13b). For one station, Dire Dawa, SON's seasonal index is more than MAM's seasonal index. Strong MAM seasonal indexes are noted over four stations. Then number of stations taken from rainfall regime B is 28 in number as already mentioned earlier in this document. Unlike regime A and C these stations have one long rainy period.

**Table 3 Classifying stations from rainfall regime A into different seasonal index group based on peak seasonal index value recorded in the months of Belg and Kiremt**

| Maximum seasonal index in the months of *Kiremt* (K) | Maximum seasonal index in the months of *Belg* (B) | | |
|---|---|---|---|
| | 0<B≤1 | 1<B≤2 | 2<B≤3 |
| 0<K≤1 | No station | No station | No station |
| 1<K≤2 | No station | Kulumsa, Seru | No station |
| 2<K≤3 | Addis Ababa Bole | Abomsa, Addelle, Assela, Hunet, Meraro, Metehar, Nura Era, Robe, Sagure and Zeway | No station |
| 3<K≤4 | Fiche, Lemi, Majete, Nazret, Shola Gebeya, Debre Birhan | Combolcha | No station |

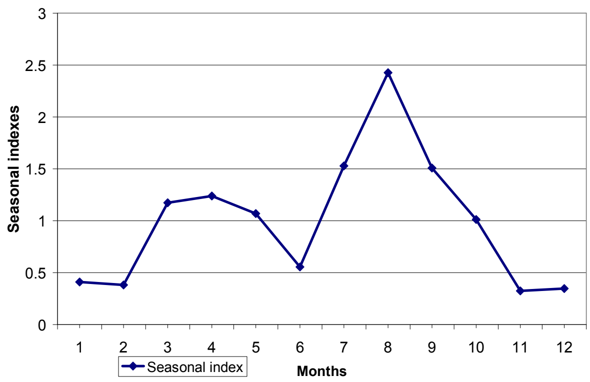
**Table 4 Classifying stations from rainfall regime C into different seasonal index group based on peak seasonal index value recorded in the months of September – November (SON) and March- May (MAM)**

| Maximum seasonal index in the months of MAM | Maximum seasonal index in the months of SON | | |
|---|---|---|---|
| | 0<SON≤1 | 1<SON≤2 | 2<SON≤3 |
| 0<MAM≤1 | No station | No station | No station |
| 1<MAM≤2 | No station | Dilla, Jinka, Robe (Bale), Worka | Dire Dawa |
| 2<MAM≤3 | No station | Arbaminhc, Gerese, Gursum, Gato, Degahabour, Hagermariam | Ginnir, Kibre Mengist |
| 3<MAM≤4 | No station | Moyalle | Yabello, Kebri Dehar |

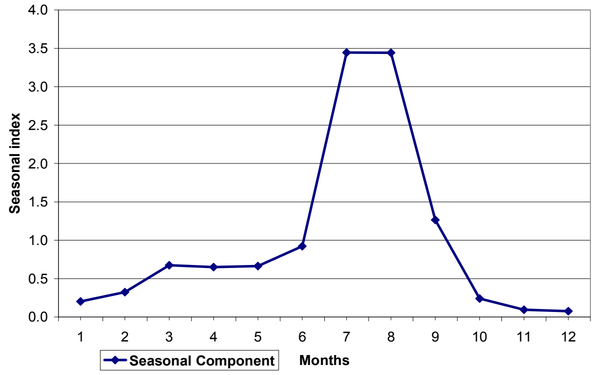
**Table 5 Classifying stations from rainfall regime B into different seasonal index group based on peak seasonal index value in the year**

| Maximum seasonal Maximum seasonal index in the year (I) | | | |
|---|---|---|---|
| 0<I≤1 | 1<I≤2 | 2<I≤3 | 3<I≤4 |
| No station | Awassa, Gore, Hossan, Jimma, Bure, Wolita Sodo | Alibo, Assendabo, Atnago, Dangila, Debre Markos, Gidayana, Nekemet, Nopa, Hurmur, Sekoru, Tibe, Arjo, Dedessa | Adet, Alem Ketema, Bahir Dar, Debre Work, Enfranz, Goha Tsion, Gondar, Maksegnit, Filkilik |

However, the length of the rainy period is not the same all over the regime (NMSA, 1996). We have tried to group these stations into different groups based on the strength of their peak seasonal index in the year. The peak seasonal index value of the year is categorized into four ranges (table 5). Over stations where the length of the rainy period is long the peak seasonal value is low (Fig. 14a) and vice versa (Fig. 14b).

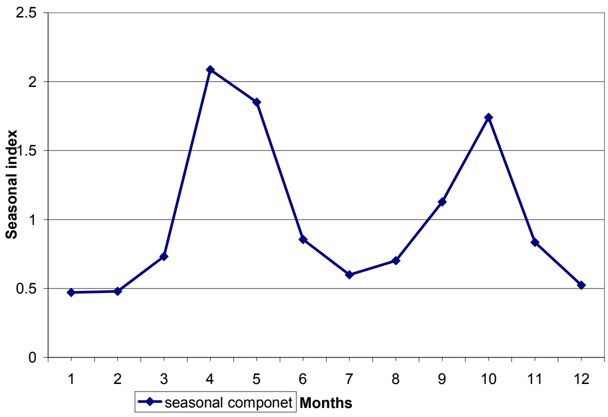



(a)

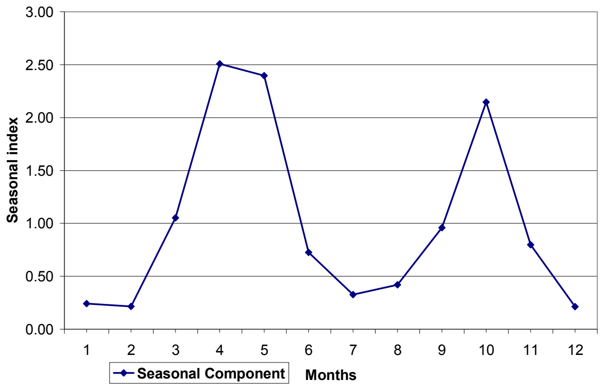



(b)

**Fig.12 Samples of seasonal index plot of stations from rainfall regime A (a) station with peak Bleg seasonal index between 1 and 2 and Kiremt between 2 and 3, Abomsa (b) station with peak Belg seasonal index between 1 and 2 and peak Kiremt seasonal index between 3 and 4, Fiche**

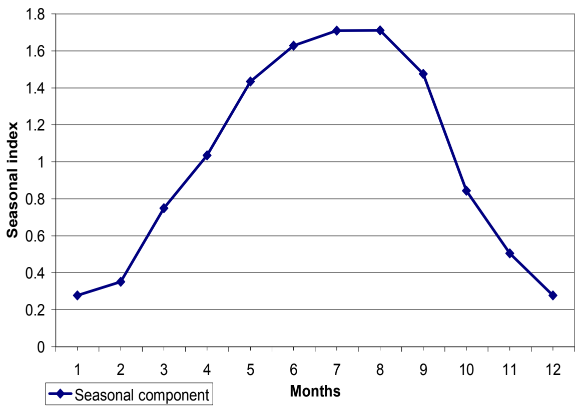



(a)

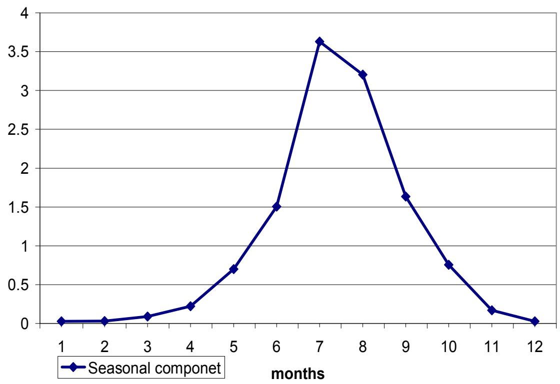



(b)

**Fig.13 Samples of seasonal index plot of stations from rainfall regime C (a) station with peak MAM seasonal index between 2 and 3 and SON between 1 and 2, Arba Minch (b) station with comparable peak seasonal indexes, Kibre Mengist**




(a)




(b)

**Fig. 14. Samples of seasonal index plot of stations from rainfall regime B (a) station with long rainy season and low peak seasonal index, Jimma (b) station with shorter rainy season and high peak seasonal index, Bahir Dar**

**Table 6. List of Trend equation, slope of the trend lines and coefficient of determination (R2) values at each station**

| No. | Station Name | Rainfall Regime | Trend equation | Slope | $R^2$ |
|---|---|---|---|---|---|
| 1 | Addis Ababa Bole | A | trt = 0.0081x + 87.705 | 0.0081 | 0.0002 |
| 2 | Abomsa | A | $tr_t$=-0.0586t + 83.67 | -0.0586 | 0.0034 |
| 3 | Adelle | A | $tr_t$= 0.03028t + 63.667 | 0.03028 | 0.0018 |
| 4 | Assela | A | $tr_t$=-0.039*t + 104.98 | -0.039 | 0.0043 |
| 5 | Combolcha | A | $tr_t$=-0.0176t + 90.116 | -0.0176 | 0.0018 |
| 6 | Fiche | A | $tr_t$=0.0045t + 90.535 | 0.0045 | 0.00004 |
| 7 | Hunte | A | trt = -0.0177t + 67.4 | -0.0177 | 0.0007 |
| 8 | Kulumsa | A | $tr_t$=-0.006t + 71.498 | -0.006 | 0.0002 |
| 9 | Lemi | A | trt = -0.0534*t + 109.75 | -0.0534 | 0.002 |
| 10 | Majete | A | $tr_t$=0.0138t + 89.064 | 0.0138 | 0.0005 |
| 11 | Meraro | A | $tr_t$ = -0.0558t + 94.618 | -0.0558 | 0.0085 |
| 12 | Metehara | A | $tr_t$=0.0245t + 39.348 | 0.0245 | 0.0017 |
| 13 | Nazret | A | $tr_t$=0.046t + 63.195 | 0.046 | 0.0054 |
| 14 | Nura Era | A | $tr_t$ = 0.0128t + 49.734 | 0.0128 | 0.0003 |
| 15 | Robe (Arsi) | A | $tr_t$ = -0.0603t + 109 | -0.0603 | 0.0058 |
| 16 | Sagure | A | $tr_t$ = -0.0041t + 65.734 | -0.0041 | 0.00008 |
| 17 | Seru | A | trt =-0.1794t + 147.9 | -0.1794 | 0.0167 |
| 18 | Shola Gebeya | A | trt = -0.0221* t + 85.999 | -0.0221 | 0.0015 |
| 19 | Ziway | A | $tr_t$ = 0.0164*t + 60.183 | 0.0164 | 0.0006 |
| 20 | Debre Birhan | A | $tr_t$ = -0.025t + 79.704 | -0.025 | 0.001 |
| 21 | Adet | B | $tr_t$=-0.0444t + 114.2 | -0.0444 | 0.0011 |
| 22 | Alem Ketema | B | $tr_t$=-0.0385t + 97.22 | -0.0385 | 0.0022 |
| 23 | Alibo | B | $tr_t$ = -0.0008*t + 113.75 | -0.0008 | 0.000001 |
| 24 | Assendabo | B | $tr_t$ = 0.0518*t + 88.954 | 0.0518 | 0.0075 |
| 25 | Atnago | B | trt = -0.066*t + 165.34 | -0.0066 | 0.0052 |
| 26 | Awassa | B | $tr_t$=0.031t + 74.453 | 0.031 | 0.004 |
| 27 | Bair Dar | B | $tr_t$=0.0165t + 114.55 | 0.0165 | 0.0003 |
| 28 | Danigila | B | $tr_{t=}$ -0.0243t + 134.44 | -0.0243 | 0.0002 |
| 29 | Debre Markos | B | $tr_t$=-0.0265 t + 118.52 | -0.0265 | 0.0026 |
| 30 | Debre Work | B | $tr_t$=-0.055*t + 88.528 | -0.055 | 0.0066 |
| 31 | Enfranz | B | $tr_t$=-0.0728*t + 99.498 | -0.0728 | 0.0026 |
| 32 | Filikilik | B | $tr_t$=0.1177*t + 69.987 | 0.1177 | 0.0123 |
| 33 | Gidayana | B | $tr_t$=0.009t + 147.09 | 0.009 | 0.00006 |
| 34 | Gohatsion | B | $tr_t$ = 0.0069*t + 94.926 | 0.0069 | 0.000070 |
| 35 | Gondar | B | trt=-0.0149t + 97.792 | -0.0149 | 0.0006 |
| 36 | Gore | B | $tr_t$=-0.1502t + 208.99 | -0.1502 | 0.0518 |
| 37 | Hosana | B | $tr_t$=0.0405t + 89.75 | 0.0405 | 0.0035 |
| 38 | Jimma | B | $tr_t$=0.0064t + 123.96 | 0.0064 | 0.0002 |
| 39 | Maksegnit | B | $tr_t$ = 0.0673*t + 66.284 | 0.0673 | 0.0061 |
| 40 | Nekemte | B | $tr_t$=-0.0041t + 172.74 | -0.0041 | 0.00002 |
| 41 | Nopa | B | t = -0.1502*t + 179.26 | -0.1502 | 0.0098 |
| 42 | Tibe | B | $tr_t$ = -0.0115x + 105.87 | -0.0115 | 0.0003 |
| 43 | Arjo | B | $tr_t$=-0.0481t + 175.24 | -0.0481 | 0.0021 |
| 44 | Bure | B | $tr_t$=0.0226t + 107.78 | 0.0226 | 0.0007 |
| 45 | Dedessa | B | $tr_t$ = 0.0691t + 121.37 | 0.0691 | 0.0024 |
| 46 | Hurmur | B | $tr_t$ =-0.1325t + 173.9 | -0.01325 | 0.0109 |
| 47 | Sekoru | B | $tr_t$=-0.0451t + 122.88 | -0.0451 | 0.0028 |
| 48 | Wolaita Sodo | B | $tr_t$=-0.0664t + 130.43 | -0.0664 | 0.0084 |
| 49 | Arbaminch | C | $tr_t$=0.0026t + 74.804 | 0.0026 | 0.00001 |
| 50 | Dilla | C | $tr_t$=-0.0753t + 115.12 | -0.0753 | 0.0068 |
| 51 | Dire Dawa | C | $tr_t$=0.0245t + 43.654 | 0.0245 | 0.0043 |
| 52 | Gato | C | $tr_t$=-0.0383*t + 83.795 | -0.0383 | 0.0036 |
| 53 | Geresse | C | $tr_t$=0.0669*t + 143.46 | 0.0669 | 0.0029 |
| 54 | Ginnir | C | trt=0.0115t + 80.515 | 0.0115 | 0.0002 |
| 55 | Gursum | C | $tr_t$ = 0.0211*t + 67.734 | 0.0211 | 0.0008 |
| 56 | Jinka | C | $tr_t$ = 0.0199t + 102.83 | 0.0119 | 0.0012 |
| 57 | Kibre Mengist | C | $tr_t$=0.0035t + 87.818 | 0.0035 | 0.00003 |
| 58 | Robe (Bale) | C | $tr_t$=0.00575t + 61.193 | 0.00575 | 0.0086 |
| 59 | Worka | C | $tr_t$=-0.1848x + 138.56 | -0.4848 | 0.0225 |
| 60 | Yabello | C | $tr_t$=-0.0142t + 51.308 | -0.0142 | 0.0006 |
| 61 | Degahabour | C | $tr_t$=-0.0484t + 36.547 | -0.0484 | 0.0085 |
| 62 | Hagere Mariam | C | $tr_t$=-0.0387t + 83.254 | -0.0387 | 0.0044 |
| 63 | Kebri Dehar | C | $tr_t$=-0.0477t + 27.644 | -0.0477 | 0.0052 |
| 64 | Moyale | C | $tr_t$=-0.0351t + 51.703 | -0.0351 | 0.0065 |

### *6.2 Trend component analysis*

The situation of monthly rainfall trend can be studied by plotting the slope of trend line of every station (table 6) on the map of Ethiopia. The plot of the slope of the trend line is shown in Figure 15. The bold zero-line separates stations with positive slope from negative slope. In between the two zero lines found stations with positive slope. To the north of upper zero contour line and to the south of lower zero contour line found negative slope. Positive and negative slope corresponds to an increase and decrease in rainfall respectively. As we can see from this figure much of the country is dominated by a decrease in rainfall. Positive trend is the case over some parts of central, western southwestern and eastern parts. The other places, the north and south have a down ward trend. The slopes are very small and are not as such very significant. The maximum positive slope is 0.12 and observed at Filikilik. The maximum negative slope is -0.48 and observed over Warak in South Ethiopia.

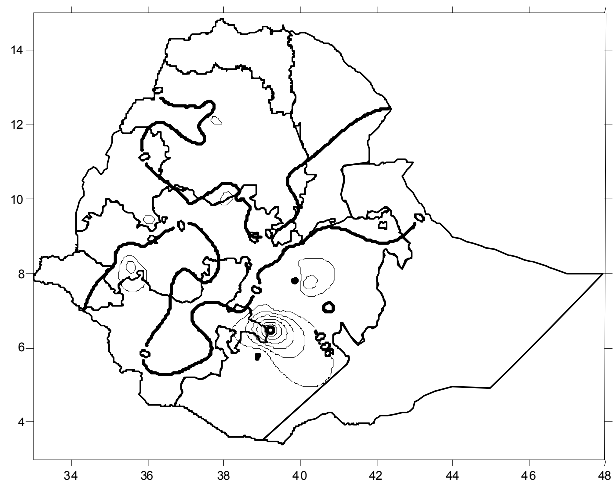
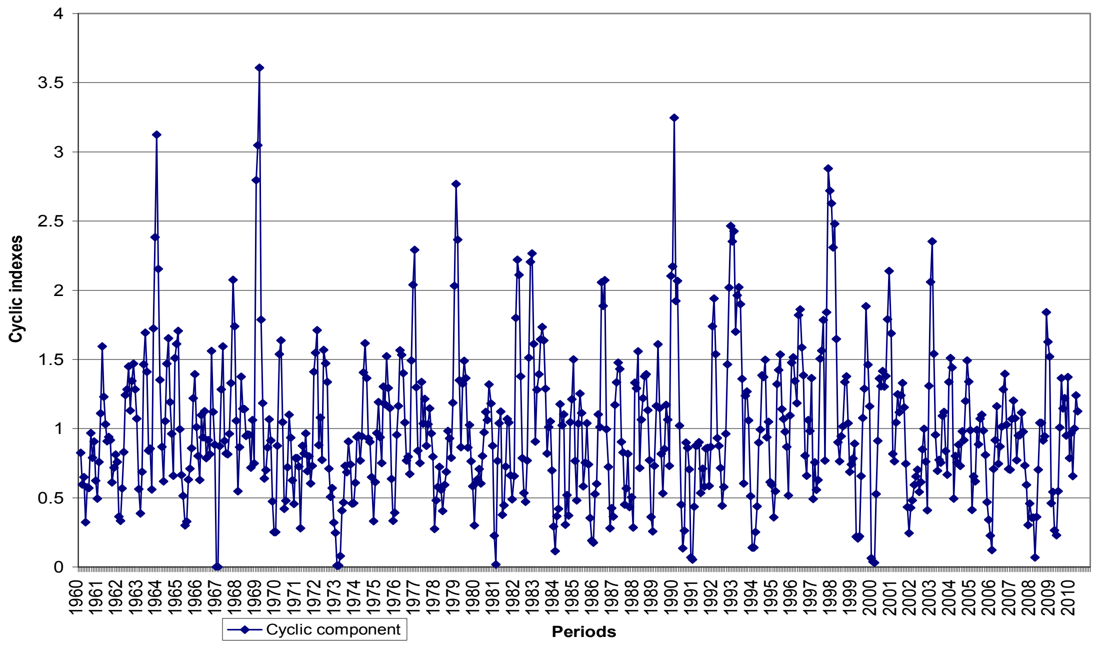



**Fig. 15. Plot of slope of trend line of monthly rainfall calculated from traditional time series analysis**

On this study trend computations are made on deseasonalized data in order to get pure trend effects. A similar trend analysis has been done on the annual rainfall original series for the whole and different parts of the country in the first National Communication of Ethiopia to the United Nations Framework Conventions on Climate Change (NMSA, 2001). It reported that there is a decline in rainfall over northern half and southwestern parts, an increasing trend in central Ethiopia and no change for the whole country. The results found from both studies are almost in agreement.

### *6.3 Cyclic component analysis*

To assess how the general rainfall cycle affects monthly rainfall levels of each station, the cyclic component is computed, and an attempt has been made to find if there is any cycle in the monthly rainfall time series of stations under investigation.



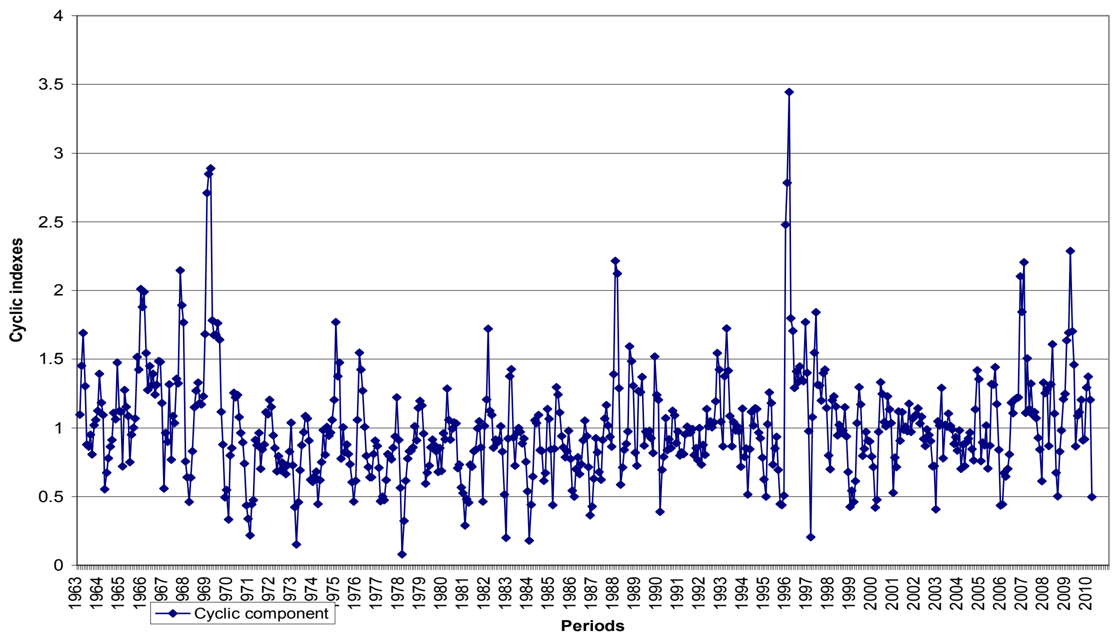




**Fig. 16 Cyclic Component of monthly rainfall identified using multiplicative time series analysis (a) Combolcha (b) Gore**

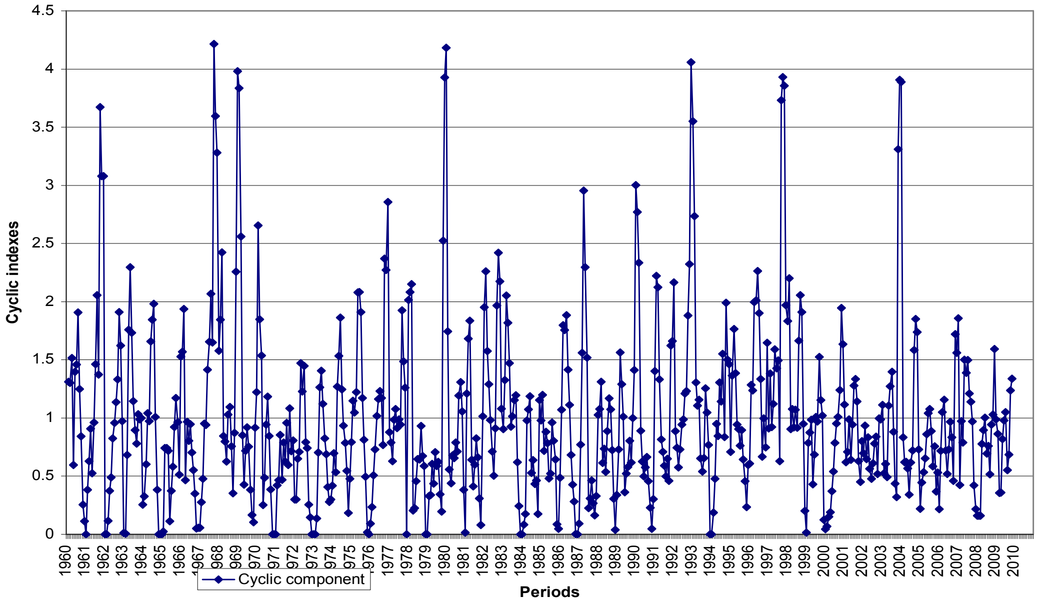



**Fig. 17 Cyclic Component of Dire Dawa monthly rainfall identified using multiplicative time series analysis**

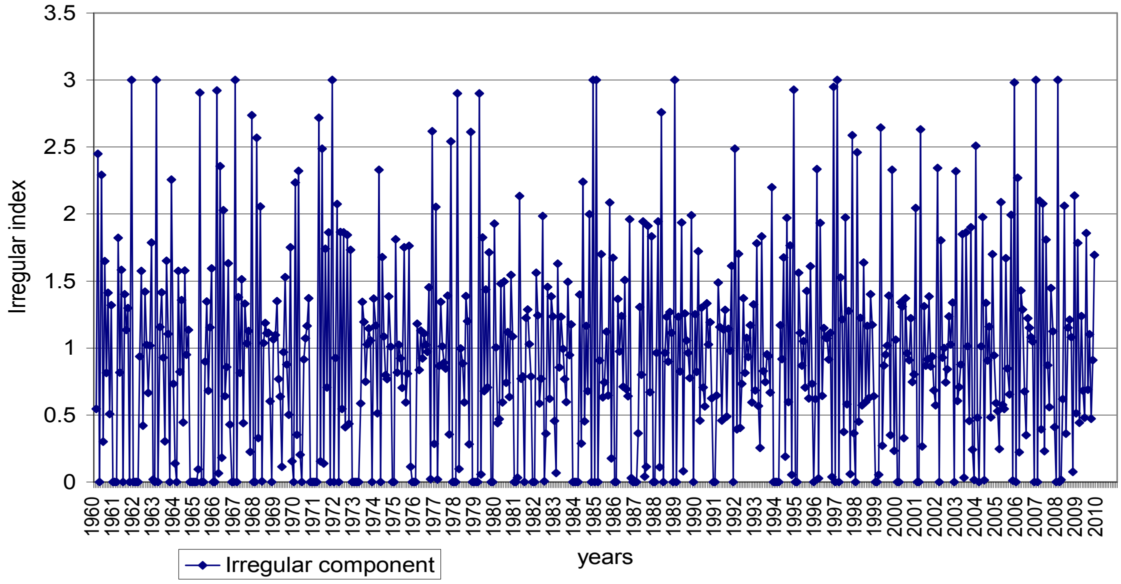



**Fig. 18 Irregular Component of Dire Dawa monthly rainfall identified using multiplicative time series analysis**

We are trying to address the following two questions:

- Would it be possible to identify amount of time elapsed between occurrences of extreme events like wet and dry months?
- What features of the monthly rainfall characteristics peaked up by the cyclic component of the time series data?

This is done by selecting one sample station from each rainfall regime. The average cyclic value for each station is one. Hence, a cyclic value more than one is above the cyclic average and less than one is below the cyclic average. We know that statistically values more than three fold of the average and less than three fold of the average are worth to consider if they exist (Fig.16 and 17). Our examination results in no station with cyclic value less than zero. The station Combolcha is taken from rainfall regime A (Fig. 16a). This station has shown a cyclic value of more than 3 in December of 1963, January and December of 1969 and January of 1990. These peak values often correspond to wet *Bega* months compared to their respective mean monthly rainfall. Especially unsmoothed cyclic series[1] values equal to three and more than three correspond to wet months. Initially Combolcha monthly rainfall shows a six years interval between two cyclic peaks and then it waits until 1990, 31 years, to repeat itself. The station considered from rainfall regime B is Gore. Gore has data for the period 1963-2010. This station is characterized by one long rainy season. In most of the years the cyclic values oscillate between 0.5 and 1.5 (Fig. 16b). There is one case in which the cyclic index exceeded 3.0, i.e., February of 1996. Unlike the one in rainfall regime A we cannot able to define cycle occurrences for this station. The station considered from rainfall regime C is Dire Dawa. Dire Dawa has data for the period 1960-2010. A cyclic value of more than 3 are seen in October, November and December of 1961, October, November and December of 1967, January and February of 1969, December of 1979, January of 1980, January of 1990, December of 1992, January of 1993, September, October and November of 1997,

[1] Unsmoothed cycle index contains both the cyclic and irregular component

November and December of 2003 and January of 2004. The time interval between two peaks is 6, 2, 10,1,10,2,1,4 and 6 years respectively. There are so many repetitions, but all are not of the same length. The 1, 6 and 10 years cycle length occurs two times and 1-year cycle length occurs only once. Unlike samples taken from regime A and regime B the numbers of occurrences of peak values are a lot for this particular station. We have examined all the 64 stations for the case when cyclic values are high and what sort of cyclic repetitions occurs. In any of the stations we have not found any systematic upward and downward regular and uniform cyclic movements. We cannot able to define a definite cycle length time for all of them. List of stations along with the year for which the cyclic component is three and more than three is given in Appendix C. One can refer this table to look at when and how often peak cycle occurs. In general, the cyclic nature of the monthly rainfall does not follow any systematic down ward or upward turn but it is able to peak up the wettest dry months.

### *6.4 Irregular component analysis*

One sample station, Dire Dawa, irregular component plot is shown in Fig. 18. It does not show any well-defined pattern. It varies between 0 and 3. In the next part of this study we will try to demonstrate the use of traditional time series decomposition technique in forecasting monthly and seasonal rainfall for the case of Addis Ababa Bole.

## 7. Summary

The selection of best stations for this study is made by comparing available data set with number of missing months at each station. Stations with 20% and more than 20% missing data are discarded if they are 1st or 3rd class stations and more than 10% if they are synoptic stations. Further securitization of the data is made by looking at the nature of missing data. Stations with more than eleven months successive missing data are eliminated from the analysis even if the percentage of missing data is within the acceptance range. For this study station with less than twenty-four years data period have not been considered. We have used traditional time series analysis in order to study the time fluctuations of monthly rainfall series of selected stations by decomposing the given monthly rainfall data into its trend, seasonal, cyclic and irregular components. All the sixty-four stations data is decomposed into its time series components separately. Trend analysis shows that positive monthly rainfall trend is the case over some parts of central, western southwestern and eastern parts while negative trend is the case over the north and south. However, the slopes are very small and are not as such very significant. The maximum positive slope is 0.12 and observed at Filikilik. The maximum negative slope is -0.48 and observed over Warak in South Ethiopia. Seasonality is the dominate feature in monthly rainfall records. The maximum zone of seasonal index shifts from one place to the other as the year progresses. In January the maximum zone of seasonal index is located in central and southern Ethiopia where as it shows a slight east ward shift in February. With more additional new higher contours the zone of maximum seasonal index maintains its February's position in March. During April the zone of maximum values shifts to southeast. The northwestern parts begin to see better values as compared to pervious four months in May. The zone of maximum seasonal index values moves to Amhara region in July and August. In September the maximum is located over parts of western Ethiopia. In October the situation over the southeastern and southern parts improved. Though there are some differences in values and location of high seasonal rainfall index values there is generally a resemblance in pattern among January, February and March, between July and August, between November and December. The strength of seasonal index is high in the country during July and August and low during January and December. In rainfall regime C all stations have peak seasonality index in April. In August the index gets more pronounced over rainfall regime A. The case when cyclic values are high and what sort of cyclic repetitions occurs have been examined. We have not found any systematic upward and downward regular and uniform cyclic movements in any of the stations. A definite cycle length cannot be defined. However, some stations have more number of high cyclic indexes than others. The irregular component varies between 0 and 3 and it does not follow any well-defined pattern. How we use time series analysis to forecast monthly and seasonal rainfall of a given station is discussed in the next document of this study.

**Acknowledgment**

I would like to thank the National Meteorological Agency of Ethiopia for giving me the chance to serve in Meteorological Research and Studies Department and also for making available every facility required to undertake this research.

## References

Arsham H. and Shao S. P. 1985. Seasonal and Cyclic Forecasting for the Small Firm: *American J. Small Business,* 4, 46-57.

Bowerman, B. L., and O'Conell, R. T. 1987: Time Series Forecasting. Unified Concepts and Computer Implementations. 2nd ed.

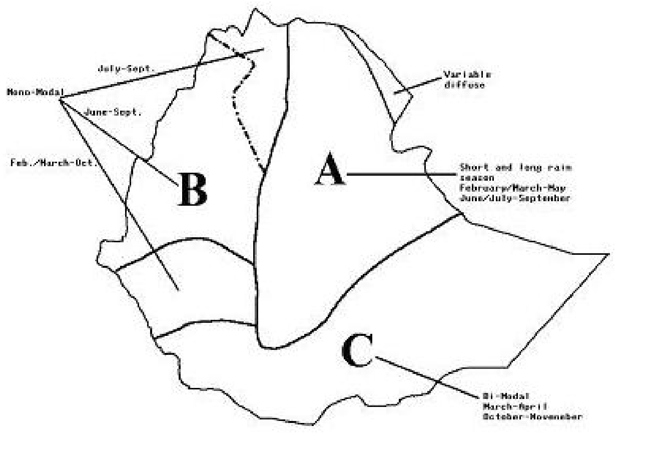
Drought Monitoring Center (DMC), 1999: Lecture notes of the first climate prediction capacity building workshop for the Greater Horn of Africa, Vol. 1 IMTR, Nairobi, Kenya.

National Meteorological Services Agency (NMSA), 1996: Assessment of drought in Ethiopia. Meteorological Research Report Series, Vol. 1, No. 2, Addis Ababa, Ethiopia.

National Meteorological Services Agency (NMSA), 2001: Initial National communication of Ethiopia to the UNFCC. Addis Ababa, Ethiopia.

National Meteorological Agency (NMA), 2011: Rainfall regime over Ethiopia [online]. Available from: http://meteo -ethiopia.net/ [Assesses 30 May 2011].

## Appendix A




Rainfall Regimes over Ethiopia (after Tesfaye Haile)

Source: http://meteo-ethiopia.net/

# Appendix B

**Latitude and longitude coordinates, class, rain fall regime and data years of meteorological stations used in this study**

| No. | Station name | Station's Rain fall Regime | class | Years for which data is available | Lat (deg. Dec.) | Lon (deg. Dec.) |
|---|---|---|---|---|---|---|
| 1 | AA Bole | A | 2 | 1954-2010 | 9.033 | 38.750 |
| 2 | Abomsa | A | 1 | 1986-2009 | 8.467 | 39.817 |
| 3 | Adele | A | 1 | 1984-2009 | 7.800 | 39.900 |
| 4 | Assela | A | 3 | 1966-2007 | 7.950 | 39.133 |
| 5 | Combolcha | A | 2 | 1960-2010 | 11.117 | 39.733 |
| 6 | Debre Birhan | A | 1 | 1967-2009 | 9.633 | 39.500 |
| 7 | Fiche | A | 1 | 1973-2009 | 9.800 | 38.700 |
| 8 | Hunte | A | 1 | 1982-2006 | 7.050 | 39.400 |
| 9 | Kulumsa | A | 1 | 1967-2008 | 8.133 | 39.133 |
| 10 | Lemi | A | 3 | 1973-2007 | 9.817 | 38.900 |
| 11 | Majete | A | 1 | 1969-2009 | 10.500 | 39.850 |
| 12 | Meraro | A | 1 | 1968-2008 | 7.450 | 39.367 |
| 13 | Metehara | A | 2 | 1985-2010 | 8.867 | 39.900 |
| 14 | Nazret | A | 1 | 1970-2009 | 8.550 | 39.283 |
| 15 | Nuraera | A | 1 | 1986-2006 | 8.833 | 39.900 |
| 16 | Robe | A | 1 | 1968-2009 | 7.850 | 39.617 |
| 17 | Sagure | A | 1 | 1973-2007 | 7.767 | 39.150 |
| 18 | Seru | A | 1 | 1978-2008 | 7.733 | 40.167 |
| 19 | Shola Gebeya | A | 1 | 1962-2009 | 9.050 | 38.767 |
| 20 | Ziway | A | 1 | 1970-2008 | 7.933 | 38.717 |
| 21 | Adet | B | 1 | 1987-2010 | 11.267 | 37.467 |
| 22 | Alem Ketema | B | 1 | 1973-2009 | 10.033 | 39.033 |
| 23 | Alibo | B | 3 | 1969-2007 | 9.900 | 37.067 |
| 24 | Arjo | B | 1 | 1972-2009 | 8.750 | 36.500 |
| 25 | Assendabo | B | 3 | 1972-2007 | 7.767 | 37.233 |
| 26 | Atnago | B | 3 | 1969-2007 | 8.317 | 36.933 |
| 27 | Awassa | B | 2 | 1973-2010 | 7.083 | 38.483 |
| 28 | Bahir Dar | B | 1 | 1962-2005 | 11.600 | 37.417 |
| 29 | Bure | B | 1 | 1975-2006 | 8.267 | 35.083 |
| 30 | Dangila | B | 1 | 1987-2010 | 11.117 | 36.417 |
| 31 | Debre Markos | B | 2 | 1960-2010 | 10.333 | 37.667 |
| 32 | Debre Work | B | 3 | 1976-2006 | 10.733 | 38.133 |
| 33 | Dedessa | B | 1 | 1983-2009 | 9.383 | 36.100 |
| 34 | Enfranz | B | 3 | 1977-2005 | 12.183 | 37.683 |
| 35 | Filiklik | B | 3 | 1972-2007 | 10.050 | 38.167 |
| 36 | Gidayana | B | 1 | 1970-2009 | 9.867 | 36.933 |
| 37 | Gohatsion | B | 3 | 1972-2007 | 10.033 | 38.233 |
| 38 | Gondar A.P. | B | 2 | 1965-2010 | 12.550 | 37.417 |
| 39 | Gore | B | 2 | 1963-2010 | 8.150 | 35.533 |
| 40 | Hosana | B | 1 | 1972-2009 | 7.550 | 37.867 |
| 41 | Hurumu | B | 1 | 1980-2004 | 8.367 | 35.783 |
| 42 | Jimma Air Port | B | 2 | 1963-2010 | 7.667 | 38.833 |
| 43 | Maksegnit | B | 3 | 1970-2006 | 12.367 | 37.550 |
| 44 | Nekemte | B | 2 | 1971-2010 | 9.083 | 36.463 |
| 45 | Nopa | B | 3 | 1978-2006 | 8.283 | 35.600 |
| 46 | Sekoru | B | 1 | 1980-2009 | 7.917 | 37.400 |
| 47 | Tibe | B | 3 | 1970-2007 | 9.033 | 37.217 |
| 48 | Wolaita Sodo | B | 1 | 1970-2009 | 6.850 | 37.750 |
| 49 | Arba Minch | C | 2 | 1988-2010 | 6.083 | 37.633 |
| 50 | Degahabour | C | 1 | 1979-2010 | 8.217 | 43.550 |
| 51 | Dilla | C | 1 | 1988-2009 | 6.167 | 38.550 |
| 52 | Dire Dawa | C | 2 | 1960-2010 | 9.600 | 41.850 |
| 53 | Gato | C | 3 | 1973-2007 | 5.467 | 37.450 |
| 54 | Gerese | C | 3 | 1973-2007 | 5.917 | 37.317 |
| 55 | Ginir | C | 1 | 1969-2009 | 7.133 | 40.700 |
| 56 | Gursum | C | 3 | 1969-2006 | 9.350 | 42.383 |
| 57 | Hagere Mariam | C | 1 | 1975-2009 | 5.633 | 38.233 |
| 58 | Jinka | C | 1 | 1970-2009 | 5.800 | 36.550 |
| 59 | Kebri Dehar | C | 1 | 1980-2003 | 6.733 | 44.300 |
| 60 | Kibre Mengist | C | 1 | 1974-2008 | 5.867 | 38.967 |
| 61 | Moyale | C | 1 | 1978-2009 | 3.517 | 39.067 |
| 62 | Robe | C | 2 | 1985-2010 | 7.133 | 40.000 |
| 63 | Worka | C | 1 | 1987-2006 | 6.483 | 39.217 |
| 64 | Yabello | C | 1 | 1986-2009 | 4.883 | 38.100 |

# Appendix B

**Cyclic component of the time series data Years with cyclic component three and more than three**

| No | Name | Cyclic Values | | Years for which data is available | Station's Rain fall Regime |
|---|---|---|---|---|---|
| | | >3 | >4 | | |
| 1 | Abomsa | 1990,1992,1993 | 1990 | 1986-2009 | A |
| 2 | Addis Ababa Bole | 1967, 968,1969,1973, 1976,2008,2009,2010 | 1973,1976,2009,2010 | 1954-2010 | A |
| 3 | Adelle | 1990,1993,1997 | No | 1984-2009 | A |
| 4 | Alem Ketema | 1978,1979,1982,1989,1990,1992,2008 | 1979,1982,1992 | 1973-2009 | A |
| 5 | Assela | 1967,1990,1996,2004,2005 | No | 1966-2007 | A |
| 6 | Combolcha | 1963,1969,1990 | No | 1973-2009 | A |
| 7 | D/Birhan | 1967,1971,1972,1997,2008 | 1967,1971,2008 | 1967-2009 | A |
| 8 | Fiche | 1977 | 1977 | 1973-2009 | A |
| 9 | Hunte | 1997,2003 | No | 1967-2008 | A |
| 10 | Kulumsa | 1976,1982 | 1976 | 1980-2004 | A |
| 11 | Lemi | 1979,1982,1986,1987,1990,1996 | 1982,1987,1990 | 1969-2009 | A |
| 12 | Majete | 1969,1997 | 1969 | 1969-2009 | A |
| 13 | Meraro | 1978,1979,1982,1990 | 1978,1979,1990 | 1968-2008 | A |
| 14 | Metehara | 1990,2008 | 2008 | 1985-2010 | A |
| 15 | Nazret | 1977,1990,1994,2000,2003,2008 | 1977 | 1970-2009 | A |
| 16 | Nura Era | 1990 | 1990 | 1986-2009 | A |
| 17 | Robe (Arsi) | 1978,1979,1987,1990,1993,1997 | 1978,1979 | 1968-2009 | A |
| 18 | Sagure | 1979,1990 | No | 1973-1007 | A |
| 19 | Seru | 1978,1995,1996,1997,1998 | 1978,1995,1996,1997,1998 | | A |
| 20 | Shola Gebeya | 1962,1967,1971,1972,1979,1986,1990,1997,2006,2007,2008 | 1971,1972 | 1962-2009 | A |
| 21 | Ziway | 1976,1979,1989,1990,1996,2000,2003,2004 | 1976,1989,1990,1996,2000 | 1970-2008 | A |
| 22 | Adet | 1995,1996 | No | 1987-2010 | B |
| 23 | Alibo | 1969,1988,1989,2003 | No | 1969-2007 | B |
| 24 | Arjo | 1972 | 1972 | 1972-2009 | B |
| 25 | Assendabo | 1997 | No | 1972-2007 | B |
| 26 | Atnago | 1997 | No | 1988-2010 | B |
| 27 | Awassa | 2004 | No | 1973-2010 | B |
| 28 | Bahir Dar | 1966,1969,1975,1976,1996,176,1996,1998,1999,2004 | 1966,1975 | 1962-2005 | B |
| 29 | Bure | 1999,2000 | No | 1975-2006 | B |
| 30 | Dangila | 1992,2007,2008 | 2007,2008 | 1987-2010 | B |
| 31 | Debre Work | 1990,2000 | No | 1976-2006 | B |
| 32 | DebreMarkos | 1969 | No | 1960-2010 | B |
| 33 | Dedessa | 1989,1990,1996 | 1989,1990 | 1983-2009 | B |
| 34 | Enfranz | 1977,1989,1990,1993,1996,1998,1999,2004 | 1977,1993,1998,1999 | 1977-2005 | B |
| 35 | Filiklik | 1977, 1996,1997, 2000,2007 | 2000 | 1972-2007 | B |
| 36 | Gidayana | 1978,1979 | 1978,1979 | 1970-2009 | B |
| 37 | GohaTsion | 1997 | 1997 | 1972-2007 | B |
| 38 | Gondar | 1969,1975,1998,1999 | No | 1965-2010 | B |
| 39 | Gore | 1996 | No | 1963-2010 | B |
| 40 | Hosana | 1982,1990,1997,2003 | No | 1972-2009 | B |
| 41 | Hurmur | 1990 | No | 1978-2009 | B |
| 42 | Jimma | No | No | 1963-2010 | B |
| 43 | Maksegnif | 1970,1982,1992,1993,1996,1997,1998,2003 | 1992,1993,1997,1998 | 1970-2006 | B |
| 44 | Nekemt | No | No | 1971-2010 | B |
| 45 | Nopa | 1981,1982 | 1982 | 1978-2006 | B |
| 46 | Sekoru | 1989,1990,1997 | No | 1980-2009 | B |
| 47 | Tibe | 1983,1989,1990,1992 | No | 1970-2007 | B |
| 48 | Wolita Sodo | 1973,1990,1997 | 1973,1990 | 1970-2009 | B |
| 49 | Arba Minch | 1993,1997 | No | 1988-2010 | C |
| 50 | Degaha bour | 1981,1983,1985,1986,1991,1992,1997,2000,2003,2004 | 1983,1991,1992,1997 | 1979-2010 | C |
| 51 | Dilla | 1990 | No | 1988-2009 | C |
| 52 | DireDawa | 1961,1967,1969,1979,1980,1990,1992,1993,1997,2003,2004 | 1967,1980,1992 | 1973-207 | C |
| 53 | Gato | 1982,1983,1993,1997,2002,2003 | 1982 | 1967-2008 | C |
| 54 | Gerese | 1993,1996,1997,1998 | 1997,1998 | 1969-2009 | C |
| 55 | Ginnir | 1980,1981,1982,1993,1997,2009 | 1981,1997,1998,2009 | 1960-2010 | C |
| 56 | Gursum | 1970,1979,1991,1992,1993 | 1992,1993 | 1970-2009 | C |
| 57 | Hager Mariam | 1978,1992,1993 | 1993 | 1975-2009 | C |
| 58 | Jinka | 1990,1997,1998 | No | 1973-2007 | C |
| 59 | K/Mengist | 1990,1998,2004 | 1990 | 1985-2010 | C |
| 60 | Kebri Dehar | 1983,1984,1985,1986,1988,1991,1994,1996,1997,2001 | 1983,1984,1985,1986,1991,1994,1997 | 1978-2009 | C |
| 61 | Moyale | 1997,1998,2006 | 1997,1998,2006 | 1969-2007 | C |
| 62 | Robe(Bale) | 1990,1997,2010 | No | 1969-2006 | C |
| 63 | Worka | 1997,1998 | No | 1986-2009 | C |
| 64 | Yabello | 1990, 1997 | No | 1970-2008 | C |

*******