Calibration of Run-off Coefficients considering different rainfall and run-off events and seasonal flows (Case study for Laelay Wukro and GumSelassa watersheds)

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ABSTRACT

In recent years many irrigation projects have been designed and constructed in the Tigray region of Ethiopia. The impounding earth dam structures are designed by undertaking hydrologic, hydraulic, geotechnical and other related studies. One of the most important inputs for sizing the structure is the volume of water that will be expected to be generated per year from the watershed with an acceptable probability. For an accurate estimation of the potential volume, stream flow and representative rainfall records are very important. However, all dams lack such important data. Thus, in the absence of locally-developed design guidelines and codes of practice, empirical equations are often considered as an alternative design option. The water resources potential of all watersheds is estimated with an empirical formula V (m^3) = 1000 x C x P x A; where V = volume of water (m^3), C= runoff of coefficient, P= 75% annual dependable precipitation (mm) and A= catchment area (km^2). The runoff coefficient (C) used in the above equation is adapted from literature based on soil, landuses and slopes of the watershed. These values are developed in other regions of the world and not calibrated for the actual watershed conditions of the region. Thus, the objective of this study is to calibrate the run-off coefficient for different rainfall run-off events and also estimate the seasonal run-off coefficients taking two watersheds as case studies.

To undertake this study, monitoring stations were installed with a tipping-bucket rain gauge and water-level recording pressure transducer. The water level was measured every 30 minutes for the Laelay Wukro and every 15 minutes for the GumSelassa reservoirs, respectively. With the input data collected from these stations a reservoir water-balance model was developed considering all inputs and possible outputs from the reservoir. Then run-off coefficients were estimated for event-based and seasonal flows. For the Laelay Wukro watershed the estimated run-off coefficient is very low, with a seasonal value C = 0.095, which is about 31% of the design estimate. Compared to Laelay Wukro, the GumSelassa watershed yields a higher run-off coefficient. However, the seasonal value is still about 70% of the design estimate. Thus, this study indicates that there is a need to calibrate the run-off coefficient for a number of events and come up with a standardized value that would enable better water resources potential estimation for a given watershed in the region in particular and, possibly, for other parts of the country.

Keywords,
Water resources potential, runoff coefficient, event base, and seasonal analysis

1. INTRODUCTION

Tigray region is found in the Northern part of Ethiopia. In this region significant achievement were made from 1994 to 2002, on the development of agriculture through irrigation by harvesting seasonal runoff. In between the mentioned period, many micro dam irrigation projects has been designed and constructed through the combined effort of governmental and non-governmental organizations. One of the most important inputs for determining the size of the water harvesting structure is the volume of water that will be expected to be generated per year from the watershed with an acceptable probability. For an accurate estimation of the potential volume, stream flow and representative rainfall records are very important. However, all dams lack such important data. Thus, in the absence of locally-developed design guidelines and codes of practice, empirical equations are often considered as an alternative design option.

The water resources potential of all watersheds is estimated with the following empirical formula.

$$V = 1000 \; x \, C \; x \, P \; x \, A \qquad (1.1)$$

Where V= volume of water (m^3)
C = Runoff coefficient
P = annual dependable rainfall with 75% probability (mm)
A = Catchment area (km^2)

Most of the reservoirs store less volume of water compared to design estimate due to insufficient inflow. Survey made on 30 dams shows that about 60%, 70%, 90% and 72% dams harvest below 50% of their design capacity in the years 2002, 2003, 2004 and 2005. This variation between the design estimate and the actual stored water is attributed to over estimation of one or a combination of factors considered during water potential estimation. These factors are runoff coefficient, rainfall and catchments area. Thus, the objective of this study is to calibrate the runoff coefficient for different rainfall runoff events and also estimate the decadal and seasonal run-off coefficients taking two watersheds as case studies.

2. DESCRIPTION OF THE STUDY AREA

2.1 Project Location

The selected projects are located in Tigray region, which are about 35km to South and 45km towards North from Mekelle for GumSelassa and Laelay Wukro respectively. Digital map of the watershed area for both GumSelassa and Laelay Wukro are prepared from digital elevation model (DEM) generated from topographic maps (1:50000 scale) in GIS environment. The watershed area for GumSelassa is 24.6km^2 and it is bounded geographically (UTM) 558 832 - 563832East and 1457466- 1466962North. Similarly the Laelay Wukro water shed area is 9.6km^2 and its geographical location is 566123 - 568705East and 1524978 - 1523490North.

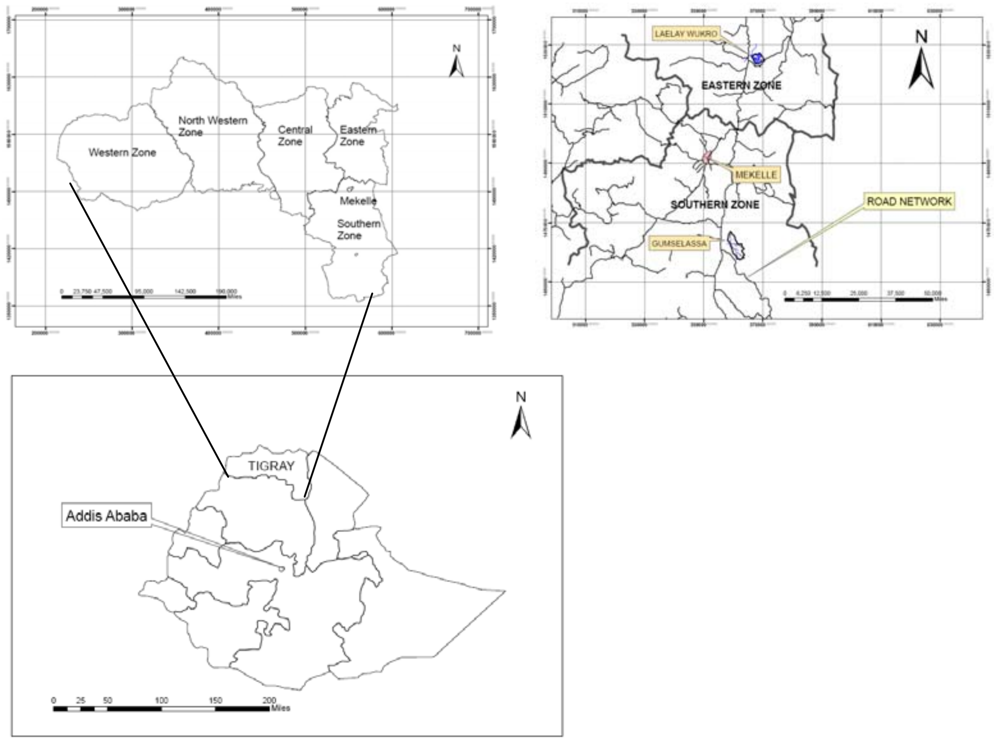

Fig 2.1 Location map of GumSelassa and Laelay Wukro Irrigation projects

2.2 Drainage

The drainage networks of both watersheds are dominated with intermittent streams. The main source of water supply is precipitation which occurs during the months of June, July and August. The drainage network is prepared from 1:50000 topographic map, and the calculated drainage density are 3.8 km km^{-2} and 0.96km km^{-2} for Laelay Wukro and GumSelassa respectively

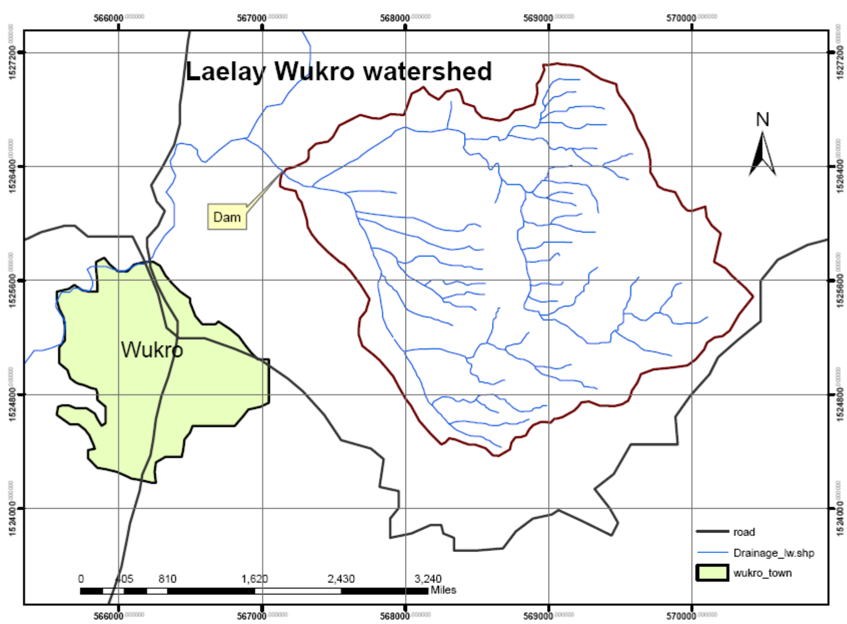

Fig 2.2 Drainage network for Laelay Wukro watershed

2.3 Slopes

Slope maps of both watersheds were prepared with ILWIS 3.3 Academic. Watershed of Laelay Wukro is dominated with steep slopes compared to GumSelassa. The mean slopes are 25.7% and 3.2% for Laelay Wukro and GumSelassa respectively.

2.4 Soils

The dominant soils in Laelay Wukro watershed are silty clay loam and silt loam. Clay and fine textured soils generally dominate GumSelassa watershed. Soil maps prepared for both watersheds are shown in Fig.2.3 and Fig 2.4.

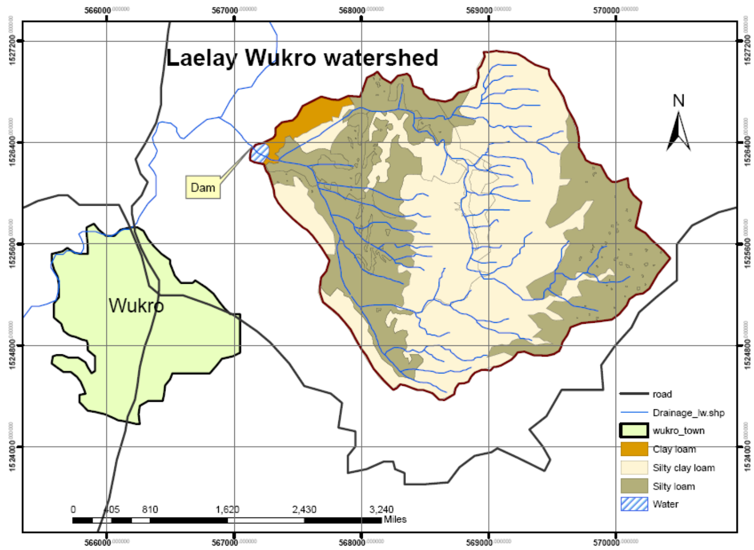

Fig 2.3 Laelay Wukro soil map

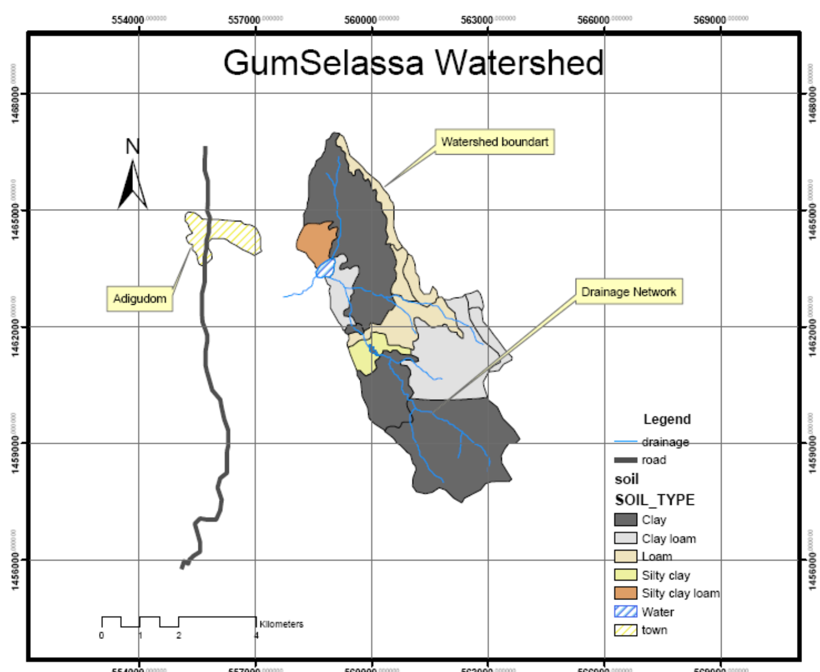

Fig 2.4 GumSelassa soil map

2.5 Landuse

Bush lands and area closure (grass land and small tress) constitute more than 56% of Laelay Wukro watershed landuse. However, the watershed area of GumSelassa is dominated with cultivable land, constituting about 92%.

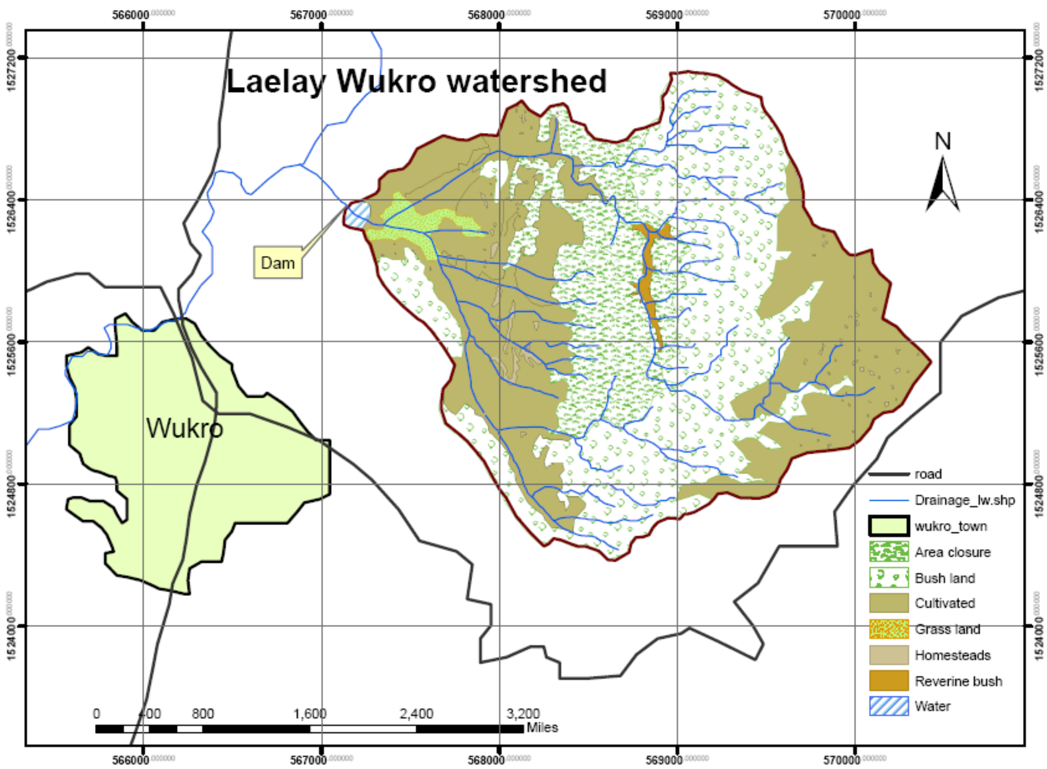

Fig 2.5 Laelay Wukro landuse map

Table 2.1 Landuse distribution of GumSelassa watershed

Landuse type	Area coverage (%)	Remark
Cultivated land	91.5	Dominant landuse
Bare land	4.70	
Bush land	2.04	
Forest	0.38	
Swamp area	0.10	
Homesteads	0.62	
Reservoir	0.66	

2.6 Design experience

About 66 dams have been designed and constructed in Tigray region (N.Haregeweyn et al., 2006). The yearly output of the catchments is estimated with equations (1.1) for all dams constructed in the region. The runoff coefficient (C) used in the above equation is adapted from literature based on soil, landuse and slopes of the watershed. One seasonal value is considered for the watershed water resources potential assessment. Basically the runoff coefficients used during project planning are developed in other regions of the world and not

calibrated for the actual watershed conditions of the region. Accordingly the seasonal runoff coefficients adapted for GumSelassa and Laelay Wukro watersheds during project planning are 0.3 (COSAERT, 1994) and 0.33 (COSAERT, 1998) respectively.

Many of the dams are failing to harvest the design inflow. Fig 2.6 shows the ration of stored water in the reservoirs to design estimate for different dams between 2002 and 2005. It is apparent to see that except few dams the majority of dams lie in the category less than 50% of the storage capacity estimated in the design.

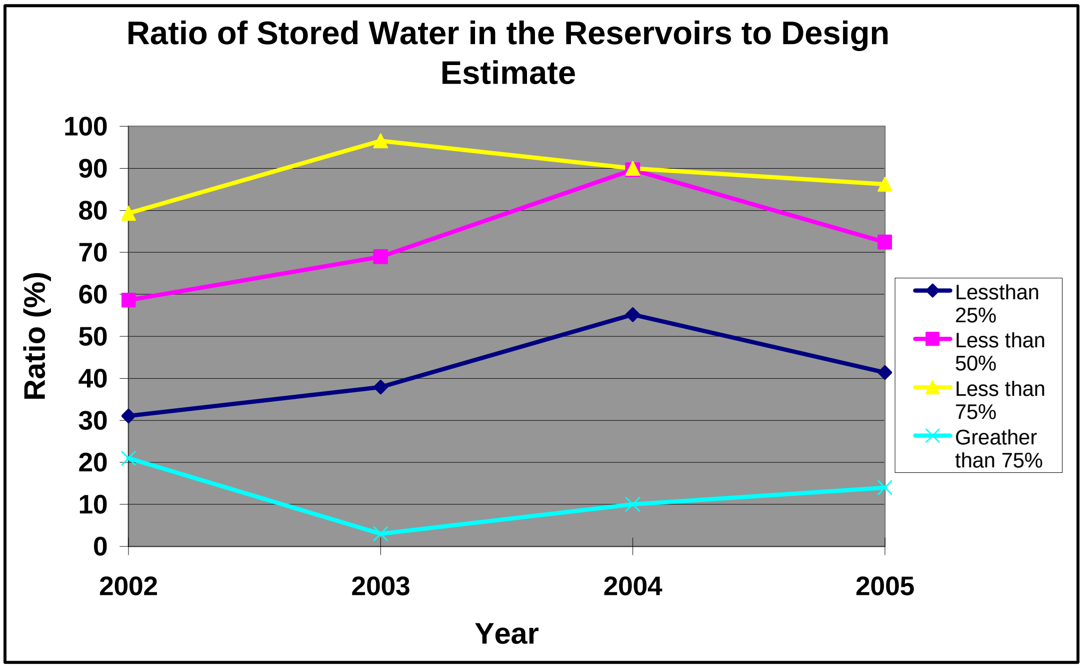

Fig 2.6 Ratio of stored water in the reservoirs to design estimate

2.7 Data collection

To undertake this study, monitoring stations were installed with a tipping-bucket rain gauge and water-level recording pressure transducer on two projects namely GumSelassa and Laelay Wukro.

Fig 2.7 Automatic weather station installed at GumSelassa

Fig 2.8 Water level recording diver installation and data reading

3. METHODOLOGY

GumSelassa Irrigation project is constructed before 13years and 10years for Laelay Wukro. Thus there could be a change in the elevation and storage relationship due to reservoir sedimentation. Thus to successfully carryout the research, the reservoir areas of GumSelassa and Laelay Wukro projects have been surveyed to prepare a new elevation and storage relationship of both reservoirs.

Considering the elevation and storage relationship of each reservoir a water balance model has been prepared for each reservoir considering all input and outputs from the reservoir (Mohammed et al., 2006). The output from the reservoir accounts evaporation loss, seepage loss, spillway outflow and irrigation release. The analysis is carried out considering different rainfall-runoff events, decadal and seasonal analysis for each project. The seasonal analysis considers the main rainfall months July and August.

The basic conservation-of-volume equation for a reservoir or a river reach for a time interval Δt (Xu P. et al.) is expressed as:

$$S_{t+\Delta t} - S_t = \sum_i I_{vol} - \sum_i O_{vol} \tag{3.1}$$

Where S_t and $S_{t+\Delta t}$ are the storage volume at start and end of the time interval Δt respectively, and $\sum I_{vol}$ and $\sum O_{vol}$ the total inflow and outflow volumes of a reservoir during the period Δt.

Rearranging the above equation gives:

$$S_{t+\Delta t} - S_t + \sum_i O_{vol} = \sum_i I_{vol} \tag{3.2}$$

Then the total inflow was divided by the measured rainfall to determine the runoff coefficient for the individual rainfall events, decadal and seasonal events accordingly.

4. RESULTS AND DISCUSSION

For analysis the rainfall events recorded at every 5min. interval has been used. Similarly the water level of each reservoir has been measured with pressure transducers at 15min interval for GumSelassa and 30min interval for Laelay Wukro reservoir respectively.

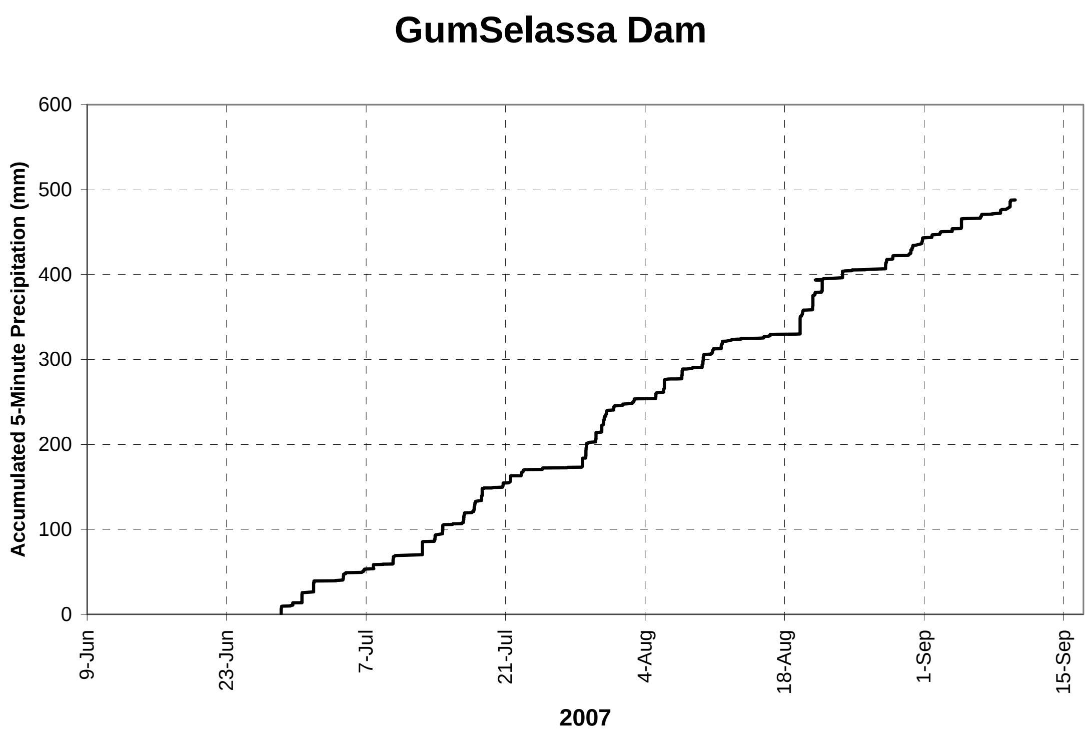

Fig 4.1 Accumulated rainfall (5min) for GumSelassa

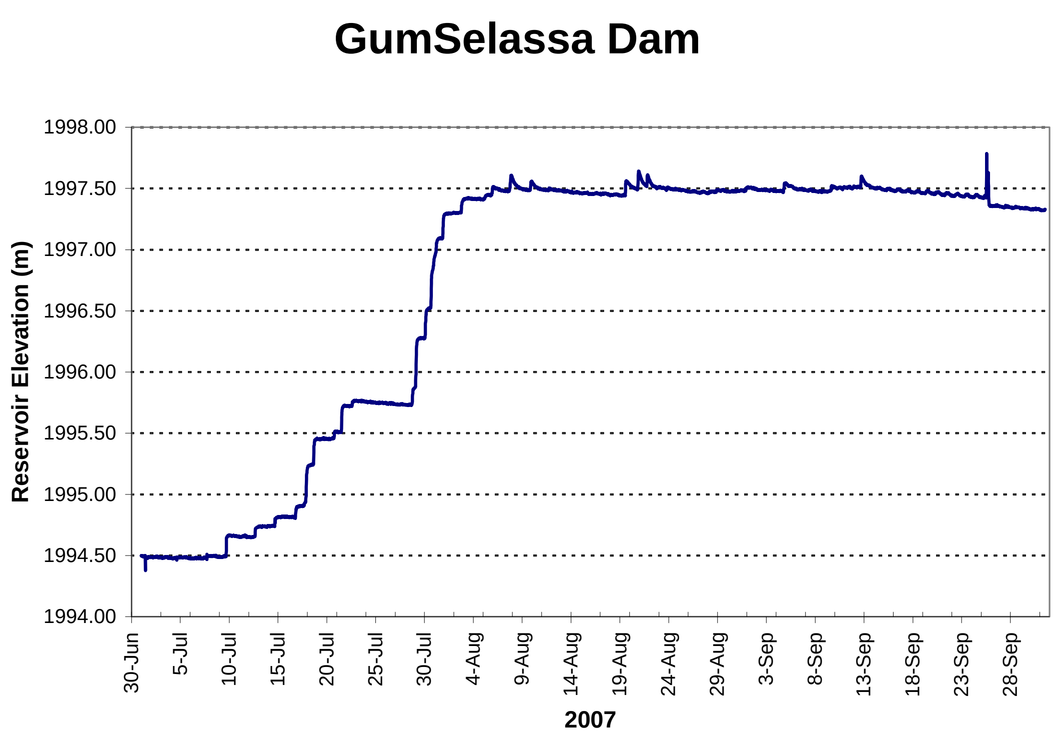

Fig 4.2 Measured reservoir water level

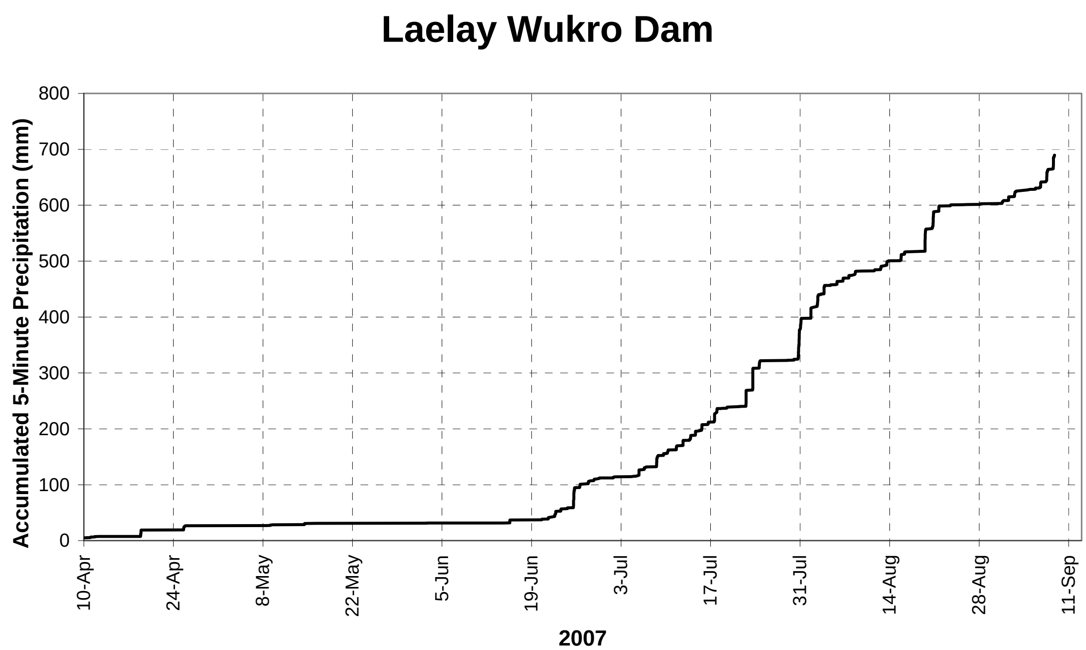

Fig 4.3 Accumulated rainfall (5min) for Laelay Wukro

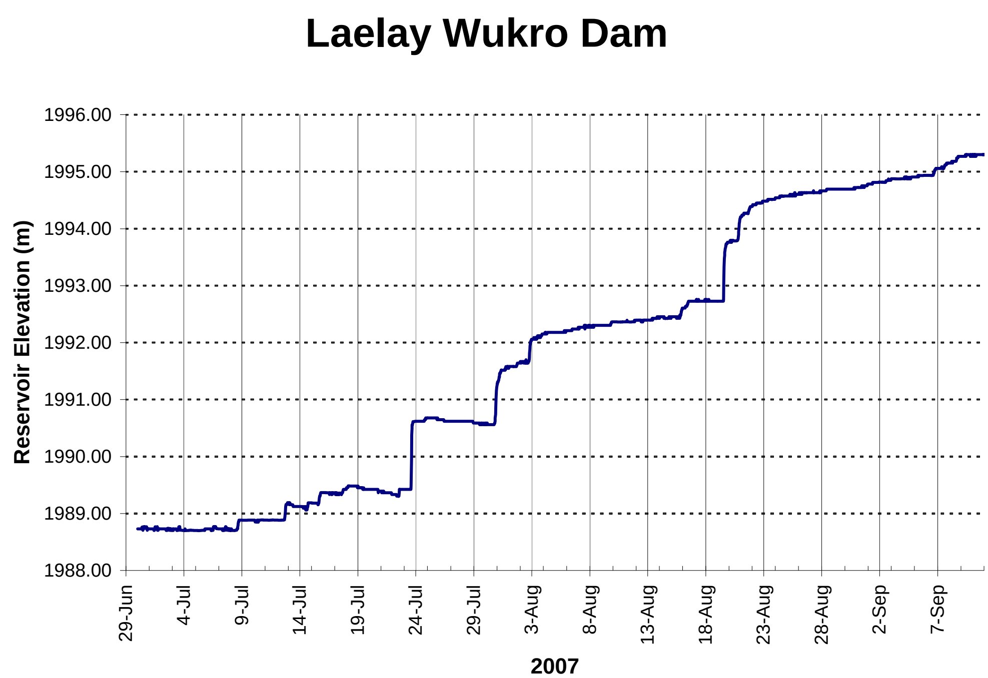

Fig 4.4 Measured reservoir water level

4.1 Event analysis

Different rainfall-runoff events have been considered during the rainy season. The following tables show summarized information from the rainfall measurement and water balance analysis model for each project.

Table 4.1 Event based analysis for GumSelassa watershed

Name	Date	Total Inflow (mm)	Event Rainfall (mm)	Runoff coefficient	Remark
		Col_1	Col_2	Col_3 = Col_1 / Col_2	
Event-1	12/07/2007	0.98	16.40	0.06	
Event-2	18/07/2007	1.81	15.60	0.12	
Event-3	21/07/2007	1.56	8.40	0.19	
Event-4	28/07/2007	2.40	10.60	0.23	
Event-5	29/07/2007	8.12	18.60	0.44	
Event-6	31/07/2007	14.73	30.60	0.48	Maximum runoff observed in the season
Event-7	1/08/2007	4.99	12.40	0.40	

Note: Col_1 from water balance simulation
Col_2 from rainfall record

According to Table 4.1, the runoff coefficient generally increases as the watershed soil moisture increases during the rainy season. At the end of the rainy season the runoff coefficient can be as high as 0.48.

Table 4.2 Event based analysis for Laelay Wukro watershed

Designation	Duration	Event inflow (mm)	Event rainfall (mm)	Runoff ration
		Col_1	Col_2	Col_3 = Col_1 / Col_2
Event-1	Jul23	7.04	39.0	0.18
Event-2	Jul31	6.25	51.2	0.12
Event-3	Aug2	3.46	20.4	0.17
Event-4	Aug19	12.62	40.4	0.31
Event-5	Aug20	5.30	29.0	0.18

The maximum runoff coefficient observed for one event is 0.31, but the rest are less than 20%. This shows that even during wet soil moisture condition the surface runoff is low compared to the design estimation.

4.2 Decadal analysis

The decadal analysis is carried out starting from first of July to end of August. High runoff coefficient in Decade 3, Table 4.3 is resulting from rainfall events (July21, July 28, July 29, Jul 31 and other events) occurred during this particular decade. Relatively low runoff coefficient has been observed during August (Table 4.3). This is because the rainfall amount is small compared to July and the number of days where no rains are also high.

Table 4.3 Decadal analysis GumSelassa project

Designation	Date	Decadal inflow (mm)	Decadal rainfall (mm)	Runoff ration
		Col_1	Col_2	Col_3 = Col_1 / Col_2
Decade-1	1-10july	3.33	43.6	0.07
Decade-2	11-20july	14.60	85.4	0.17
Decade-3	21-31july	40.32	90.6	0.44
Decade-4	1-10Aug	11.65	67.0	0.17
Decade-5	11-20Aug	9.92	63.2	0.16
Decade-6	21-31Aug	9.85	66.8	0.15

The maximum runoff coefficient observed in Laelay Wukro is only 0.25, and for the first two decades it is less than 5%.

Table 4.4 Decadal analysis Laelay Wukro project

Designation	Date	Decadal Inflow (mm)	Decadal rainfall (mm)	Runoff ration
		Col_1	Col_2	Col_4 = Col_1 / Col_2
Decade-1	1-10july	0.32	48.40	0.006
Decade-2	11-20july	3.00	76.40	0.04
Decade-3	21-31july	17.36	158.60	0.11
Decade-4	1-10Aug	7.67	84.40	0.091
Decade-5	11-20Aug	21.48	106.20	0.20
Decade-6	21-31Aug	4.94	19.80	0.25

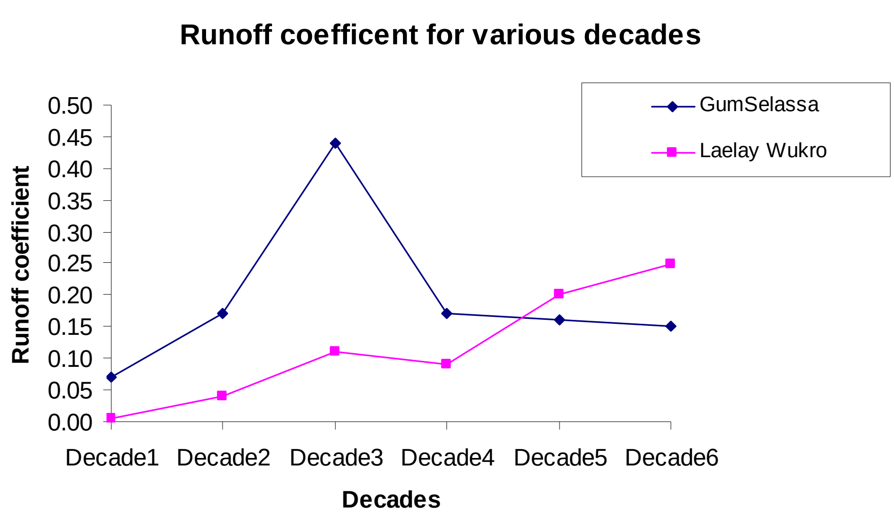

Figure 4.5 Decadal Runoff coefficients for GumSelassa and Laelay Wukro irrigation projects

Figure 4.5 depicts the runoff coefficient increases from June to wards the August, as the soil moisture increases, especially for Laelay Wukro watershed. For almost similar depths of rainfall and rainfall intensity, GumSelassa watershed gives more runoff coefficient compared to Laelay Wukro. This low runoff coefficient for Laelay Wukro is attributed to the part of the

watershed covered with bush land, area closure and grazing land. In addition every year biological and physical conservation measures were in place in the watershed that will increase the soil infiltration opportunity time, and thus decrease surface runoff. Unlike Laelay Wukro, more than 90% of GumSelassa watershed is cultivated land with fine textured soils which are less impervious and can generate more runoff.

4.3 Seasonal analysis

The runoff coefficient is estimated considering the rainfall-runoff events from July – August, which are basically the main rainy months in the region. The estimated seasonal runoff coefficient for GumSelassa is higher than Laelay Wukro irrigation project as shown in the following table.

Table 4.5 Seasonal runoff coefficient

Project Name	Seasonal inflow (mm)	Seasonal rainfall (mm)	Runoff ration	Remark
	Col_1	Col_2	Col_4 = $\frac{Col\_1}{Col\_2}$	
GumSelassa	89.67	416.6	0.22	
Laelay Wukro	46.8	493.8	0.095	Low runoff compared to design estimate

The seasonal runoff coefficient, C observed for Laelay Wukro is by far less than the design estimate. It is about 31% of the design estimate and about 70% for GumSelassa. Thus these values recall for calibration of more dams and came up with runoff coefficients representative to the watershed conditions of the region.

5. CONCLUSION AND RECOMMENDATION

The water resources potential assessment of a given watershed is a key component in the development of micro dam irrigation projects. It has a direct impact on the economics and safety aspect of the intended project. In order to estimate the water resources potential with higher degree of accuracy long term records of stream flow and precipitation are vital. Often this data are not available in the all projects designed and constructed. Hence use of empirical equations is still an alternative for the designers and planners.

The core part of the empirical equation was estimating the runoff coefficient, which in turn depends on soil, landuse and slopes of the watershed. Meanwhile these coefficients are not calibrated for the existing conditions in the region. Thus an attempt has been made to calibrate the coefficients by establishing two monitoring stations in two selected watersheds. The rainfall was measured at 5min interval with a tipping bucket and also water level of the reservoirs with pressure transducers. Coupling these records with the reservoir elevation storage relationship a water balance has been developed accounting all inflow and outflows.

The analysis was done on the basis of event, decadal and seasonal. Comparing both watersheds GumSelassa watershed generates more runoff than Laelay Wukro watershed. In event based analysis the maximum runoff coefficient found for Laelay Wukro is 0.31 and 0.48 for GumSelassa watershed. Considering the seasonal analysis the runoff coefficient estimated for both watersheds is less than the design estimate, which is only 31% for Laelay watershed.

The rainfall amount recorded in the year 2007 is more than the mean annual rainfall of both catchments. Thus the reason for low runoff towards the reservoir is mainly due to over estimation of runoff coefficient. Therefore it is necessary to calibrate more dams having different landuse and soil combinations in order to come up a runoff coefficient that represent the actual conditions of the region.

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