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Sangale, Felix

Lake Victoria Environmental Management Project (LVEMP)

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Okungu John, and Opango Peterlis Ministry of Environment and Natural Resources (LVEMP),
Water Quality Component, P. O. Box 1922, KISUMU. Telephone, 035-42350, 44584
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Abstract

The continuous collection of both hydrological and Meteorological data has been a problem in most areas of the world. Therefore, such data normally have gaps in the time series. For proper water quality management of any river or lake basin there must be a basis for quantification of pollution loads transported in the water. This is only possible if discharge data is known for the duration of study. In order to fill gaps existing in such data, a modelling approach can be employed to generate the missing data. An appropriate model must therefore be used in such cases. The changes in discharge depend on precipitation but can also be heavily influenced by various activities in the catchment.

Estimation of flow for rivers Sio, Nzoia and Yala draining the northern catchment of the Kenyan basin of Lake Victoria was carried out for a 50-year period. This study used the NAM hydrological model in order to fill in the missing data for a time series and estimate the flow. In order to generate initial continuous rainfall data for a minimum of 5 years, employing a double mass curve technique using the data measured at different stations did a correlation. Lake level (stage) was used to estimate rainfall for the gaps after the correlation. Continuous data for 50 years from 1950 to 2000 was finally generated and used for the calculation of discharge for the three rivers. The variation in discharge for the 50 years period was therefore evaluated.

The average discharge results showed that Nzoia had a discharge of 118 m³/s; Sio 12.1 m³/s and Yala had 27.4 m³/s. There was a general increase in flow over the years contributing to the water balance of the lake and also pointing to increase in rainfall run-off possibly resulting from degradation of the catchment.

Key words: Model, Discharge, Simulation, Catchment, Stage

Introduction

Lake Victoria Basin, Kenyan side has an area of about 47164 km² and is divided into two catchment areas. These are Lake Victoria South and Lake Victoria North catchment areas. Lake Victoria South is drained by rivers Nyando, Sondu/Miriu, Gucha/Migori and the South Awach as the major rivers while Lake Victoria North is drained by rivers Nzoia, Yala, Sio and the North Awach

The total area of the Lake Victoria North catchment is 19,615 km². This is distributed amongst the river catchments as follows:

- River Nzoia has a catchment area of 12,842 km², a length of 355 Km and a mean discharge of 118 m³/s
- River Yala has a catchment area of 3,351 km², a length of 261 Km and a mean discharge of 27.4 m³/s
- River Sio has a catchment area of 1,437 km², a length of km and a mean discharge of 12.1 m³/s

- North Awach Rivers have a catchment area of 1,985 km² and a mean discharge of 3.8 m³/s.

Resources of water basically originate from the atmosphere, where rain, snow and ice are the main supplies. Water is stored and transported by surface systems (rivers, lakes and surface run-off) and sub-surface systems (root-zone and groundwater). Indirect man induced water resources are treated sewerage effluent and desalinated water. The storage in these natural systems can be affected by land use changes and soil cover destruction.

Natural forest and woodlands can influence the total run-off. These natural cover optimize distribution of water in space and time, reduces flooding, spate flows and soil erosion they also enhance ground water recharge through improved percolation and infiltration.

The hydrological cycle consists of 4 major components; atmosphere, unsaturated zone, saturated zone and surface water. Modeling of the hydrologic cycle can be done using specific physical models each having their own basic equations, boundary conditions, assumptions and links (Spaans, 1988). There are hydrological and meteorological stations scattered within the catchment for data collection. However, it was realized that there were notable gaps in the hydrological and meteorological data caused by various factors including lack of funds to maintain field observation stations. There was therefore lack of important information in the time series for input into water quality model for proper management. It was therefore necessary to fill these gaps so as to establish a continuous flow of data.

The effect of water pollutants depends on the volume of water into which the pollutant is carried amongst other factors as this determines the dilution capacity of the water body. The objective of this study is therefore to estimate an average flow of water from the Lake Victoria North catchment via Rivers Nzoia, Yala and Sio over 50 year period as this forms the basis for accurate estimation of pollution loads into Lake Victoria.

The last or near last stations for each of the named rivers were chosen for determining the amount of discharges of water from the northern part of the Kenyan part of the catchment.

The following stations are therefore used:

| | | |
|---|------------|-----------------------------|
| 1 | R.G.S 1AH1 | River Sio at Mundika, Busia |
| 2 | R.G.S 1EF1 | River Nzoia at Rwambwa |
| 3 | R.G.S 1FG1 | River Yala at Yala town |

A modeling approach was used in the study. NAM model was used. NAM is a lumped, conceptual rainfall – run-off model, simulating the overland flow, inter-flow and base flow components of the moisture contents in four storages. NAM hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. Final parameter estimation must be performed by calibration against time series of the hydrological observations.

When discussing surface water the prime interest concern river discharges and related questions on the frequency and duration of extreme (floods) and draught (Laat, 1980). When both precipitation and evapo-transpiration change, so does the groundwater recharge and river runoff including its seasonality and extremes (Falkenmark, 1989).

Accurate estimation of the runoff can give an indication of land use changes and destruction of soil cover. Studies on the adverse effects of cattle grazing in forests have shown the infiltration capacity is greatly reduced in hardwood and softwood forests from 190 to 1.3 and 280 to 33 mm/hour respectively (GOK/UNEP, 1981). The presence of forests and soil cover reduces the likelihood of serious soil erosion as the root system physically binds the soil and the canopy and ground litter physically protect the top soil by intercepting potentially destructive heavy rainfall and reducing the resulting runoff. Interception by the overhead canopy spreads the flow of water to the ground over longer period of time and allows more time for infiltration into the soil, which recharges ground water.

Materials and methods

A 50-year period was required for the filling of the gaps before the estimation could be done. Modeling for estimation and simulation of rainfall, surface runoff and river flows in the Lake Victoria basin required that continuous data be obtained for the period. This would therefore be used to calculate the water balance for the lake.

The data was collected from different sources including Water development database at the Headquarters Nairobi, Kenya Meteorology Department, Lake Victoria basin Database created by Hydromet project and updated by Lake Victoria Water Resources Project (FAO) and Water Quality Component (LVEMP) field data.

Materials

River discharge and water level (stage) measurements were gathered using the following equipment.

1. Current meter plus counter with inbuilt auto stop watch
2. Tape measure
3. Boat
4. Bridge Jib/Trolley
5. Sinker weights
6. Automatic data loggers, logging water levels at given intervals
7. Automatic chart recorders, for continuous recording of water levels
8. Manually read staff gauges
9. Scientific calculators

Rainfall and evaporation data were collected by use of standard rain gauges and evaporation pans at specific stations in the catchment.

Method

Discharge measurement

Ten to twenty verticals were selected along the cross-section of the river depending on the width and shape at the selected stations. Velocity, V , of water was measured at each of the verticals using current meter set at 0.6 of the depth from the water surface (point of mean velocity for each particular vertical). At the same time width, w and depth, d were recorded at each vertical this gave the area of the cross-section

$$\text{Area, } a = \sum wvd$$

Hence, $a \times v = q$ (discharge per unit time)

With the discharges and the observed stages, a stage/discharge relationship for each station was developed and applied to daily readings of respective stations in time series.

Estimation of flow from each catchment

This exercise was meant to develop a Rainfall / Runoff relationship using the NAM Model which has been adopted for the Kenyan side of the Lake Victoria Basin so as to be able to estimate the flow from these catchments into the Lake.

Rainfall stations representing the upper, middle and lower parts of each catchment respectively were taken and the daily rainfall data sought for the period 1950-2000. Since there were gaps in the available data, nearby reference stations in nearly similar environment were used for correlation. A double mass curve for the stations was developed and the resultant equation in each case was applied to fill in the minor gaps for the selected stations where the reference station had data. For the remaining major data gaps, typical wet, dry and average years were determined from the resultant data with reference to the lake level s which had a complete time series; so that in a year where the lake level were highest it was assumed to be a typical wet year and where the levels were average or lowest the years were taken to be average and dry respectively. The data from these typical years was therefore used to fill in the missing records in order to complete the time series in consideration.

In the same manner, Evaporation data was sought, rearranged and the data gaps filled accordingly. The rainfall and evaporation stations were then weighted respectively depending on the size that each of the stations represents within the catchment, after which weighted values were deduced for the whole time series.

A specific period of about five (5) years (or more) where the observed river discharges and the weighted rainfall and evaporation formed a complete time series was selected and applied to the NAM model for Calibration after which the NAM parameters were manipulated to attain the best relationship.

Table 1(i): Meteorological Data- Rainfall and Evaporation

| River Basin | Station Number | Station Name | Rain/Evap | Reference Stn | Completion status | | | |
|-------------|----------------|---------------------------|------------------|----------------|-------------------------|-----------------|----------------------|------------|
| | | | | | Time series preparation | Correlation | Insert typical years | Final data |
| Sio | 8934161 | Alupe Met Stn Bungoma | R | Kadenge | LVBD+HD+MD done | Done | Done | Done |
| | 8934134 | W/S Alupe Met Stn Bungoma | R | Elgon Downs | LVBD+HD+MD done | Done | Done | Done |
| | 8934161 | Alupe Met Stn Bungoma | E | Not used | Done | | Done | Done |
| | 8934134 | W/S Bungoma | E | Not used | Done | | Done | Done |
| Nzoia | 8934134 | W/S Bungoma | R | Elgon Downs | LVBD+HD+MD done | Done | Done | Done |
| | 8935133 | Eldoret Exp Farm | R | Elgon, Bungoma | LVBD+HD+MD done | Done | Done | Done |
| | 8834098 | Kitale Met Stn | R | Elgon Downs | LVBD+HD+MD done | Done | Done | Done |
| | 8934140 | Kadenge | R | Bungoma | LVBD+HD+MD done | Done | Done | Done |
| | 8934134 | Bungoma Eldoret Exp | E | Not used | Done | | Done | Done |
| | 8935133 | Farm | E | Not used | Done | | Done | Done |
| | 8934140 | Kadenge | E | Not used | Done | | Done | Done |
| | Yala | 8935133 | Eldoret Exp Farm | R | Elgon, Bungoma | LVBD+HD+MD done | Done | Done |
| 8934140 | | Kadenge | R | Bungoma | LVBD+HD+MD done | Done | Done | Done |
| 9034011 | | Maseno Vet Eldoret Exp | R | Not used | done | Done | Done | Done |
| 8935133 | | Farm | E | Not used | Done | | Done | Done |
| 8934140 | | Kadenge | E | Not used | Done | | Done | Done |

Table 1(ii): Hydrological Data River Discharge

| River Basin | Station no. | Station name | Completion status at | | | | | | |
|-------------|-------------|-----------------|----------------------|--------------|-----------------------------|---------------|----------------------|----------------------|----------------------------|
| | | | Data reorganisation | Rating curve | Discharge from rating curve | RR model type | RR model calibration | RR model application | Final discharges 1950-2000 |
| Sio | 1AH01 | Sio (mouth) | Done | Not req'd | Not req'd | NAM | Done | Done | Done |
| Nzoia | 1EF01 | Rwambwa (mouth) | Done | Not req'd | Not req'd | NAM | Done | Done | Done |
| Yala | 1FG01 | Yala Town | Done | Not req'd | Not req'd | NAM | Done | Done | Done |

Lastly, the full data time series was applied to the NAM model to get the total discharge from each catchment into Lake Victoria.

The stations used for correlation and filling gaps are shown in Table 1

Results

1. Good rainfall correlations were attained by use of Double Mass Curves and gaps in the data sets filled accordingly. The selected rainfall stations were good representatives of the catchments studied. Fig. 1 (a-e).
2. The NAM model adequately filled gaps in the discharge data sets, and the discharges from the three catchments showed the highest contribution from Nzoia followed by Yala almost four times lower and lowest was Sio with discharge about 11 times lower than Nzoia's discharge. Table 3.
3. A general increase in discharge was noted for all the catchments from 1950 to the year 2000. Table 4.

Discussion

The simulation of discharge data using NAM model yielded comparable data as forecasted by an earlier study, (JICA, 1991). This indicates the model is an important tool for estimation of discharge for our conditions. Spaans (1988) noted that simulation models generally enable a more detailed description of reality.

The lake level data is an accurate indicator for estimation of rainfall patterns. Falkenmark (1989) reported, "Natural hydrological indicators useful in seeking information from past centuries and millennia include flood records, lakeshore lines, sediments, tree-rings, river morphology etc."

The average discharge in the period 1990-2000 is higher than for the period 1950/60 possibly because of increase in over land transport due to soil cover destruction in the catchments. Assuming a steady state of the lake outlet and probably a similar increase for all the other river basins for Lake Victoria a rise in water level in the lake can be explained. Application of this model to all catchments in the lake basin will give a good calculation of the water balance for Lake Victoria and will result in a better understanding of the hydrology of the Lake Victoria Basin. The changes in annual discharges from the studied rivers points to an increase in run-off regimes from the catchments. These changes might have been caused as a result of destruction of indigenous forests in the catchment and subsequent low level annual cropping or fallow as well as overgrazing. JICA, 1980, reported, "replacement of rain forest species by pine plantation has increased stream flows to the extent of an approximate 18% reduction in interception and evapo-transpiration losses."

Table 2: One Example of the Weighting Method

| RAINFALL | | | | | | EVAPORATION | | | | | | |
|-----------|-----------|---------|------------------|--------------------|---------|----------------------|-----------|---------|------------------|--------|---------|----------------------|
| Date | | Bungoma | Eldoret Exp Farm | Kitale Met Station | Kadenge | <i>Weighted rain</i> | | Bungoma | Eldoret Exp Farm | Kitale | Kadenge | <i>Weighted evap</i> |
| | Wt | 0.35 | 0.24 | 0.33 | 0.08 | (mm/day) | Wt | 0.51 | 0.41 | 0 | 0.08 | (mm/day) |
| 01-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.6 | 4.6 | | 4.6 | 4.6 |
| 02-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.7 | 4.8 | | 4.0 | 4.7 |
| 03-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.9 | 4.5 | | 4.5 | 4.7 |
| 04-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.6 | 4.9 | | 3.8 | 4.7 |
| 05-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.8 | 4.2 | | 4.7 | 4.6 |
| 06-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.8 | 3.6 | | 4.5 | 4.3 |
| 07-Jan-79 | | 4.2 | 0.0 | 1.5 | 0.0 | 2.0 | | 4.5 | 4.2 | | 4.8 | 4.4 |
| 08-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 4.9 | 4.4 | | 4.8 | 4.7 |
| 09-Jan-79 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | 5.1 | 4.6 | | 4.3 | 4.9 |

Table 3: Final Average and Annual Discharges for the three river catchments and comparison with JICA forecast

| RIVER | Average Discharge, m ³ /s | Annual Discharge, mm | JICA Discharge Projections for 2000, m ³ /s |
|-------|--------------------------------------|----------------------|--|
| SIO | 12.1 | 312.9 | 11.22 |
| NZOIA | 118.0 | 338.0 | 118.65 |
| YALA | 27.4 | 359.5 | 16.28 |

Table 4: Change in average Daily Discharges for the three river catchments 1950 - 1960 and 1990 - 2000

| RIVER | 1950 - 1960 Discharge, m ³ /s | 1990 - 2000 Discharge in m ³ /s |
|-------|--|--|
| SIO | 10.8 | 11.7 |
| NZOIA | 108.8 | 142.2 |
| YALA | 20.7 | 28.6 |

Conclusion

- The modeling approach generated useful data that successfully filled the gaps in Hydrological and Meteorological data.
- NAM model proved to be good at discharge estimation.
- Higher flow was recorded during the last decade than the earlier years.
- There is a marked destruction of soil cover in the river catchment that caused a reduction on infiltration resulting in increased run-off hence, river flows.

Recommendation

- The estimation of discharge should continue in the Kenyan side of the basin and the whole Lake Victoria basin so as to estimate an accurate water balance for the lake.
- Catchment degradation should be curbed so as to increase infiltration and reduce overland transports thus avoid flash surface runoff.
- Due to increased flows and resulting floods there is need for intervention methods to be put in place to manage the lower zones of the rivers prone to flooding.

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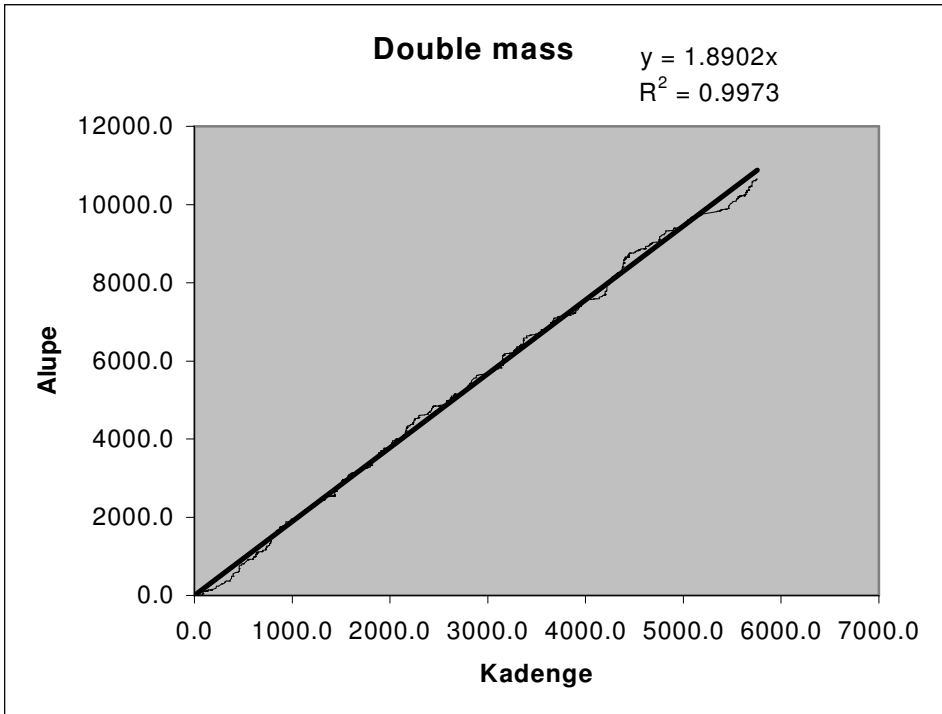


Fig. 1a: Double Mass curve correlating rainfall at Alupe and Kadenge stns.

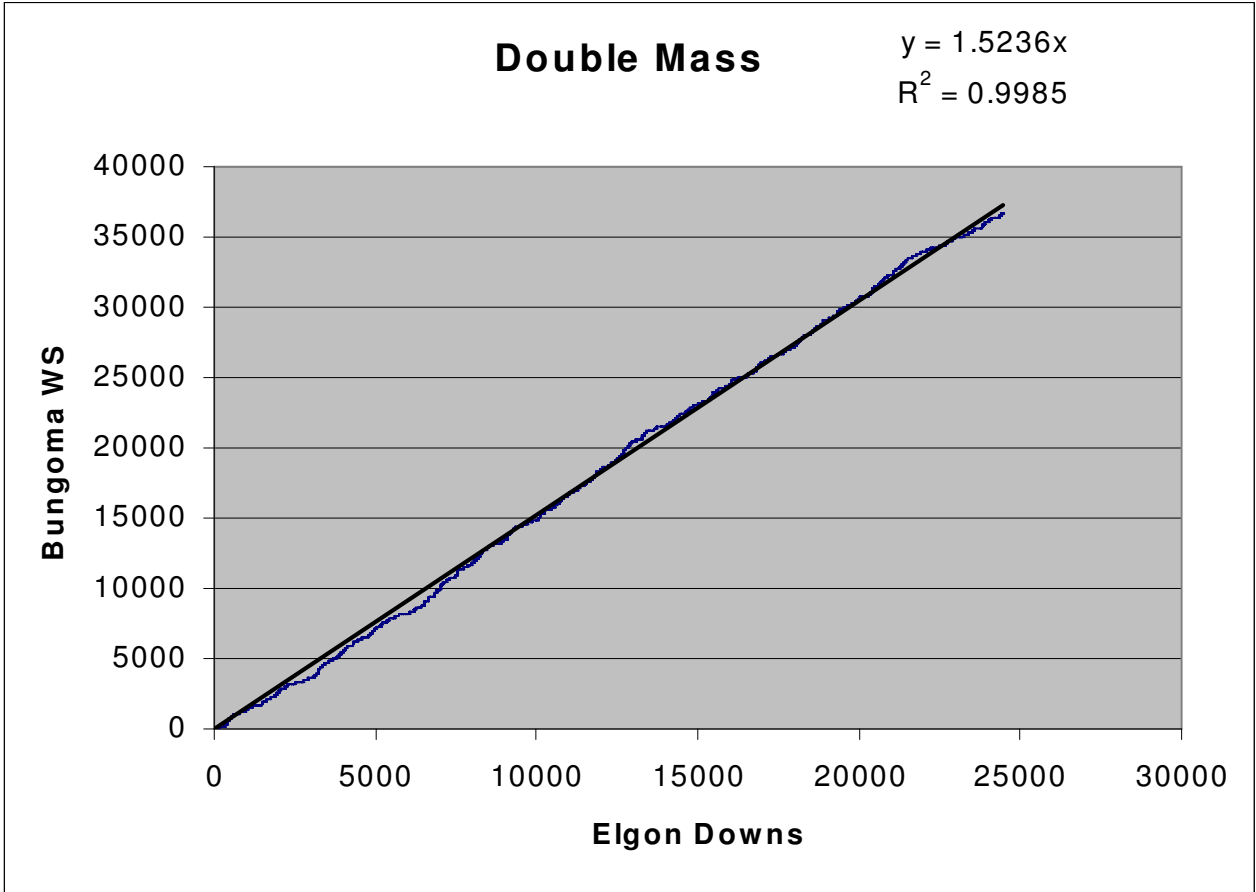


Fig. 1 b: Double Mass curve correlating rainfall at Bungoma WS and Elgon Downs stns.

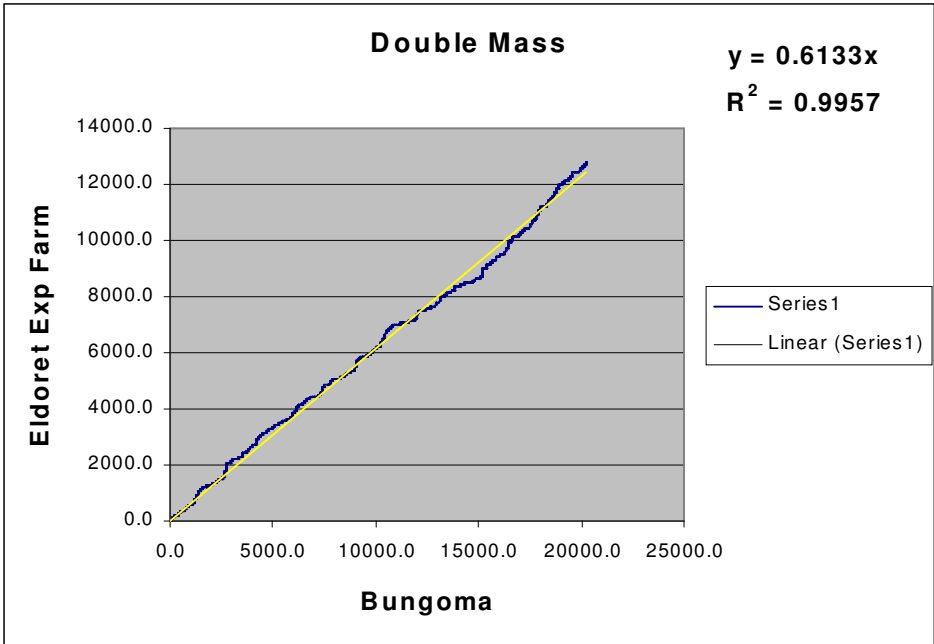


Fig. 1c: Double Mass curve correlating rainfall at Eldoret Exp Farm and Bungoma stns.

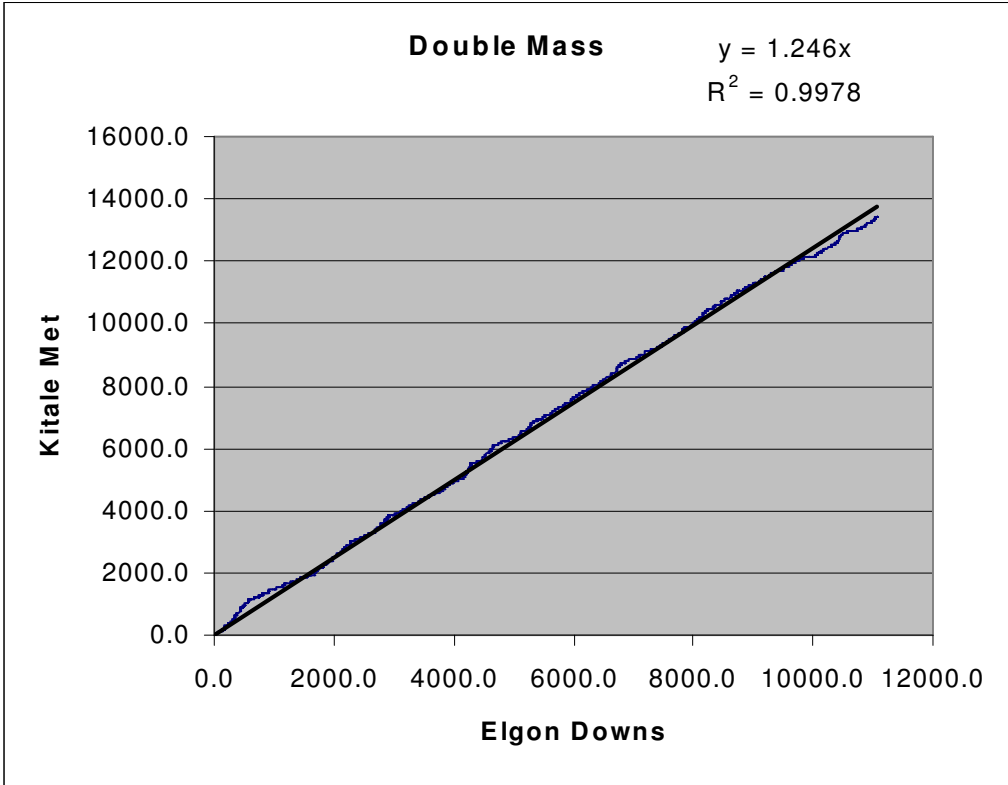


Fig. 1d: Double Mass curve correlating rainfall at Kitale Met and Elgon downs stns.

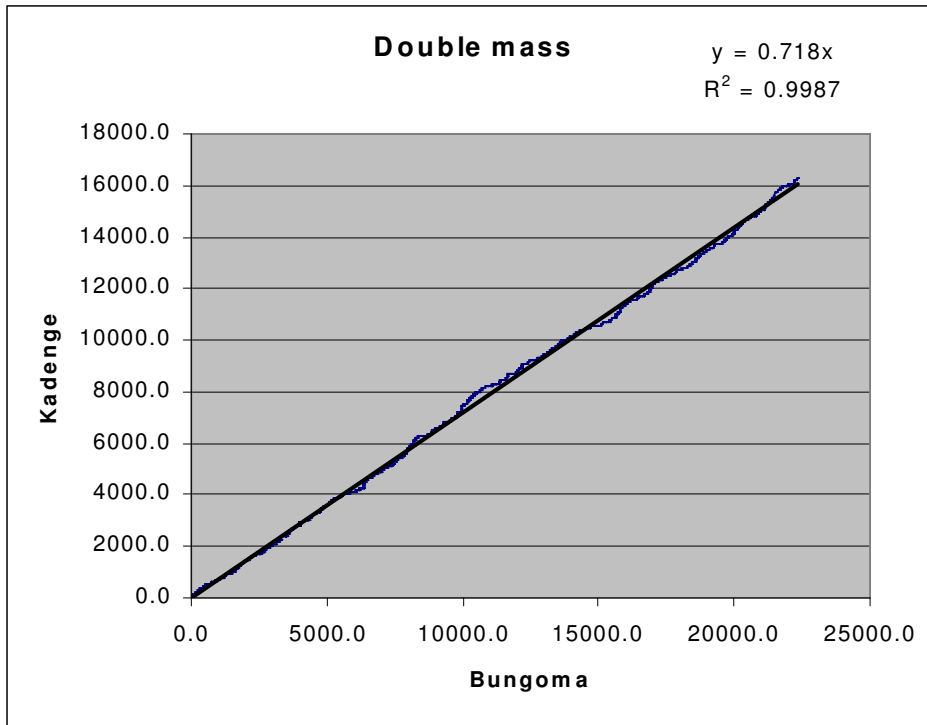


Fig. 1e: Double Mass curve correlating rainfall at Kadenge and Bungoma stns.

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