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Full Length Research Paper

Homogeneity tests on rainfall records for selected meteorological stations in Ethiopia

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Long records of climatologically time series data is one of the key input in many research acclivities like climate change, agriculture and the like. Value of such data sets is highly dependent on its homogeneity level. This entails the need for such data sets to be free from artificial trends or changes caused by non-climatic factors like change in measuring instrument and station relocations. Pertaining to this fact, the study tried to assess the homogeneity in daily rainfall data sets of 54 weather stations found across Ethiopia. Annual mean and annual maximum rainfall were used as testing variables. Four statistical testing methods namely, standard normal homogeneity test (SNHT), Buishand range test, Pettitt test, and von Neumann ratio tests were employed in the study. As the result showed, 74% of the stations were found useful for further climate change analysis. However, the percentage of useful stations varies as different testing variables and test methods used. For instance, 89% and 73% of the stations were found homogeneous when annual maximum and mean rainfall were used as testing variable respectively. This discrepancy infers, the need to consider simultaneously multiple testing variables as well test methods to detect inhomogeneity in stations data sets correctly.

Keyword: Homogeneity, climate, rainfall, standard normal homogeneity test, buishand range test, pettitt test, von Neumann ratio test, Break year

INTRODUCTION

Climate change is one of the global issue these days and many researches are undertaken study on climate change at different spatial and temporal scale across the world. The reliability of outputs of climate change researches depend on the input data used in the studies. Long records of climatologically time series data is one of the key input data in climate change researches and it is very important for such kind of data sets to be free from artificial trends or changes. However, time series climate data are often exhibit spurious (non-climatic) jumps and/or gradual shifts due to station relocations, changes in instrumentation or changing in observing practices. These could force misleading information to be produced. Therefore, it is quite important undertaking homogeneity test to detect possible inhomogeneity's for such kind of data sets before it is used for further analysis.

Homogeneity test in time series climate data can be considered as part and parcel of data preparation and quality checking step. Different statistical methods as well as approaches are developed to detect homogeneity in time series climate data and make adjustment to it. For instance, a bivariate test can be used to detect a single systematic change in mean in an independent time series data (Kironoet al. 2007). This test is very similar with standard normal homogeneity test (SNHT). Another statistical method to detect in homogeneity in time series climate data is the penalized maximal t test(PMT) (Wang et al. 2006). The test considers position of each station change-point to reduce the effect of unequal sample sizes. Residuals from unrelated regression equation(SUR) model can be considered as test to detect homogeneity in time series data (Costa et al. 2006).

It is known that the statistical methods used for homogeneity test have their own strong and weak side. For instance, Wang et al. (2006) compared PMT with SNHT and found that PMT is more powerful in detecting all the change-points that are not too close with the end of time series and weak in at the end of time series.

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Therefore, it is suggested that running multiple test together and compare each other helps to reach to a proper decision. In this regard, Wijngaad et al. (2003) employed four homogeneity tests, named SNHT, Buishand range (BR) test, Pettitt test and von Neumann ratio (VNR) test to the European Climate. In the same way, Suhaila et al. (2008) employed these four methods to test the daily rainfall series of Peninsular Malaysia from 1975 to 2004. Meanwhile, Stepanek et al. (2009) used SNHT, bivariate test and Easterling and Peterson test to detect inhomogeneity's of air temperature and precipitation series of Czech Republic. In Ethiopia, Seleshi and Camberlin (2006) used multiple analysis of series for homogenization (MASH) technique.
In this study , Wijngaard et al. (2003) approach that integrate the four tests, SNHT, Buishand range (BR) test, Pettitt test and von Neumann ratio (VNR) test, is adopted to detect inhomogeneity in time series of annual rainfall data of 54 weather stations found across Ethiopia.

MATERIAL AND METHOD

Data preparation

30 years daily rainfall data collected from 54weather stations, which are located across the countryare considered for this study (Figure 1). During selecting the stations, essential considerations are taken including the amount of missing data, errors and evenness of stations distribution which can mislead the homogeneity test.

Statistical Methods

The homogeneity tests used in this study include the Standard normal homogeneity test (SNHT), the Buishand range (BR) test, the Pettitt test, and lastly the von Neumann ratio (VNR) test. The null hypothesis test assumed that the annual values Yi of the testing variables Y are independent and identically distributed and the series are considered as homogeneous. In the alternative hypothesis, if the series has break in the mean, then it is considered as inhomogeneous in SNHT, BR test and Pettitt test. Since VNR test assumes the series is not randomly distributed under alternative hypothesis, unlike the other tests, VNR is not able to give information on the year break.
Difference also exist among the tests. For instance, it is easier to detect breaks in the middle of the series for BR test and Pettitt test, whereas SNHT detects break easily near the beginning and the end of the series. Additionally, unlike Pettitt test, SNHT and BR test assume Yi is normally distributed.

Standard Normal Homogeneity Test (SNHT)

A statistic T(y) is used to compare the mean of the first y years with the last of (n-y) years and can be written as below:

$$T_y = y\bar{z}_1 + (n-y)\bar{z}_2 \text{ , y = 1,2,3...,n}$$

Where

$$\bar{z}_1 = \frac{1}{y}\sum_{i=1}^{n}\frac{(y_i - \bar{y})}{s} \quad \text{and}$$

$$\bar{z}_2 = \frac{1}{n-y}\sum_{i=y+1}^{n}\frac{(y_i - \bar{y})}{s}$$

The year y consisted of break if value of T is maximum. To reject null hypothesis, the test statistic, is greater than the critical value, which depends on the sample size.

$$T_0 = \max_{0 \le y \le n} T_y$$

Buishand Range Test

The adjusted partial sum is defined as:

$$S_0^* = 0 \text{ and} S_y^* = \sum_{i=1}^{y}(Y_i - \bar{Y}) \text{, y= 1,2,3....n}$$

When the series is homogeneous, then the value ofS_0^* will rise and fall around zero.The year y has break S_y^* when has reached a maximum (negative shift) or minimum (positive shift). Rescaled adjusted range, R is obtained by

$$R = \frac{\left(\max\limits_{0 \le y \le n} S_y^* - \min\limits_{0 \le y \le n} S_y^*\right)}{S}$$

The $R/\sqrt{n}$ is then compared with the critical values given by Buishand (1982).

Pettitt Test
This test is based on the rank, ri of the Yi and ignores the normality of the series.

$$X_y = 2\sum_{i=1}^{y} r_i - y(n+1), \text{ y = 1,2,3...n}$$

The break occurs in year k when

$$X_k = \max_{0 \le x \le 1} |X_y|$$

The value is then compared with the critical value by Pettitt (1979).

Von Neumann Ratio Test
It is a test that used the ratio of mean square successive (year to year) difference to the variance. The test statistic is shown as follows:

$$N = \frac{\sum_{i=1}^{n}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

When the series is homogeneous, then the expected value E(N) = 2. When the samples has a break, then the value of N must be lower than 2, otherwise it implies that the sample has rapid variation in the mean

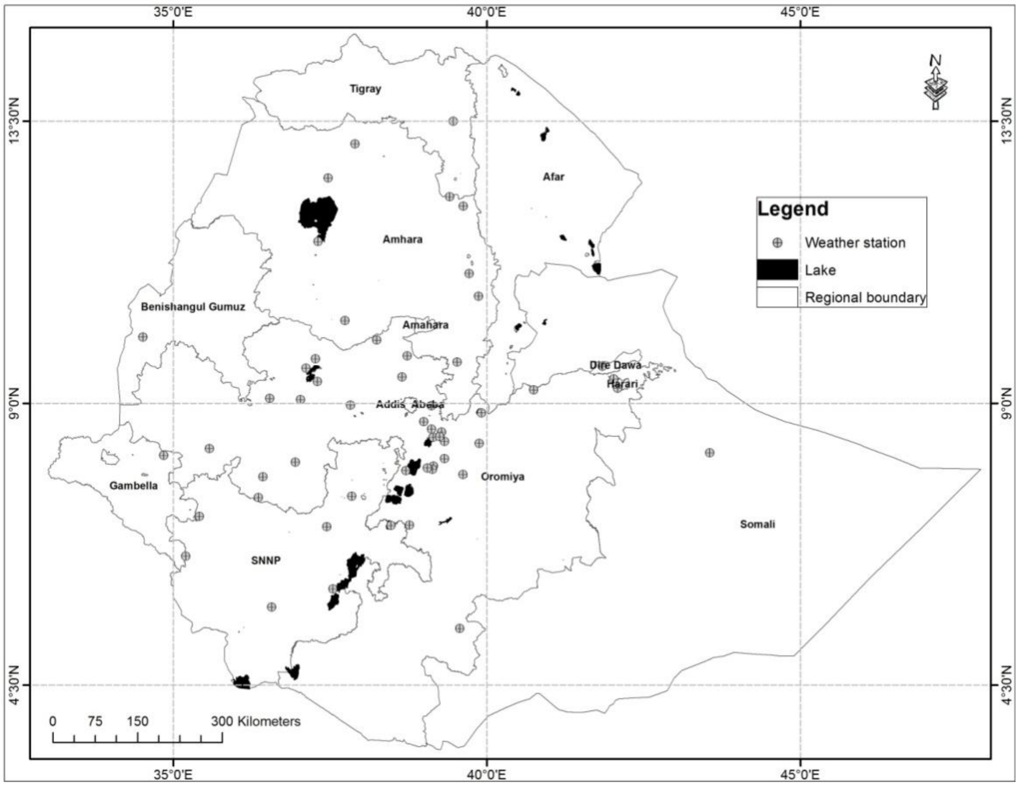


Figure 1: Weather station distribution

Table1: Distributions of stations by homogeneity status using mean annual rainfall as testing variable

Test assessment	No. Stations	%	Status
Not rejected by any test	33	61.11	Useful
Rejected by one of test	7	12.96	Useful
Rejected by two of test	5	9.26	Doubtful
Rejected by three of test	3	5.56	Suspect
Rejected by four of test	6	11.11	Suspect
Total	54	100	

Interpretation of the test results

The four statistical test results classified into useful, doubtful and suspect according to Wijngaard et al. (2003). Each class is defined in the following way.

Useful: The series that rejects one or none null hypothesis under the four tests at 5% significance level are considered. Under this class, the series is grouped as homogeneous and can be used for further analysis.

Doubtful: The series that reject two null hypotheses of the four tests at 5% significance level is placed in this class. In this class, the series have the inhomogeneous signal and should be critically inspected before further analysis.

Suspect: If three or more of the tests reject the null hypothesis at 5% significance level the series is classified into this category. In this category, the series can be deleted or ignored before further analysis.

RESULTS AND DISCUSSION

Annual mean and annual maximum of each rainfall station are tested by the four homogeneity tests. The critical values used for SNHT, BR test, Pettitt test and VNR test are 6.95, 1.43, 57 and 1.30, respectively according to Wijngaard et al. (2003).

Table 1. shows the results of the homogeneity tests for 54 stations based on annual mean rainfall. Out of the total, 40 stations were found useful, meaning not rejected or rejected only by one of the tests. Five stations are found doubtful, meaning rejected by two of the tests, and 9 stations are found under suspect, meaning rejected by 3 or more of the tests. As discussed in the methodology section, the four test methods employed in the study detect breaks in the data set at different time points (beginning, middle, end) of the time series. The means

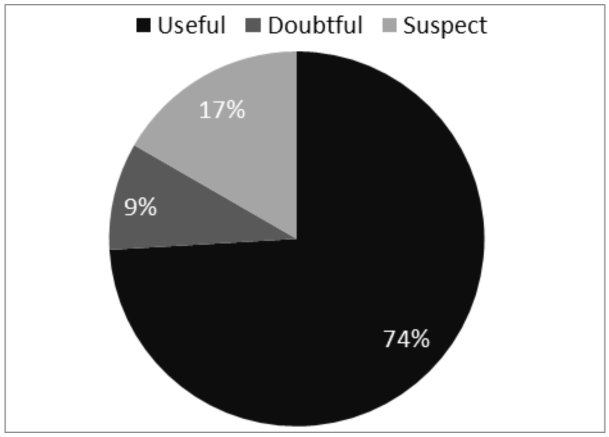
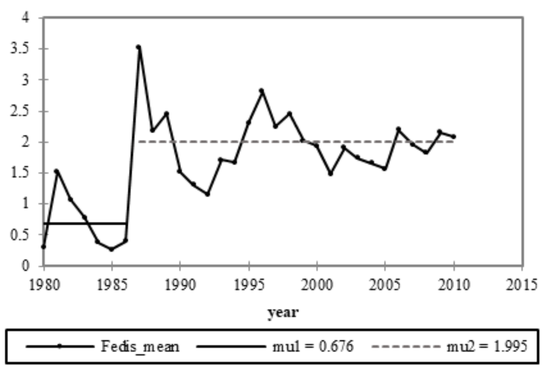
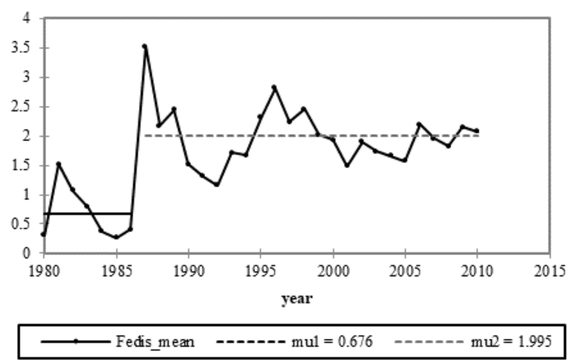


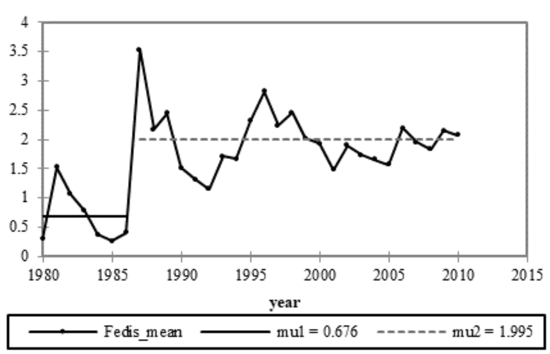
Figure 2. Percent (%) distributions of status of stations



a) Pettitt's test



b) SNHT



c) Buishand's test

each of the 9 stations labeled as suspected has at least three breaks possibly caused by different non-climate factors at different location (time point) of the data set. Thus when three or more tests simultaneously reject a given station it can be concluded that different non climatic factors has forced the data set to lose its homogeneity at different time points of the time series.

Figure 1. reveals nearly 74% of the stations are homogeneous based on annual mean rainfall data and can be considered as useful for further analysis like climate change studies which need reliable continuous and homogeneous data.

Stations falls under suspect are Fedis, Fiche, Metu, Mojo, Neshi, Arata, Gonder, Negelle and Nekemete. The first six stations are rejected by four test while the remaining three stations are rejected by three tests (annex1). These stations cannot be used for further analysis because it leads to misleading result.

Figure 3. Test statistics of annual mean rainfall for Pettitt, SNHT and Buishand test of Station Fedis

Table 3. Stations fall under suspect based on using two climate variables, annual maximum and annual mean rainfall

No	Suspected station based on annual mean rainfall	Suspected station based on annual maximum rainfall	Testing climate variables used for detection
1	Fedis	Fedis	2
2	Fiche	-	1
3	Metu	Metu	2
4	Mojo	-	1
5	Neshi,	Neshi	2
6	Arata	-	1
7	Gonder	-	1
8	Negelle	Negelle	2
9	Nekemete	-	1
10	-	Arsi robe	1
11	-	Kofele	1

Based on annual maximum rainfall data, 48 stations are found useful, 1 station is doubtful and 5 stations fall under suspect. Table 2 shows the status of the stations accordingly.

Table2: Distributions of stations by homogeneity status using annual maximum rainfall as testing variable

Figure 2. shows 89% of the stations are homogeneous based on annual maximum rainfall data and can be considered as useful for further analysis.

Inhomogeneity's are found in Fedis,Metu, Negelle, Neshi, Arsi robe and Kofele stations' annual maximum rainfall data as it is confirmed by the rejection of the four testes for the first five stations and rejection by two test for the last station in the list. Accordingly, these stations cannot be used for further analysis because it leads to misleading result.

Figure 3. Test statistics of annual maximum rainfall for Pettitt, SNHT and Buishand test of Station Fedis from 1980 to 2010

Table 3 shows list of stations fall under suspect based on using the two climate parameters, annual maximum and annual mean rainfall. Inhomogeneity is detected in both annual maximum and annual mean rainfall data for Fedis, Metu, Neshi and Negele stations. For Fiche, Mojo, Arata, Gondor, Nekemete, Arsi robe and Kofele stations inhomogeneity is detected either using annual maximum or annual mean rainfall data but not both. This implies that only one climate variables is not enough to identify and detect inhomogeneity in climate data

CONCLUSION

Annual mean and annual maximum rainfall data are used as a testing climate variables to detect homogeneity in the data. It is found that these two variables were successfully used to detect inhomogeneity in the data. The results were assessed by classifying the stations into three categories, which are useful, doubtful and suspect. When annual mean rainfall is used, 74 % of the stations are useful, 9% of the stations are doubtful and 17 % of the stations are suspect. However, 89% of the stations are useful, 2 % of the stations are doubtful and 9% of the stations are suspect when annual median is used. Those stations data that fall under useful category can be used for further climate based study.

Two different testing climate variables are used in testing the homogeneity of the daily rainfall series. It is clearly observed that only one testing climate variable is not enough to detect inhomogeneity in stations data. Especially, annual mean may obscure breaks in time series data unlike annual maximum as a result detection become difficult. Thus it is advisable to use together testing climate variables to efficiently detect inhomogeneity in time serious data particularly for climate change studies that solely depend on the quality of data.

In the future, it is encouraged to consider station history, observation practices and missing value in the data during studying of homogeneity. This will give evidence to evaluate the breaks detected and make correction.

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Annexes

Annex 1: Stations judged by one or more of the tastes as inhomogeneous using annual mean rainfall as testing variable

		Homogeneity Test (p-values)				**No. Tests Reject**	
S.N	**Stations**	Pettitt's test	SNHT	Buishand's test	von Neumann's test	**H0**	**Class**
2	Alemaya	0.658	0.490	0.673	0.265	0	Useful
4	Arba_Minch	0.927	0.899	0.965	0.464	0	Useful
5	Areka	0.403	0.583	0.359	0.246	0	Useful
7	Awassa	0.901	0.975	0.945	0.258	0	Useful
8	Baco	0.763	0.249	0.223	0.071	0	Useful
9	Bahir_Dar	0.152	0.300	0.205	0.182	0	Useful
10	Agaro	0.379	0.599	0.478	0.302	0	Useful
11	Bonga	0.140	0.071	0.082	0.426	0	Useful
12	Degahabur	0.290	0.354	0.226	0.180	0	Useful
14	MeisoAVA	0.930	0.985	0.862	0.859	0	Useful
15	Combolcha	0.493	0.784	0.506	0.495	0	Useful
16	Debark	0.431	0.432	0.250	0.238	0	Useful
17	Debre_Berhan	0.466	0.739	0.398	0.742	0	Useful
18	Debre_Markos	0.561	0.454	0.343	0.777	0	Useful
19	Debre_Zeit	0.301	0.777	0.466	0.895	0	Useful
29	Gohatsion	0.483	0.412	0.520	0.435	0	Useful
31	Hosana	0.854	0.546	0.938	0.765	0	Useful
32	JIMMA	0.276	0.448	0.328	0.202	0	Useful
33	Jinka	0.258	0.202	0.185	0.094	0	Useful
34	Kemisse	0.192	0.286	0.114	0.497	0	Useful
35	Kobbo	0.503	0.516	0.413	0.145	0	Useful
36	Kofele	0.531	0.409	0.663	0.225	0	Useful
37	Kulumsa	0.289	0.291	0.561	0.210	0	Useful
38	Limu_Genet	0.851	0.536	0.935	0.678	0	Useful
39	Mekele	0.147	0.213	0.220	0.160	0	Useful
40	Melkasa	0.147	0.337	0.147	0.476	0	Useful
41	Metehara	0.254	0.411	0.319	0.110	0	Useful
44	Nazeret	0.945	0.559	0.941	0.942	0	Useful
48	Shambu	0.159	0.260	0.210	0.201	0	Useful
49	Tepi	0.225	0.466	0.709	0.502	0	Useful
53	Gunna	0.730	0.855	0.720	0.426	0	Useful
54	Huruta	0.733	0.907	0.734	0.574	0	Useful
51	Ziway	0.315	0.734	0.452	0.602	0	Useful
1	Alamata	0.047	0.154	0.295	0.165	1	Useful
24	WS_Combolcha	0.032	0.287	0.087	0.707	1	Useful
25	KokaDam	0.008	0.288	0.137	0.194	1	Useful
26	Wonji	0.758	0.009	0.939	0.214	1	Useful
28	ASSELA	0.060	0.092	0.039	0.199	1	Useful
43	Mizan_Tefferi	0.018	0.254	0.134	0.029	1	Useful
50	A_Robe	0.262	0.540	0.316	0.019	1	Useful
3	Ambo	0.103	0.016	0.068	0.005	2	Doubtful
6	ASSOSA	0.057	0.209	0.045	0.004	2	Doubtful
20	Derba	0.122	0.200	0.033	0.020	2	Doubtful
21	Dire_Dawa	0.039	0.217	0.085	0.023	2	Doubtful
27	Chefedonsa	0.295	0.021	0.272	0.001	2	Doubtful
30	Gondar	0.007	0.103	0.010	0.002	3	Suspect
45	NEGELLE	0.146	0.007	0.092	0.008	3	Suspect
46	Nekemte	0.030	0.098	0.038	0.016	3	Suspect
13	Fedis	0.003	< 0.0001	0.000	0.001	4	Suspect
22	Fiche	0.013	0.005	0.001	0.010	4	Suspect
23	Mojo	0.013	0.008	0.005	0.020	4	Suspect
42	Metu	0.000	0.000	< 0.0001	0.001	4	Suspect
47	NESHI	0.006	0.038	0.017	0.030	4	Suspect
52	Arata	0.001	0.000	< 0.0001	0.000	4	Suspect

Annex 2: Stations judged by one or more of the tastes as inhomogeneous using annual maximum rainfall as testing variable

S.N	Stations Stations	Homogeneity Test (p-values) Pettitt's test	SNHT	Buishand's test	von Neumann's test	No. Tests Reject H0	Class Status
1	Alamata	0.785	0.379	0.635	0.610	0	useful
3	Ambo	0.534	0.684	0.704	0.462	0	useful
4	Arba_Minch	0.135	0.086	0.063	0.516	0	useful
5	Areka	0.276	0.587	0.383	0.553	0	useful
6	ASSOSA	0.187	0.143	0.078	0.494	0	useful
7	Awassa	0.389	0.679	0.452	0.894	0	useful
10	WS_Combolcha	0.319	0.241	0.922	0.588	0	useful
11	Agaro	0.492	0.073	0.273	0.585	0	useful
12	Bonga	0.196	0.093	0.143	0.118	0	useful
15	MeisoAVA	0.913	0.410	0.550	0.877	0	useful
16	Combolcha	0.820	0.381	0.675	0.189	0	useful
17	Debark	0.629	0.495	0.566	0.126	0	useful
18	Debre_Berhan	0.927	0.760	0.904	0.327	0	useful
19	Debre_Markos	0.523	0.575	0.651	0.538	0	useful
20	Debre_Zeit	0.406	0.302	0.681	0.071	0	useful
21	Derba	0.665	0.874	0.745	0.276	0	useful
22	Dire_Dawa	0.209	0.297	0.114	0.245	0	useful
23	Fiche	0.635	0.521	0.848	0.500	0	useful
24	Mojo	0.281	0.167	0.075	0.488	0	useful
25	KokaDam	0.063	0.112	0.100	0.155	0	useful
27	Chefedonsa	0.056	0.252	0.109	0.167	0	useful
28	ASSELA	0.448	0.678	0.740	0.342	0	useful
29	Gohatsion	0.709	0.998	0.971	0.666	0	useful
31	Hosana	0.974	0.830	0.985	0.892	0	useful
32	JIMMA	0.803	0.244	0.629	0.268	0	useful
33	Jinka	0.536	0.585	0.508	0.735	0	useful
34	Kemisse	0.662	0.504	0.515	0.260	0	useful
35	Kobbo	0.948	0.962	0.941	0.544	0	useful
37	Kulumsa	0.225	0.382	0.304	0.089	0	useful
38	Limu_Genet	0.108	0.312	0.129	0.953	0	useful
39	Mekele	0.232	0.222	0.334	0.599	0	useful
40	Melkasa	0.484	0.637	0.402	0.292	0	useful
41	Metehara	0.831	0.816	0.733	0.609	0	useful
44	Nazeret	0.962	0.257	0.935	0.218	0	useful
46	Nekemte	0.667	0.453	0.934	0.768	0	useful
48	Shambu	0.241	0.626	0.385	0.399	0	useful
49	Tepi	0.399	0.578	0.347	0.315	0	useful
52	Huruta	0.386	0.677	0.507	0.309	0	useful
54	Ziway	0.763	0.803	0.524	0.929	0	useful
2	Alemaya	0.315	0.154	0.323	0.037	1	useful
8	Baco	0.059	0.183	0.054	0.006	1	useful
9	Bahir_Dar	0.147	0.361	0.197	0.029	1	useful
13	Degahabur	0.118	0.142	0.028	0.147	1	useful
26	Wonji	0.037	0.288	0.103	0.674	1	useful
30	Gondar	0.038	0.215	0.072	0.122	1	useful
43	Mizan_Tefferi	0.088	0.151	0.127	0.021	1	useful
50	Arata	0.008	0.360	0.125	0.188	1	useful

51	Gunna	0.132	0.352	0.138	0.001	1	useful
36	Kofele	0.078	0.033	0.041	0.255	2	Doubtful
14	Fedis	0.002	0.046	0.002	0.001	4	Suspect
42	Metu	0.004	0.023	0.008	0.002	4	Suspect
45	NEGELLE	0.011	0.013	0.012	0.020	4	Suspect
47	NESHI	0.009	0.002	0.008	0.009	4	Suspect
53	A_Robe	0.003	0.001	0.001	0.023	4	Suspect