QUALITY OF HYDRO-METEOROLOGICAL DATA IN REMOTE STATIONS: THE CASE OF WEITO RIVER WATERSHED, ETHIOPIA

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ABSTRACT

Engineering studies of water resources development and management heavily depends on hydro-meteorological data. Some of the errors, manual or machine, might exist in the stream flow observation that we collect from different organizations. The main objective of this study was to identify the implications of hydro-meteorological data quality on water resources planning in Weito Watershed. Hydrological and meteorological data of 1985-2011 were collected from MoWIE and NMA. Grubbs T-test was used for identifying outliers in the observed data. In addition, F and t-test for stability of variance and mean were carried out, respectively. Estimation of D-days average minimum flow was also done. Based on 1985-2011 hydro-meteorological data, Grubbs T-value, F-test, and t-test yielded value of 2.86, 0.897 and -0.05, respectively. This indicates, stability of the historical data against mean and variance with no or insignificant outlying values. During the identified dry periods, average minimum flow during 7, 15, and 30 days showed water availability above 5m^3/s in the river. The statistical data analysis test and D-days average minimum flow indicated no inflated historical data problem in Weito gauged near bridge. However, the local community did not agree with the results obtained. Therefore, we strictly recommend stake holders, research institutions, and organizations to further verify the quality of these data.

Key words: Data quality, Grubbs T-test, Hydro-meteorological and Weito

1. Introduction

Engineering studies of water resources development and management heavenly depends on hydrological and meteorological data (Worku et al., 2013). Hydrological data include stream flow and sediment flow while climatic data contains more than seven variables such as precipitation, temperature, sunshine, relative humidity, and others. An adequate and reliable record of these data play an important role in the assessment of water resources of a region, or the efficient design of water resources projects (WMO, 2014). Some manual or machine errors might exist in the stream flow observation that we collect from different organizations. Any fault of reading in these data might cause a serious problem to water resource projects and developments designed based on these data (Gebregiorgis and Hossain, 2012).

In Ethiopia, Ministry of Water, Irrigation and Electricity (MoWIE) collects hydrological data such as stream flow data from many of the rivers in the country. The hydrology and water quality directorate under the MoWIE is responsible for hydrological data collection, processing analysis and dissemination to users (http://mowie.gov.et/mandate-and-responsibility). The Ministry carries out this work mainly by employing both automatic and non-automatic gauging instruments. The automatic gaging instruments are advantageous over the non-automatic devices in that they record stream flow continuously. However, these were only implemented recently in few of the watersheds.

The major gauging stations in the country were equipped with non-recording type devices (staff gauge) which needs frequent maintenance and monitoring. These facilities further need updating the rating curve from time to time. However, updating the rating curve was not done frequently as required in the Ministry. This might be due to lack of budget, adequate human resources, and problems related to access to remote stations. Weito gaging station in the Weito Watershed is also not exceptional. Meteorological data including precipitation, wind speed, sunshine hour, relative humidity and others are collected by National Meteorological Services Agency (http://www.ethiomet.gov.et/). However, the Weito Watershed was highly characterized by severe drought for several decades. Stream flow record from MoWIE data base indicated surplus surface water potential in the basin (Mohammed et al., 2017; Worku et al., 2017).

In most Ethiopian river basins, hydro-meteorological data are characterized by poor data quality such as long years missing, unrealistic and extreme values. For meteorological data, such poor data quality can be corrected using nearby stations with the same property. However, for low quality stream flow data in rivers like Weito, gauged only at a single point, infilling long years missing records is very difficult. Therefore, using different and appropriate techniques, and improving the quality of stream flow data before any hydrological analysis is very important. In the study area, there were several investments demanding water. This watershed was often the cause for several conflicts of water use right by upstream and downstream users mainly because of water shortage. However, the recorded data didn't support the claim of water shortage in the watershed. Therefore, the aim of this study was to identify the cause of the contradiction between the recorded data and the existing situation.

2. Description of the study area

Weito Watershed is located at the lower end of Ethiopian Rift Valley Lakes Basin, between 36.6°E–38.1°E longitudes and 4.9°N - 6.3°N latitudes. It is one of the main rivers in Abaya-Chamo-Chew Bahir sub-basin system. It originates from Guge Mountains, flowing south into Lake Chew Bahir. Fig-1 shows the physical characteristics of Weito River Basin and its drainage system.

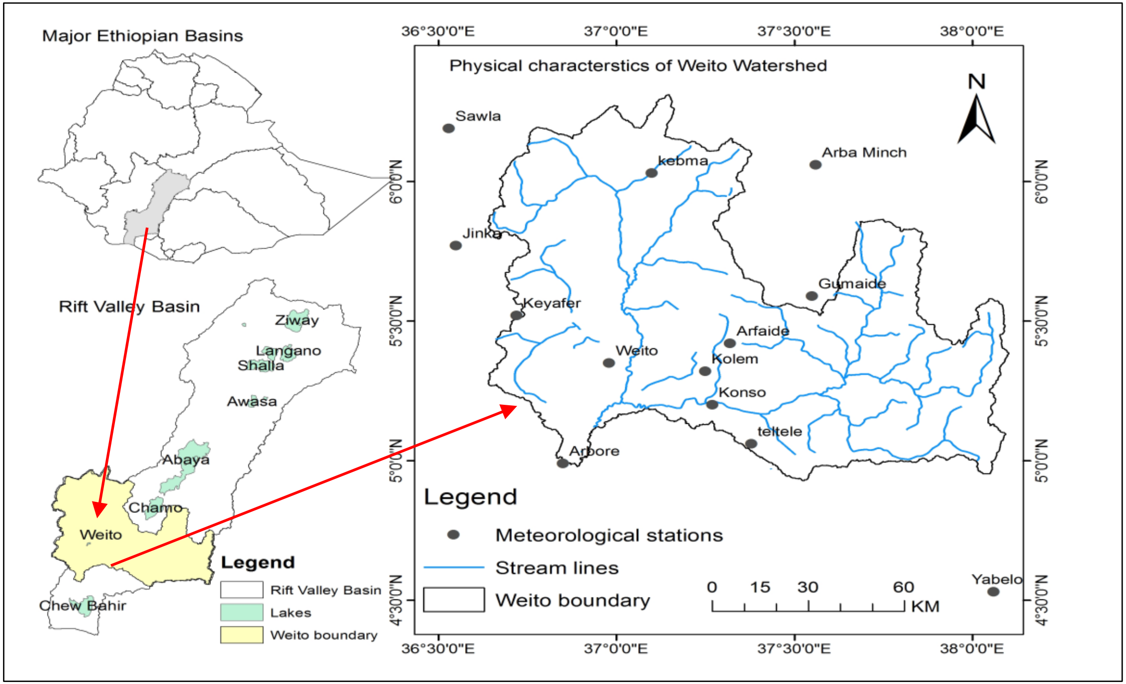

Fig-1 Physical characteristics of Weito Watershed

The river flow of Weito watershed is gauged at Weito near the bridge. The long term mean annual flow is approximately 109cumecs. It attains its peak flow in April (254Cumecs) and in October (124cumecs).

Weito River Basin is classified under bimodal rainfall region with two main rainy seasons. The main rainy season is from March to May which accounts for more than 40% of the annual rainfall. At the same time, the short rainy season extends from September to November. The annual rainfall ranges from 400mm in the dry lowlands to 2000mm in the mountain regions, with annual average of 500mm. The mean annual temperature varies between 22°C and 24°C. Weito Watershed falls under semi-arid tropical lowland climate.

3. Methods and Materials

3.1. Data sets used in this study

In order to analyze the impacts of poor stream flow data quality in Weito Watershed, important hydrological (stream flow) and meteorological data such as precipitation, and temperature (Maximum and minimum) in the basin were collected from different organizations. The data of stream flow taken around the bridge covers from 1980 to 2011. However, stream flow data with same length was used to make it similar with the available precipitation data of 22 years (1990-2011). Then, the hydro-meteorological data, thus, selected passed through different steps and procedures in order to check the absolute and relative consistency, homogeneity, and stationarity. Finally, the quality of each data was evaluated using different scenarios and comparisons. Table-1 shows data sets used in the study and respective organizations disseminating the data.

Table-1 Data sets used in the study and respective organizations disseminating the data

Data sets	Temporal resolution	Spatial Resolution	Organizations	Remark
Discharge	Daily	-	MoWIE	Weito near bridge
Precipitation	Daily	App. 10kms	NMA	in and neighboring stations
Tmax &Tmin	Daily	-	NMA	in and neighboring stations

The available meteorological data included precipitation, minimum and maximum temperature. These data were obtained from 17-meteorological stations around the watershed. The data included 22 to 59 years of precipitation and temperature. However, reliable and sufficient wind speed, relative humidity, and sunshine hour were not available. Table-2 shows the meteorological stations used for this project.

Table-2 Meteorological stations used for this project

S No	Station name	Lat	Long	Start Date	End date	Rainfall	Tmax	Tmin
1	Gerese	5.6	37.2	1990	2011	yes	yes	yes
2	Jinka	5.5	36.3	1980	2011	yes	yes	yes
3	Kemba	6.0	37.1	1987	2011	yes	no	no
4	Kolem	5.2	37.1	1990	2011	yes	no	no
5	Konso	5.2	37.3	1986	2011	yes	yes	yes
6	Sawula	6.2	36.5	1970	2011	yes	yes	yes
7	Gatto	5.3	37.3	1990	2011	yes	yes	yes
8	Weito	5.2	37.0	1990	2011	yes	no	no
9	Arba Minch	6.1	37.4	1987	2011	yes	yes	yes
10	Key Afer	5.3	36.4	1985	2012	yes	yes	yes

S No	Station name	Lat	Long	Start Date	End date	Rainfall	Tmax	Tmin
11	Arbore	5.0	36.9	1990	2011	yes	no	no
12	Dimeka	4.6	36.3	1987	2011	yes	no	no
13	Gumaide	5.6	37.6	1976	2011	yes	no	no
14	Teltele	5.1	37.4	1970	2011	yes	yes	yes
15	Arfaide	5.4	37.3	1990	2011	yes	no	no
16	Hagere Mariam	5.6	38.2	1980	2011	yes	yes	yes
17	Turmi	5.0	36.5	1988	2011	yes	yes	yes

3.2. Hydro-meteorological data screening

3.2.1. Stream flow data screening

Quality of stream flow data of Weito River gauged near the bridge was assessed by using non statistical methods. These were plotting, visual inspection, test for outliers, and test for stability of mean and variance.

3.2.2. Rough Screening and Plotting

Rough screening allowed visual detection of whether the observations had been consistently or accidentally credited to the wrong day, or whether they contained misplaced decimal points. In addition, plotting the data brought about good understanding the quality of the recorded flow in each period. We were, thus, able to observe the trends and discontinuities in the flow data.

3.2.3. Test for outliers

An outlier is an observation that deviates significantly from the bulk of the data either due to errors in data collection, recording, or due to natural causes. Timothy et al. (2013) and Borislava et al. (2014) assert that outliers can be identified visually by plotting the data or by a variety of statistical tests like Grubbs T-test, Grubbs and Beck (G-B) test. Similarly, Dixon's test of ratios and Youden's rank test can be applied to achieve the same outcome (Dahmen & Hall, 1990). In this particular project, Grubbs T-test was used to identify outlying observations. In the Grubbs T-test, the statistic (T) is calculated as:

$$T = \frac{X - \overline{X}}{S} \tag{1}$$

Where X is observed mean monthly flow, $\overline{X}$ is the mean of observed mean monthly flow, and S is the standard deviation of observed mean monthly flow during 1985-2011. According to this test, the value of X is considered an outlier if T is greater than the corresponding critical value for Grubbs T-test. For statistical tests of out-lying observations, it is generally recommended that a low significance level (such as 1%) be used and that significance levels greater than 5% should not be common practice. For statistical tests of out-lying observations, at 2.5% significance level and for twenty-seven years number of observations, the critical value for Grubbs T value is read as 2.86 from Grubbs T-table (Grubbs, 1969).

3.2.4. Tests for stability of mean and variance

Dahmen and Hall (1990) stated that F-test for stability of variance and t-test for stability of mean verify not only the stationarity of a time series, but also its absolute consistency and homogeneity. According to this method, if F-test shows stable variance and t-test shows stable mean, then we can say that the time series is stationary, consistent and homogenous.

The F-test statistic is the ratio of the variances of two split non-overlapping sub-sets of a time series. The mean monthly observations of stream flow from 1985 to 2011 were divided into two equal time series (i.e. (27*12)/2 =162 monthly stream flow observations in each time series). Then, the variance of both time series was calculated using:

$$F = \frac{Variance\ of\ series\ 1}{Variance\ of\ series2} \tag{2}$$

According to this method, the variance of the time series was stable if and only if:

$$F\{V1, V2, 2.5\%\} < F_t < F\{V1, V2, 97.5\%\}$$

Where, $V_1 = n_1 - 1$,$V_2 = n_2 - 1$ where n_1=n_2=162 (number of observation points in each subsets). Note that both F {v_1, v_2, 2.5%} and F {v_1, v_2, 97.5%} values were read as 0.73and 1.36 respectively using v_1, v_2 and percentile rows (2.5% or 97.5%).

The t-test for stability of mean involves computing and then comparing the means of two non-overlapping sub-sets of time series. The same subsets from the F-test were used for calculating the t-test values. The test statistic (t_t) was given as:

$$t_t = \frac{\bar{X}_{series1} - \bar{X}_{series2}}{\left[\frac{(n1-1)S_1^2 + (n2-1)S_2^2}{n1+n2-2} * (\frac{1}{n1} + \frac{1}{n2}\right]^{0.5}} \tag{3}$$

Where, $\overline{X}$ is mean of the series, n is the number of monthly stream flow records and s is the standard deviation of the two series. According to this test, the mean of the time series was stable if and only if,$t(V, 2.5\% < t_t < t(V, 97.5)$. Where, v = n − 2 and t value is read from (Dahmen & Hall, 1990).

3.2.5. The D-days average minimum flow

An estimate of D-days minimum average flow is very crucial for stream flow quality checkup. It is indicator of minimum flow conditions during drought period that occurs once in N years (WMO, 2008). For example, a 7-days low flow for a stream is a statistical estimate of the lowest average flow that may be experienced during a consecutive 7-days period with an average recurrence interval of N years. In this study, 7-days, 15-days, and 30-day minimum average flows collected from the bridge around Weito gauging station were computed using stream flow records (1985-2011). D-days stream flow values can change over time due to natural climatic variability and/or changes in water use and stream flow regulation. Therefore, they are updated every 15 years to account for possible changes in low flow frequency.

3.2.6. Meteorological data screening

A given data might be inconsistent due to either natural or manmade causes. These might include alterations to land use and relocation of the observation station. Therefore, in order to select representative meteorological stations for different analysis and estimation of areal rainfall, checking homogeneity of group stations was found to be essential. Therefore, non-dimensional parametrization (NDP) and double mass curve (DMC) was used to determine the homogeneity of the selected gauging stations monthly rainfall records based on their location.

A non-dimensional precipitation p*i* value for month i can be estimated as;

$Pi = \frac{\bar{P}_i}{\bar{P}}$ Where, $\bar{P}_i$= monthly averaged precipitation for the station i and $\bar{P}$ = average yearly precipitation of the station.

The selected stations were plotted for comparison with each other; for instance, fig-2 showed the results of homogeneity analysis for some groups of stations. In this figure, one could understand that the type of rainfall in the watershed area was bimodal and homogenous.

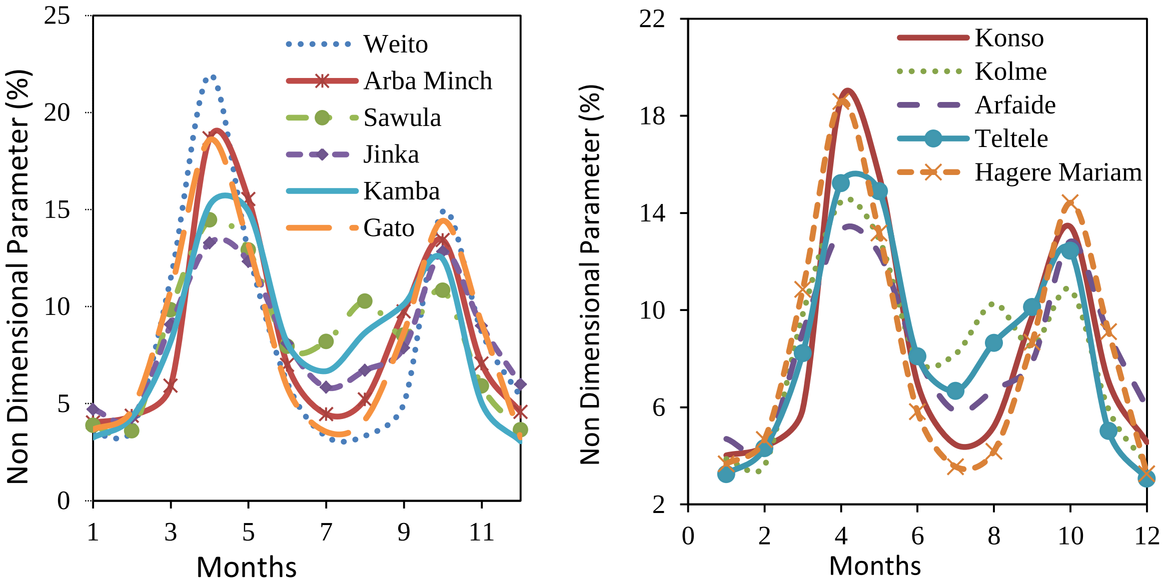

Fig-2 Consistency test for some of the meteorological stations using NDP

A time series observational data is relatively consistent and homogeneous if the periodic data are proportional to an appropriate simultaneous period. This proportionality could be tested by using double mass analysis in which accumulated rainfall/hydrological data was plotted against the mean value of all neighborhood stations. The consistency of each meteorological station was checked by using DMC. Fig-3 presents the consistency of the stations.

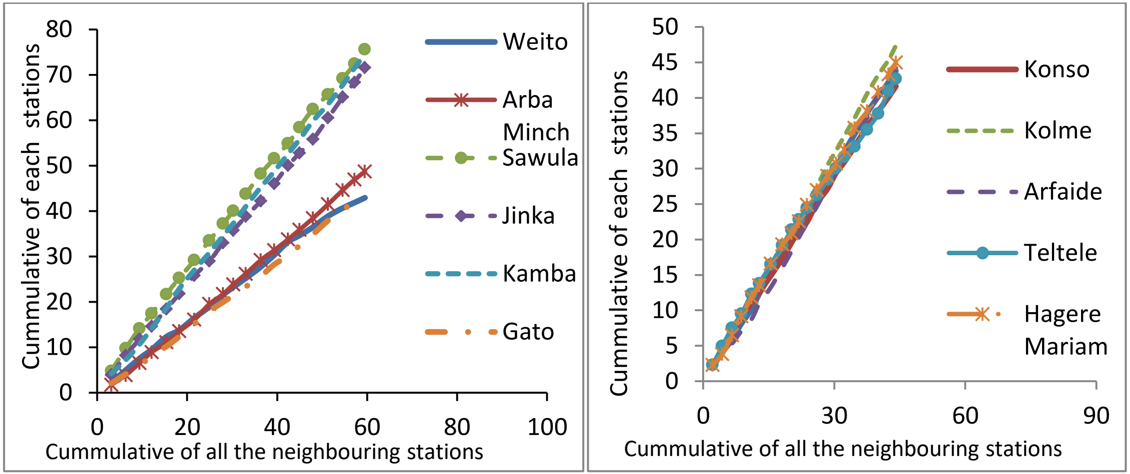

Fig-3 Consistency test for selected meteorological stations using DMC

4. Results and Discussions

4.1. Results of statistical analysis by Grubbs' T-test, F-test and t-test

Grubbs' T-test was used to check the outlying data; whereas, F and t-test were used to assess the stability of variance and mean of stream flow data. Grubbs' T-values, thus, obtained on monthly basis indicated no significant deviation from the population. Fig-4 shows mean monthly Grubbs' T-value. The method showed the presence of only eight outliers (lines above red line in Fig-4). However, all daily flow observation records during these months were believed to be reasonable and were not true outliers when compared to flow values before and after them. The variance of the data was checked by F-test where F {v_1, v_2, 2.5%} and F {v_1, v_2, 97.5%} values were read as 0.73 and 1.36, respectively. Thus, the variance of the monthly flow time series is was considered stable if and only if, $0.73 \leq F_t = 0.897 \leq 1.36$ and hence stable variance. T-test was used to check the stability of the mean of the stream flow data. The upper and lower boundary of T-value was -1.96 and 1.96, respectively. A t_value of-0.05 was obtained for stream flow around the bridge. Therefore, we can conclude that the mean of the two series was stable.

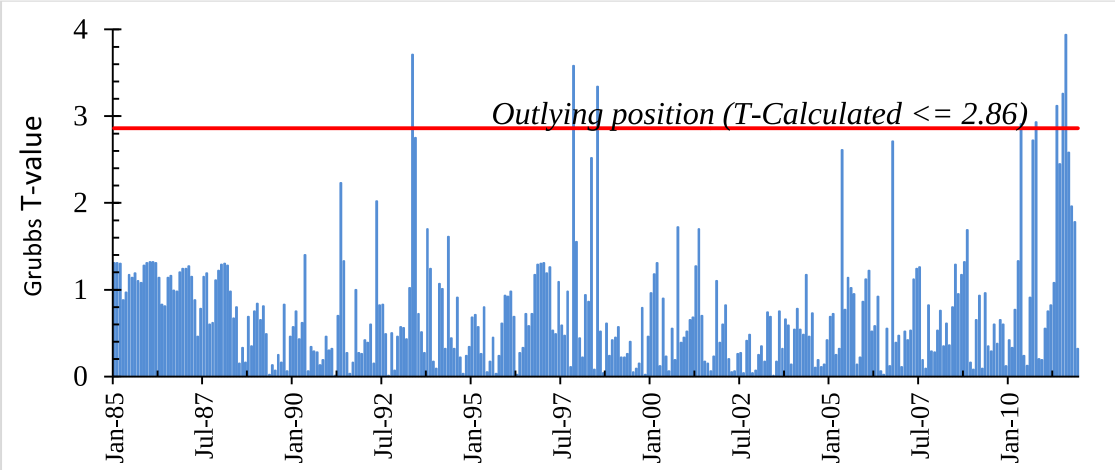

Fig-4 Plots of monthly Grubbs T-test result of Weito near Bridge (1985-2011)

To further strengthen this, schematic plot of mean monthly flow against the mean areal rainfall was drawn. However, many discrepancies were observed. Unlike rainfall, the stream flow decreased from 1993 to 1996 and increased from 2009 to 2011. Fig-5 illustrated the diagrammatic plot of areal rainfall against mean monthly rainfall.

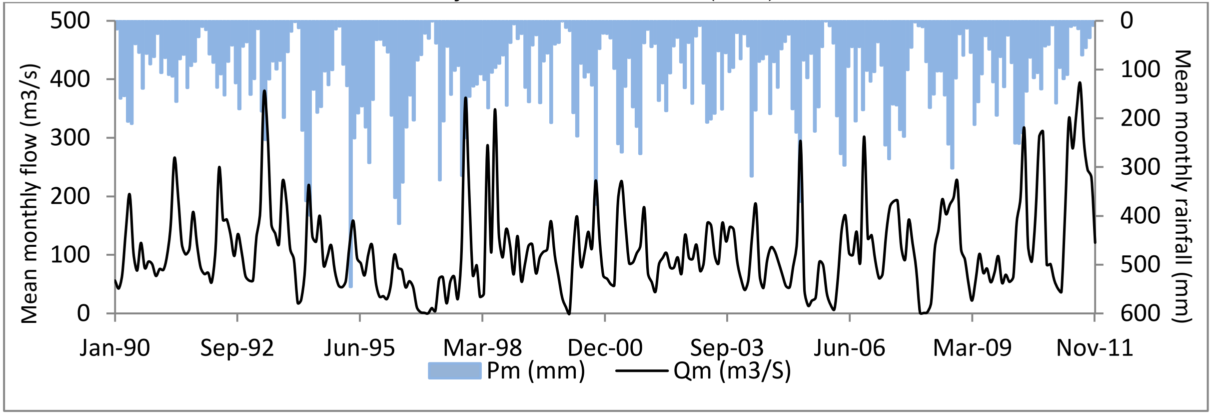

Fig-5 Schematic plot of mean monthly stream flow near bridge and Weito areal rainfall (1990-2011)

4.1. Results of the D-days average minimum flow

The 7, 15, and 30-days average minimum flow plot showed that there was significant amount of water in the river in most of the years (Fig-6). For instance, the recorded flow data indicated minimum average flow in the river for 7, 15, and 30 consecutive days were approximately 22, 23 and 32cumecs in 2010, respectively. Likewise, an average minimum flow of 5, 10, and 32 cumecs were recorded in 2011 for 7, 15 and 30 consecutive days, respectively. This suggests the river had an average flow of at least 5 and 22 cumecs in any week of the year 2010 and 2011, respectively. However, extreme water scarcity problem was observed since 2009 according to the information from local communities. Moreover, historical observation by the local community indicated that the river dried up for over a week in 2010 and 2011.

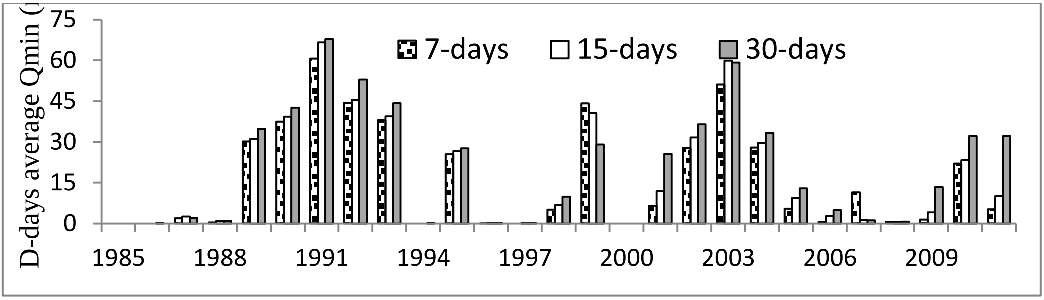

Fig-6 D-days plot of average minimum flow

It is not common to see either sudden increment of river discharge unless there is reasonable high precipitation at the upstream or vis-a-versa. However, we noticed abrupt decrease and increase of flow values in the recorded data of Weito River (Table-3). For instance:

- On 30-04-98, a river flow of 318 cumecs was recorded although the rainfall extent was 4.57mm from 28 to 30 April 98 and the recorded flow on the previous day was only 66 cumecs.

- On 11-07-07, a river flow of 324 cumecs was recorded although there was no recoded rainfall in all of the stations within the watershed from 08 to 11 July 2007 and the recorded flow on the next day was only 82 cumecs.
- From 21 to 22 July 2011, the flow decreased by 90 cumecs although the areal average rainfall increased by about 19mm over similar period. Then, from 22 to 23 July 2011, the flow increased by 254 cumecs. Some of the other major differences observed in the recorded flow were described in Table-3.

Date	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***
19-05-93		17.93	22-11-97		9.73	26-04-98		0.80	30-07-98		13.59	26-09-06		0.03
20-05-93		2.10	23-11-97		13.9	27-04-98		0.60	31-07-98		8.16	27-09-06		0.23
21-05-93		5.41	24-11-97		5.22	28-04-98		3.89	01-08-98		10.07	28-09-06		0.11
22-05-93	311	11.56	25-11-97	600	3.32	29-04-98	66	0.00	02-08-98	358	2.46	29-09-06	88	0.36
23-05-93	274	2.45	26-11-97	643	1.23	30-04-98	318	0.68	03-08-98	344	3.61	30-09-06	86	8.44
24-05-93	**515**	4.15	27-11-97	854	3.18	01-05-98	120	5.48	04-08-98	150	0.77	01-10-06	308	3.81
Date	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***
21-11-06		3.86	19-06-07		0.18	08-07-07		0.00	04-11-08		20.49	03-05-10		19.22
22-11-06		10.57	20-06-07		5.65	09-07-07		0.00	05-11-08		7.91	04-05-10		9.18
23-11-06		5.56	21-06-07		1.06	10-07-07		0.00	06-11-08		9.47	05-05-10		10.07
24-11-06	71	4.83	22-06-07	81	6.52	11-07-07	324	0.00	07-11-08	490	16.74	06-05-10	393	11.89
25-11-06	64	0.50	23-06-07	219	1.12	12-07-07	82	0.00	08-11-08	299	0.89	07-05-10	454	23.14
26-11-06	257	4.32	24-06-07	528	6.02	13-07-07	85	10.59	09-11-08	718	0.00	08-05-10	739	11.90
Date	**Flow**	**RF***	**Date**	**Flow**	**RF***	**Date**	**Flow**	**RF***						
15-03-10		0.00	28-05-11		30.8	18-07-11		3.98						
16-03-10		0.00	29-05-11		10.9	19-07-11		0.00						
17-03-10		0.53	30-05-11		20.2	20-07-11		6.40						

18-03-10	92	6.68	31-05-11	292	18.5	21-07-11	314	8.47
19-03-10	96	22.76	01-06-11	324	0.89	22-07-11	224	27.54
20-03-10	302	11.29	02-06-11	520	6.01	23-07-11	478	10.08

Table-3 Major river flow differences observed on a daily basis and the areal rainfall intensity for six consecutive days

5. Conclusion and Recommendations

Hydro-meteorological data at different gauging stations might have errors for various reasons. Statistical errors could be improved by implementing appropriate methods such as outlier test by Grubbs' T-test, and stability check-up against mean and variance of the population by F and t-test. In this regard, the result obtained from Weito Watershed was safe. Based on the available data, 7, 15, and 30 days' average low flow from 1985-2011 data confirmed the availability of significant quantity of water in the river especially after 1989. In general, the above-mentioned methods were good indicators of historical data quality. However, these methods might not be sufficient and hence further investigations such as field observations and consultation of elders might be needed. Lack of validation of rating curve, human error due to lack of competence, or lack of due attention might lead to error in data quality. Therefore, we strongly recommend further assessment and improvement of the quality of observed data for this particular station.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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