GOVERNMENT OF KENYA

SECTORIAL STUDY AND NATIONAL PROGRAMMING FOR COMMUNITY AND RURAL WATER SUPPLY, SEWERAGE AND WATER POLLUTION CONTROL

REPORT No. 16

SURFACE WATER RESOURCES IN KENYA

WORLD HEALTH ORGANIZATION

BRAZZAVILLE

JUNE 1973

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1 INTRODUCTION

1.1 General

This is Report No 16 from the WHO Sectorial Study and deals with the surface water resources of Kenya. A previous Report, No 7, covers groundwater resources. A list of the Project reports is presented in Appendix F. The manpower input to this Report has been a ten month assignment of a WHO hydrologist and his counterpart hydrologist, with six hydrological trainees and two assistant hydrologists helping in the processing of hydrological data. In addition to the counterpart staff engaged on a full-time basis, many other members of the Hydrology Section have contributed on a part-time basis to the study.

A Bibliography is presented in Appendix E.

During the course of the study the Training School of the Water Department launched a six months' course in Hydrology. The Project Hydrologist and counterpart Hydrologist have given about one hundred lectures at this course.

1.2 Scope

The terms of reference for the hydrologist included the collection and analysis of available hydrological and meteorological data in respect of surface water resources and characteristics. The Plan of Operation stated that hydrological maps presenting stream run-off data should be prepared. Recommendations should also be made concerning the hydrological network in Kenya.

Discussions were held at an early stage of this part of the Project with the Water Resources Branch of the Water Department, to establish how the needs of the Department could best be satisfied with the manpower resources available.

The availability of meteorological data in the form of statistics and maps has been improved since the preparation of the Plan of Operation for this Project. Therefore it was decided to put all the emphasis on the processing of hydrological data.

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Over the past few years the Water Department has carried out computer processing of stream flow data for publication. At the time of preparation of this Report, computer print-outs from 113 stations were available.

At an early stage it became clear that, apart from the 113 print-outs, data was required from additional gauging stations for the preparation of run-off maps.

Flow duration curves were drawn for 172 stations.

Regular meetings were held with the Water Resources Branch of WD throughout the study, to discuss progress and to obtain decisions on parameters for the maps presenting stream run-offs.

The central part of the country with relatively high rainfall and dense population is relatively well covered by the river gauging network, whereas the dry northern part of the country has very few streams and few gauging stations. Run-off data in the coastal area, apart from Shimba Hills, is scarce and has not been included in the mapping.

The maps presenting run-off data for central Kenya (from Lake Victoria in the west to the eastern slopes of Mount Kenya in the east; from Machakos in the south to Mount Elgon in the north) cover an area of almost 30 per cent of the country. About 85 per cent of the population lives within the mapped area. (See Maps Nos 1 and 3, Appendix C).

Two different parameters have been used for the hydrological maps: the mean annual run-off and the 95 per cent duration run-off. The mean annual run-off indicates the amount of water available if reservoirs were built to take care of floods. The 95 per cent duration flow represents the amount of flow available for water schemes without construction of storage in the rivers.

Recommendations regarding future water resources studies are discussed in Section 11 of the Report.

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The estimated demand for domestic water in the year 2000 in relation to surface water availability is presented in Appendix D.

The following information has been presented in separate Annexes to the main Report:-

1) Discharge tables showing monthly means in cumecs for 172 stations.

2) Discharge frequency histograms for manually calculated stations.

3) Flow duration curves for 172 stations.

1.3 Acknowledgement

During the initial phase of the Project it became clear that in order to reach the goals desired, more manpower than estimated in the Plan of Operation was required. A request to this effect was accepted by the Water Department and two assistant hydrologists and six hydrological trainees were allocated full time to the Project.

This extra contribution of manpower and the continuous co-operation and technical assistance from the Hydrology Section of the Water Department is much appreciated.

The good co-operation by the Survey of Kenya in giving priority to the study's cartographic work is also very much appreciated.

2 SUMMARY

The drainage system of Kenya is determined by the Great Rift Valley, running approximately from North to South, from the flanks of which waters flow westwards to Lake Victoria and eastwards to the Indian Ocean. The Rift Valley itself has an internal drainage system. There are five main drainage areas in Kenya, namely: Lake Victoria, Rift Valley, Athi River, Tana River and Ewaso Ng'iro (see also Map No 1, Appendix C).

Kenya has a mean annual rainfall of about 500 mm varying from less than 200 mm in the arid areas to over 1 000 mm over the major mountain ranges. The annual variations are large and the rainfall is often erratic.

Evaporation and transpiration reduce the effectiveness of rainfall and influence the amounts which eventually serve the water resource system of the country. Potential evaporation may be as high as 3 000 mm at altitudes of 300 m. At higher altitudes it is accordingly reduced by lower temperatures, but may still exceed 1 000 mm per annum at an altitude of 3 000 m.

Relative to area and population, Kenya has limited surface water resources with the perennial rivers concentrated in the central and coastal areas of the country. About two per cent of the total area of the country or 13 000 km^2 is Lake area.

Reduction in the ability of over-grazed and eroded soils to absorb and retain the rainfall which they receive, results in water regimes characterized by flashy floods and absence of dry weather flow. The maintenance and conservation of the country's water resources is very closely tied to proper range and forest management.

The Hydrology Section of the Water Department is responsible for collecting and evaluating data on surface water resources of Kenya.

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The first river gauging station was opened in 1921. A network of stations was successively built up. A major extension of the network was made in the mid-forties. In the early sixties there were 500 stations in operation. The number of stations was reduced in 1963. Today there are some 355 stations in operation.

Prior to 1970 stream flow data were manually computed and records of monthly means and extremes of flow at selected river gauging stations were published at six month intervals. In 1970, the Water Department embarked on a computer processing programme to publish the daily values of stream flows in a regular manner.

At the start of the study computer print-outs were available for 113 stations for the period 1961-1970. Work was in progress to computerise data prior to 1961 for these stations and to include additional stations in the publication programme.

One of the objectives for Kenya's water development programme stated in the current 5 year plan is "to improve the state of knowledge of the country's water resources and hydrology and to develop adequate long-term master plans for urban and rural water development".

This study may be seen as one of the links in meeting this objective.

The terms of reference for the study included collection and analysis of available hydrological data in respect of surface water resources and characteristics. The need for hydrological maps giving information on stream run-off was stressed in the Plan of Operation.

The preparation of hydrological run-off maps on a countrywide basis is not a routine task. Few countries have this type of map although they are very useful for planning of the utilization of the water resources and land use. Hydrological maps published for Norway have served as an input to the study.

Processing of available data from river gauging stations including flow duration analysis were done by the study team. Data from the 113 stations mentioned above served as a major input to the study. Minimum, mean and maximum daily discharges had already been calculated for these stations. The selection of the stations was based on other criteria than preparation of run-off maps. The geographic distribution of the stations is such that analysis of data from additional stations was necessary to fill information gaps.

Processing of data from 97 additional stations was carried out, including flow duration analysis. For these stations mean monthly discharges were used while for the other 113 stations, daily mean discharges were used.

All the data which served as an input to the preparation of run-off maps is presented in Annexes under separate covers, Annex I for Drainage Area 1, Annex II for Areas 2 and 3 and Annex III for Areas 4 and 5. The data includes tables showing available records of monthly and annual mean discharges for the period 1956-1972 in m^3/s.

For the manually calculated stations frequency histograms of the distribution of different discharges are presented. Flow duration curves for 172 stations are included in the Annexes as well as a schedule showing the duration of records for all stations.

Mean monthly discharges and monthly discharges with 95 per cent duration (low flow) in l/s per km^2 drainage area for 172 stations have been plotted on separate maps (see Maps 6 and 7 in Appendix C).

The mean annual rainfall map was superimposed on the above-mentioned maps, showing specific run-offs to guide the drawing of the run-off maps of areas with the same specific run-off.

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Nine different intervals ranging from less than 0.15 $1/s\ km^2$ to more than 8 $1/s\ km^2$ were selected for the map showing low flow analysis (95 per cent duration). The map has been printed in colour to facilitate reading. (Map No 4, Appendix C).

On the mean specific run-off map, the intervals vary from less than 1 $1/s\ km^2$ to more than 30 $1/s\ km^2$. (Map No 5, Appendix C).

The maps should serve as a guide for water resources planning on a broad scale. Most of the discharge figures refer to relatively large drainage areas which means that local run-off conditions for smaller streams do not become apparent.

For more detailed run-off calculations it is recommended that the planners utilise the back-up data presented in the Annexes.

The mean run-off map is more accurate than the low flow map as longer records are required to obtain reliable extreme values.

The maps together with the discharge data presented in the Annexes should serve as a valuable input to the Water Apportionment Board in their processing of applications for Water Permits. It is urgent, however, that a more efficient data bank of permits issued is developed as knowledge of previous commitments is of equal importance to total water availability when water is allocated.

Approximate domestic water requirements for year 1969 and 2000 have been calculated for densely-populated and arid areas. A brief discussion on domestic water demand versus surface water availability is presented in Appendix D.

There is still considerable basic data for additional gauging stations unprocessed. It is important that this information is utilized and that the backlog of work is cleared.

Future hydrological work should include updating of drought and flood frequency analysis.

Work done to date will serve as an input to water balance studies.

3 RECOMMENDATIONS

3.1 The Kenya Government should Prepare a Water Resources Plan

Further studies of Kenya's water resources is a major component of the planned Master Water Plan Project. The work volume involved in upgrading the knowledge of the country's water resources is such that additional trained personnel will be required.

Activities to be considered in such a Project are discussed in Section 11 of the Report.

3.2 Catchment Area Research should be continued and expanded

It is recommended that the catchment area research experiments in the forest zone be continued and the scope of the programme be expanded by the inclusion of well-directed experiments to study the effects of land use changes when forest areas are opened to cultivation by small-holders. Such research is essential for land use planning in view of the ever-rising pressures on the highly productive stream source forest areas.

3.3 Annual Hydrological Seminars should be held for Provincial and Headquarters Staff

It is considered most important that hydrological staff from the Headquarters and the Provinces get together to discuss common problems at regular intervals. This would enable field staff to learn how the collected data is being utilized and the Headquarters staff to understand the field problems.

3.4 Steps should be taken to improve the reliability of some of the river gauging stations

Recommendations for the improvement of the reliability of individual gauging stations, based on information collected during field trips, have been made separately by the Study. It is recommended that a programme is established to improve the stations.

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3.5 <u>The work assignments to Headquarters hydrological staff should be more goal-oriented</u>

The Headquarters hydrological staff has in the past spent considerable time on answering requests for data for individual water schemes. These special requests should be reduced in number and the preparation of replies should be considerably simpler as a result of the issue of hydrological year books and data presented in Annexes to the Report.

It is recommended that assignments given to the Headquarters Hydrologists should be more goal-oriented. The tasks should be on longer terms with specific terms of reference and a set time limit for the task.

4 COLLECTION AND PROCESSING OF HYDROLOGICAL DATA IN THE PAST

The systematic collection of stream flow data started in the early 1920's. The first river gauging station was established in 1921. Lake level observations on Lake Naivasha started as early as 1908. Initially the emphasis was on obtaining low flow information on the streams of the Kenya Highlands for the planning of water supplies for the white farmers. Thus the first 8 gauging stations came into operation in 1921 in Kiambu and Nairobi districts (sub-drainage area 3B). During the rest of the 1920's another 3 stations were established in area 3B and one station in area 4C on Thika River. In the early 1930's the network was enlarged and the country was divided into 5 main drainage areas. Within these areas the first stations were established where the white settlers were concentrated as shown below:

Drainage Area 1	The Eldoret area
Drainage Area 2	The Nakuru area
Drainage Area 3	The former White Highlands and the Coast in Shimba Hills for Mombasa Water Supply
Drainage Area 4	The Nyeri area
Drainage Area 5	The Nanyuki area

Gauging stations were later established also in the Kenya Highlands settled by the African population, i.e. on the eastern and south-eastern slopes of Mount Kenya (Drainage Area 4), the eastern slopes of the Aberdares (sub-drainage areas 3B, 3C, 4A, 4B, 5B) and the western Mau Escarpment (sub-drainage area 1J 1G).

Most of the stations were located along the then existing roads, frequently at road bridges for easy access. This meant that the siting sometimes did not result in optimal hydrological conditions.

In the later 1940's and in the 1950's the network was extended to cover also the low potential areas of the country in order to obtain a comprehensive picture of the water regimes of the whole country.

Up to the early 1960's about 500 stations were being operated by the Hydrology Section. A review of the network in 1963 resulted in the closing down of some stations. The number of stations as at December 1972 was 355. See Table 4.1

Table 4.1 Regular Gauging Stations operated by Water Department in December 1972

TYPE OF STATION	DRAINAGE AREA					TOTAL
	1	2	3	4	5	
Staff (only) stations	53	39	41	50	13	196
Weir and flume stations	20	16	25	17	21	99
Automatic recorder stations with staff	15	2	6	17	5	45
Automatic recorder stations with weir	0	2	4	6	3	15
TOTAL	88	59	76	90	42	355

5 FACTORS AFFECTING RUN-OFF

5.1 General

Significant factors affecting the run-off are precipitation and evaporation, both of which are to a large extent dependent on the altitude. Further factors affecting run-off are vegetative cover, surface gradient and geology. Different soils and rocks have different infiltration characteristics, which means that the delay between precipitation and run-off varies depending on the capacity of the ground to store water. Erratic rainfall conditions are found particularly in the dry areas, while in the more humid areas conditions are not so irregular.

5.2 Meteorological Factors

The mean annual rainfall is less than 250 mm for one quarter of the country. On the eastern slopes of Mount Kenya it exceeds 2 400 mm. About 15 per cent of the country has over 800 mm rainfall per year, which corresponds quite well to high and medium ecological potential zones. (See WHO Sectorial Study Report No 2). In the remaining area, with annual rainfall less than 800 mm where annual potential evaporation ranges from 1 800 to more than 2 600 mm, the high evaporation is a contributing factor to seasonal run-off.

Eighty-seven per cent of areas with rainfall over 800 mm per year are found in central Kenya and the remaining thirteen per cent along the coast. The run-off map for central Kenya covers more than 75 per cent of this high rainfall area. Map No 8 in Appendix C shows the mean annual rainfall.

5.3 Vegetation

Map No 9 in Appendix C shows forested areas in central Kenya, based on information received from the Forest Department.

Gazetted forests consist mostly of forests which the Government wishes to protect, or land which is set aside for future afforestation. Some of these have been declared "protected catchments" in the terms of the Water Act and no land use changes can be effected in these catchments.

The forest areas form a very small percentage of the land area of Kenya while these are the areas from which the major rivers originate. The situation therefore calls for strict and sensible hydrological and forestry practices in these regions before any land use changes are effected. Research work is in progress in two such forest catchments to determine whether land use changes will have any detrimental effects on the stream flow regime either in total flow or in seasonal distribution.

5.4 Geology

As has already been pointed out, the storage capacity of water in soils and rocks affects the discharge pattern of the rivers during dry periods. Because of the broad scale in which this work has been carried out, it was felt that the geology aspects for the discharge pattern are too detailed to be taken into consideration. The geology and hydrogeology have therefore been omitted pending more detailed studies in limited areas in the future.

6 CRITERIA FOR THE PREPARATION OF HYDROLOGICAL MAPS

The parameters for the hydrological maps depend on the purpose for which the maps are prepared.

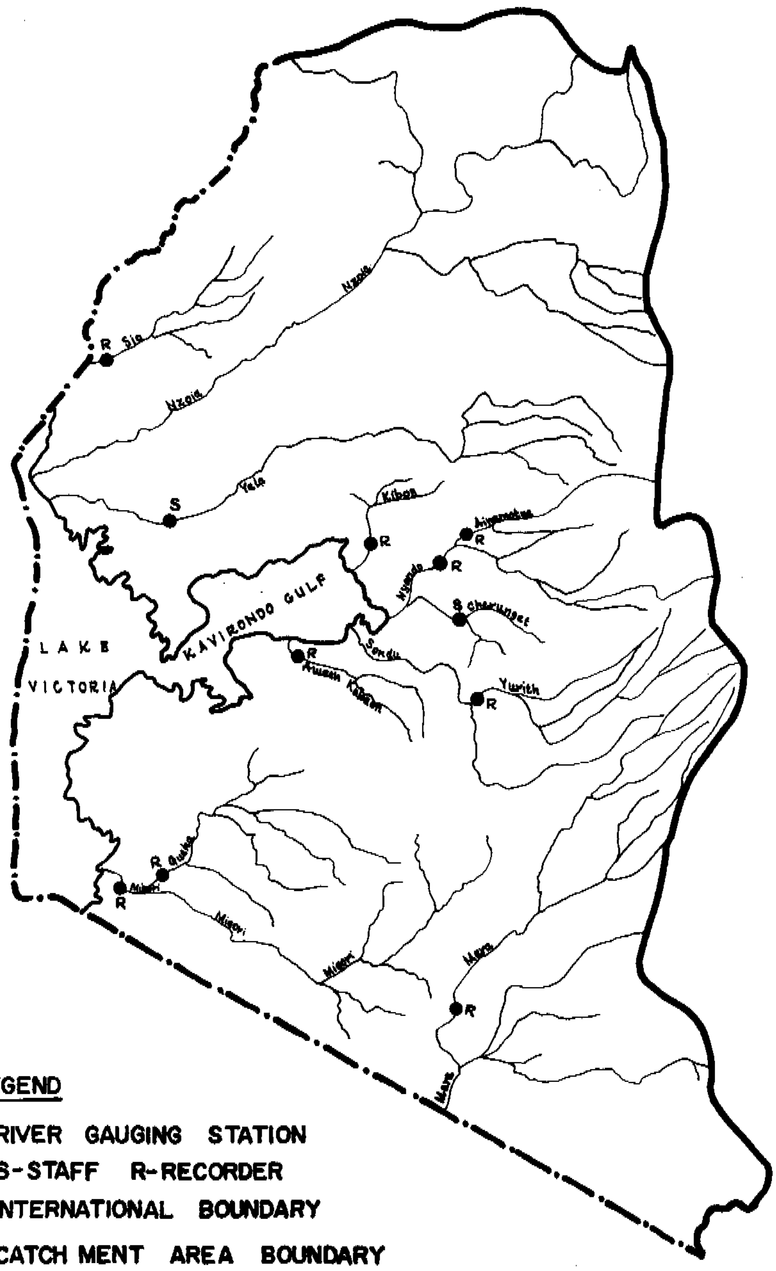
After consultations with the Water Department it was decided that the study should present stream flow records, hydrological flow duration curves and run-off maps.

The maps are meant to guide water resources planners through giving a visual impression of the amount and distribution of surface water resources in Kenya.

The planner of an individual water scheme wishes to know the low flow discharge available without introduction of stream storage, or alternatively the potential water availability if storage is introduced. The water source for community water supplies is usually required to meet the needs during low flow. The 95 per cent duration flow was selected as the low flow parameter. Map No 4, Appendix C, shows specific flow for 95 per cent duration in $l/s/km^2$ and Map No 6 the actual discharges in m^3/s. The 95 per cent duration flow is calculated by flow duration analysis.

The mean annual run-off maps (Nos 5 and 7 in Appendix C) will serve a major input for water balance studies and also show potential water availability when stream storage is introduced. The mean annual flow is defined as the arithmetic mean for the period included in the flow duration analysis.

RIVER GAUGING STATIONS ESTABLISHED 1967-71 BY THE HYDROMETEOROLOGICAL SURVEY OF LAKES VICTORIA, KYOGA & MOBUTU SESESEKO AND TAKEN OVER BY WATER DEPARTMENT ON 1. 7. 72



LEGEND

● RIVER GAUGING STATION
S-STAFF R-RECORDER
—·— INTERNATIONAL BOUNDARY
—— CATCH MENT AREA BOUNDARY

WHO / KENYA-3202

FIG. 7.1

7 DATA COLLECTION AND PROCESSING

7.1 General

- Kenya is divided into 5 major drainage areas. See Map No 1, Appendix C.

Drainage Area No 1	The Lake Victoria Basin
Drainage Area No 2	The Rift Valley Area
Drainage Area No 3	The Athi-Galana-Sabaki River basin and basins with rivers entering the ocean south of this river.
Drainage Area No 4	The Tana River basin
Drainage Area No 5	The Ewaso Ngiro basin

From 1921 to 1972, almost 700 stations have been opened, some of which have been closed.

In December 1972, there were 355 gauging stations of different kinds operating in Kenya, for example, staff stations, weir and flume-stations and recorder stations (see Table 4.1). From 1 July 1972, the Water Department has taken over 9 river gauging stations in Drainage Area No 1 from the Hydrometeorological Survey of Lakes Victoria, Kyoga and Mobutu Sese Seko (Albert) (see Figure 7.1). In addition to the river gauging stations, two lake level stations on Lake Victoria were taken over.

Manually operated stations are read once or twice a day and in remote areas once a week, by local people who deliver monthly readings of the gauge staffs to the Provincial offices of the Water Department. Monthly reports with staff readings are then sent to the Headquarters of the Water Department, Nairobi, where they are checked and processed.

7.2 Selection of Stations for Mapping

At the start of the project, daily, monthly and mean annual discharges were available from computer print-outs for 113 stations for 1956-70. These had been prepared by the Water Department for routine publication of hydrological data. Because of the geographical distribution of these 113 stations, there were insufficient data for the

Figure 7.2 Frequency Diagram

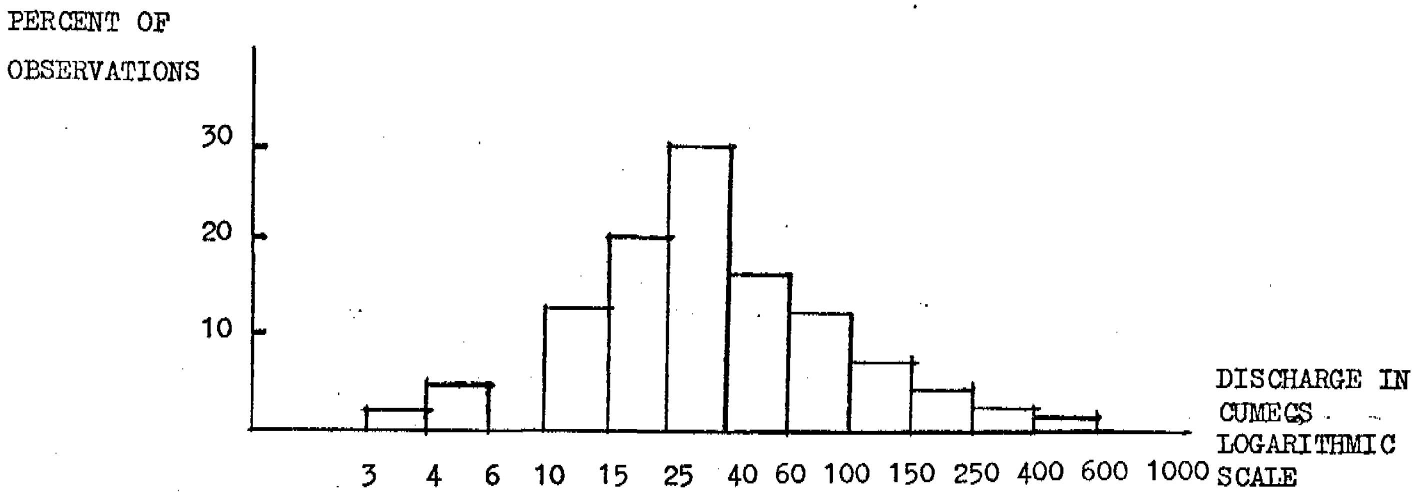
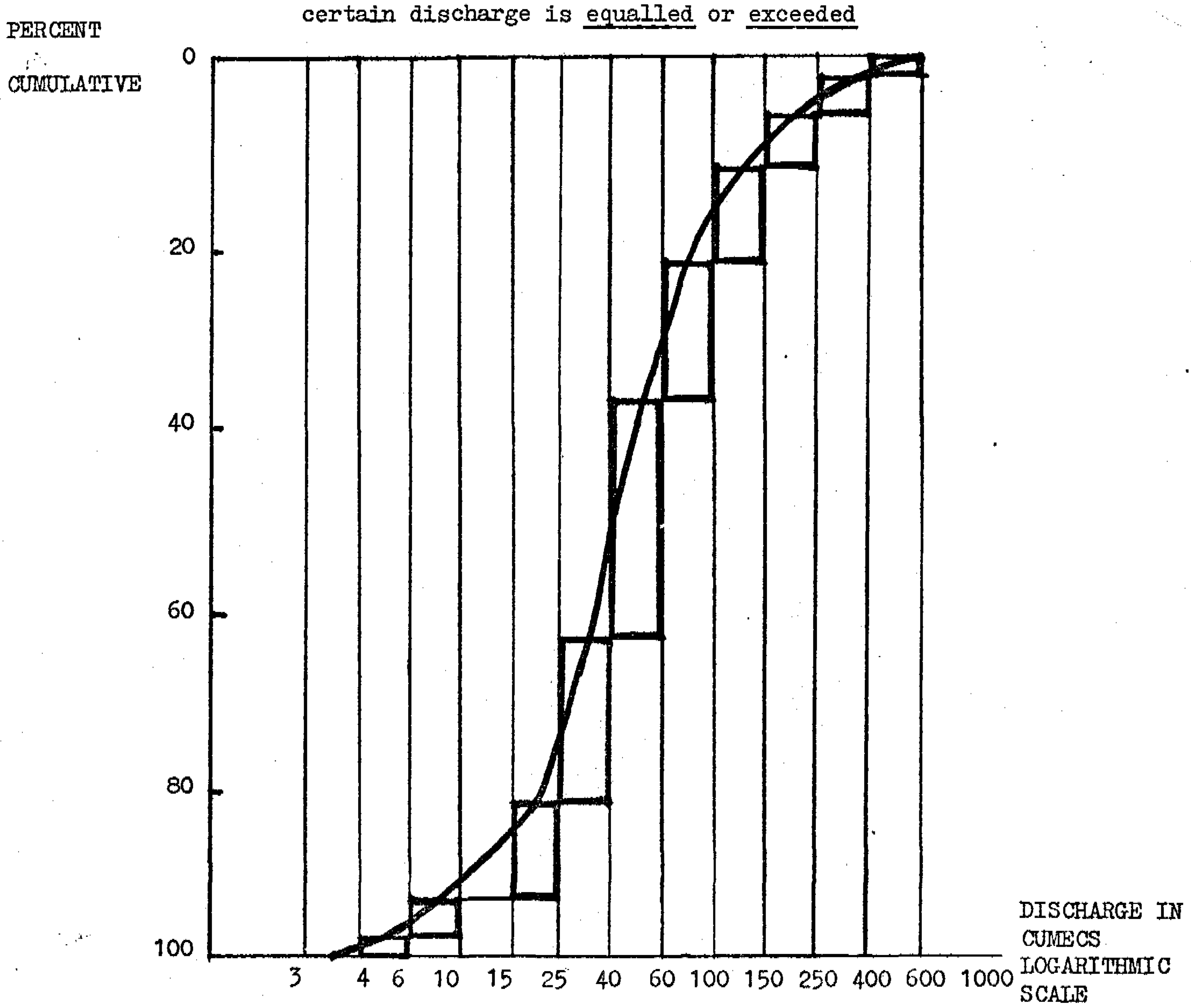


Figure 7.3 Flow Duration Curve
(Accumulative Frequency Diagram)

Note that the curve indicates the frequency for which a certain discharge is equalled or exceeded



construction of hydrological maps. Additional stations had to be selected to obtain a proper distribution of stations as an input to the mapping. Ninety-seven stations were thus selected (see Appendix B) and data from these were used for the mapping. For 62 of the stations complete analyses were undertaken by the Project and the data are presented in the Annexes. The remaining 35 stations had relatively short records and are therefore not included in the Annexes.

7.3 Preliminary Analysis

The information given from the field consists of gauge height readings, which have to be converted to discharges. It is therefore necessary to construct a rating table. Forty-five stations have been rated by the project.

The daily or monthly mean discharges are the input data for calculation of the 95 per cent duration flow and the mean annual discharge.

Catchment areas were checked by using the latest topographic maps.

7.4 Flow Duration Analysis

The flow duration curve is a cumulative frequency curve showing the percentage of time specified discharges were equalled or exceeded during a given period. It combines in one curve, the flow characteristics of a stream throughout the range of discharge, disregarding the sequence of occurrence.

Monthly discharges were tabulated over selected discharge intervals. The frequency of occurrence of discharges within each interval was calculated on a percentage basis (see Figure 7.2). A curve showing the accumulative percentage starting with the lowest discharge interval is called a "flow duration curve". The points on the curve show the percentage of days or months a certain discharge was equalled or exceeded. A flow duration curve is shown in Figure 7.3. The 95 per cent duration discharge was read on the curves constructed for the low flow parameter.

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A computer programme for the flow duration analysis was available at the Water Department. This programme, written in Cobol language, has been run for 113 stations. It utilizes daily discharges for the flow duration analysis and tabulates the result. The percentage of time the discharge was less than the interval, is indicated for each interval in question. This is a slight deviation from the definition of a flow duration curve given in the previous paragraph. The computerized tables were therefore recalculated in order to fit the definition. The values have been plotted on semilogarithmic paper and the percentages given refer to discharges that occurred during the period studied.

The monthly mean discharges were used for the flow duration analysis in respect of the manually computed stations. The plotting was thus reduced to 1/30th compared with the case when daily discharges were used.

The flow duration analysis is based on data from calendar years where discharges were available for 11 or 12 months of the year. Years for which records were missing for more than one month were excluded from the analysis.

For some stations flow duration curves were drawn on the basis of both monthly and daily means to study the discrepancy between the two methods. The difference was very little, with the exception of stations with extremely erratic run-off. This type of stream is found in the dry areas where the precipitation conditions are very erratic and extreme and the soil is usually covered by sparse vegetation. For this type of run-off condition, the end parts of the flow duration curve would show more extreme values if based on daily discharges as compared with mean monthly discharges. This would affect the 95 per cent duration value. The reliability of the low flow data is less than for the mean annual flow. The differences between daily and monthly analysis shown above further stress this fact. It is important that the user of the 95 per cent duration flow data is aware of the effect the input data has on the result of the flow duration analysis.

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If the flow duration curve is based on a long record, it may be used to predict the distribution of future flows. For this it is necessary to plot the frequencies on probability paper by choosing a plotting position. However, this has not been done in the present study as it was felt that the records were not long enough. The curves have been plotted on semilogarithmic paper showing actual percentage of frequencies during the time period studied.

River basin run-off characteristics are presented in Appendix A.

8 PROCESS OF MAPPING (Maps referred to are presented in Appendix C)

The mapping of run-off data has been carried out on an available base map (scale 1:500 000) produced by the Water Department (see Map No 3). This map covers the central densely populated part of Kenya and shows rivers and gauging stations that were in operation in 1972. The run-off figures for specific mean, and specific 95 per cent duration flow, respectively, were indicated on two separate base maps. As mentioned in Section 7, data for a further 35 stations were plotted (see Appendix B) but not presented in the Report due to their varying quality.

Run-off intervals for maps Nos 4 and 5 are based on a frequency analysis of the computed data. Nine and eight intervals are used for the respective maps.

The run-off maps were drawn based on the specific run-off figures on the base map and the mean annual precipitation map (Map No 8) and the topographic map, all maps to the scale 1:500 000. The mean annual precipitation map, on transparent material, was superimposed on the base map to facilitate the mapping. In areas with sparse run-off data the topographic and rainfall maps as well as advice from senior hydrologists with local field knowledge guided the mapping.

As the run-off figures refer to relatively large catchment areas, the map does not indicate the local conditions in minor streams. The run-off for the larger rivers differs from the adjoining tributaries. The specific run-off in these big rivers has been presented by a coloured band along the river, with different specific run-off in the surrounding tributaries.

Maps Nos 6 and 7 show the figures for the run-off in m^3/s for each river gauging station for 95 per cent duration run-off and mean annual run-off respectively.

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These maps give the actual discharge in the rivers and also make it possible to evaluate the accuracy of the specific run-off maps.

The mean annual rainfall is given on Map 8. This map is redrawn from the "Mean Annual Rainfall Map of East Africa, (scale 1:2 000 000) 1971 Edition, Survey of Kenya.

Map 9 shows the forest cover and is taken from a map (scale 1:1 000 000) received from the Forest Department of the Ministry of Natural Resources in January 1973.

The working scale for Maps Nos 3-9, has been 1:500 000. In this Report they have been reduced to A2 size, resulting in a scale of approximately 1:840 000. The cartographic work was carried out by the Survey of Kenya. The specific run-off maps were printed with two base colours, giving 9 and 8 different shades, respectively.

9 RELIABILITY OF DATA

The reliability of hydrological data depends on the duration of records and the accuracy of individual data.

The analysis of stream flow data with probability techniques requires records of about 25 years' duration to produce results with reasonable accuracy.

The selection of sites for river gauging stations requires careful consideration. During the course of the study all the five drainage areas have been visited and quite a number of stations were studied. The majority of the stations were well sited but some, especially those sited at road bridges, had less favourable hydrological conditions. There were cases where the velocity of the water was too high, or too low, resulting in erosion or sedimentation of the river channel. This is a source of error as the rating table originally established for the station will no longer be valid. Recommendations for improvement of the reliability of individual stations have been given to the Hydrology Section during the course of the study.

In general, gauging stations with automatic recorders give more accurate results than manually read staff gauges. Of the 355 stations now in operation in Kenya, 60 are equipped with automatic recorders.

There is wide variation in the skill and thoroughness among the weir readers employed by the Water Department. It is very difficult to evaluate errors introduced through misreadings. Sometimes there is no data provided from manually read stations, resulting in gaps up to several months in the records.

10 USE OF HYDROLOGICAL MAPS AND DATA

The aim has been to produce maps for practical use indicating areas with equal specific run-off. The specific run-off changes along a river, depending mainly on the amount of precipitation in the different parts of the catchment area, but also on evaporation, topography and geology.

Most of the discharge figures calculated refer to relatively large drainage areas whereby the more local run-off conditions do not become apparent. Consequently, the maps should be used with caution in estimating the run-off, especially where smaller rivers are concerned.

In dry areas, traversed by rivers which are fed upstream from catchments in more humid areas, the map will indicate the conditions for the whole catchment at that part of the main river, and not the specific run-off for small streams within the catchment. In certain cases, therefore, the main river has one colour for its discharge while the surrounding catchment area has another colour for the tributaries.

The specific run-off maps are intended for hydrological purposes and to give a visual idea of the amount and distribution of the run-off in Central Kenya. To convert l/s per km^2 into mm/year, for direct comparison with precipitation and evaporation, the specific run-off figures should be multiplied with a factor 31.5

For more detailed information the reader should turn to the Annexes where monthly stream flow records and flow duration curves are set out.

The rainfall map is given to facilitate the evaluation of the run-off maps. The forest cover map serves as a guide for the distribution of suspended material in the rivers, mainly silt.

The base maps with figures showing mean annual and 95 per cent duration run-off are associated with the time period of the records utilized. The figures will change with the utilization of water for irrigation, industrial and domestic purposes. The Kenya Water Act requires that users obtain water permits for extraction of surface water. The Water Apportionment Board issues water permits and WD keeps records of commitments.

The considerations of these permits are based on hydrological data supplied by the Hydrology Section of the Water Department.

The forthcoming publication of daily discharge data and the data compiled by this study, especially the flow duration analysis carried out, will serve as an important input to decisions on water permits.

11 FUTURE WATER RESOURCES STUDIES

11.1 Evaluation of River Gauging Data not yet Processed

Earlier in the Report it is mentioned that close to 700 river gauging stations have been opened in Kenya. At the present time there are some 355 stations in operation.

It is important that data from all the stations are processed and made available to users. The publication programme therefore, must be stepped up. Prior to publication of the data, routine analyses and checks must be carried out to establish the reliability of the data.

11.2 Hydrological Network

The existing network gives a fairly reasonable picture of surface water resources in high potential areas. The existing network should, however, be reviewed with the aim of establishing the optimum number of primary and secondary stations.

There is considerable need for extension of the network into the semi-arid and arid areas of the country. The work will entail detailed planning and field inspections. Judicious use should be made of index catchments in these areas to avoid opening of a large number of stations.

11.3 Analyse Frequency and Distribution of Floods and Droughts

It is necessary to update the analysis of the frequency and distribution of floods and droughts.

11.4 Water Balance Studies

In critical areas of the country water balance studies should be carried out. The extent to which this will be required depends on future water demand studies.

Collaboration with hydrogeologists will be required to determine groundwater recharge and discharge.

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11.5 Establish Data Bank for Water Permits Issued

It is essential that a more efficient data bank on water permits issued is developed for the benefit of the Water Apportionment Board. Information from the files regarding water permits issued is difficult to retrieve. The retrieval system will become rather complex as water permits are given with varying conditions such as that the permit is not valid during low flow or that a certain percentage of the water should be returned.

11.6 Water Quality Network

Only irregular sampling for water quality has been undertaken in the past in Kenya. A programme of monitoring of lake and river water has been planned by the Water Department to collect the basic data on water quality and silt to assist in the formulation of standards, techniques and operational requirements including the provision of legal powers. It is important that this network is established at the earliest and data collected and published on a regular and continuing basis.

See also Report No 5, "Water Pollution Control in Kenya".

APPENDIX A

River Basin Runoff Characteristics
The runoff is given in l/s per km^2

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL RUNOFF		95% DURATION RUNOFF	
		M^3/S	$L/S, KM^2$	M^3/S	$L/S, KM^2$
1AA1	565	7.51	13.3	1.5	2.7
1AD1	477	3.12	6.54	0.39	0.82
1BA1	262	1.03	3.93	0.26	0.99
1BB1	1470	3.84	2.61	0.76	0.52
1BB2	140	1.45	10.4	0.56	4.0
1BC1	684	4.89	7.15	1.6	2.3
1BE1	715	2.22	3.10	0.31	0.43
1BE2	20.7	0.132	6.33	0.042	2.0
1BE4	46.6	0.398	8.54	0.090	1.9
1BE5	77.7	1.08	13.9	0.15	1.9
1BE6	808	3.67	4.54	0.56	0.69
1BG1	25.9	0.212	8.19	0.019	0.73
1BG2	49.2	0.285	5.79	0.046	0.94
1BG4	54.4	0.499	9.17	0.054	0.97
1BG5	33.7	0.137	4.07	0.023	0.68
1BG7	684	4.99	7.30	0.76	1.1
1CA2	717	2.59	3.61	0.058	0.081
1CB3	51.8	0.711	13.7	0.14	2.7
1CB5	697	4.08	5.85	0.33	0.47
1CB8	167	1.44	8.62	0.066	0.40
1CC1	588	2.63	4.47	0.12	0.20
1CE1	2440	14.1	5.78	1.4	0.55
1DA2	8420	44.3	5.26	7.2	0.86
1DB1	446	5.38	12.1	1.2	2.7
1DC1	119	0.819	6.88	0.15	1.2
1DD1	10100	56.4	5.59	15	1.5
1EB2	359	6.94	19.3	2.0	5.5
1ED1	1210	20.9	17.3	6.1	5.0
1EE1	11800	87.2	7.39	28	2.3
1FC1	909	6.60	7.26	1.3	1.4
1FE2	1580	14.8	9.37	3.7	2.3
1FG1	2390	27.4	11.5	6.4	2.7
1FG2	2860	31.8	11.1	9.0	3.2

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL RUNOFF		95% DURATION RUNOFF	
		M^3/S	L/S, KM^2	M^3/S	L/S, KM^2
1GB11	142	1.30	9.15	0.19	1.3
1GG1	298	1.84	6.17	0.21	0.70
1HA1	62.2	0.613	9.86	0.19	3.0
1HA2	10.4	0.083	7.98	0.016	1.5
1HA4	117	1.67	14.3	0.38	3.3
1HB5	101	0.71	7.03	0.19	1.9
1HD1	508	6.29	12.4	0.95	1.9
1JA2	179	3.67	20.5	0.54	3.0
1JA5	49	0.515	10.5	0.007	0.14
1JF4	73	0.058	0.795	0.011	0.15
1JF6	394	5.97	15.2	1.3	3.2
1JG1	3290	41.1	12.5	8.6	2.6
1KA5	3.6	0.050	13.8	0.014	3.8
1KA8	264	5.32	20.2	0.68	2.6
1KB1	3100	40.9	13.2	7.8	2.5
1KB3	1110	16.1	14.5	2.7	2.4
1KB7	342	6.46	16.5	1.4	4.2
1KC3	3050	13.0	4.27	0.89	-
1LA3	679	11.3	16.6	0.76	1.1
1LB2	697	3.68	5.28	0.38	0.55

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL REPORT		95% DURATION RUNOFF	
		M^3/S	L/S, KM^2	M^3/S	L/S, KM^2
2B2	58	0.980	16.9	0.20	3.4
2B5	135	2.69	19.9	0.55	4.1
2B5A	135	2.73	20.2	0.48	3.6
2B7	135	13.5	100.0	1.8	13.
2B9	1340	4.70	3.50	1.8	1.4
2C5	185	2.23	12.1	0.89	4.8
2C7	893	5.37	6.01	0.074	0.083
2EB1	46	0.108	2.35	0.027	0.59
2EB3	331	0.643	1.94	0.044	0.13
2EC2	288	0.141	0.490	0.015	0.052
2EC3	48	0.231	4.81	0.022	0.46
2EC4	32.4	0.022	0.679	0.015	0.46
2ED1	135	1.26	9.33	0.24	1.7
2ED2	108	0.449	4.16	0.042	0.39
2EE7	1180	3.03	2.57	0.40	0.34
2EE8	500	2.08	4.16	0.43	0.85
2EE9	580	3.18	5.48	0.72	1.2
2EF3	60	0.125	2.08	0.005	0.083
2EG1	595	1.67	2.81	0.17	0.29
2FA2	155	0.291	1.88	0.038	0.25
2FC5	125	0.610	4.88	0.028	0.22
2FC6	4.0	0.044	11.0	0.019	4.8
2GA3	136	0.633	465	0.009	0.066
2GB1	1430	7.22	5.05	1.3	0.94
2GC4	695	3.59	5.17	0.60	0.86
2GC5	119	0.718	6.03	0.22	2.5
2K1	678	4.63	6.83	0.10	0.15
2K3	832	4.94	5.94	0.20	0.24
2K6	581	1.09	1.88	0.064	0.11

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL REPORT		95% DURATION RUNOFF	
		M^3/S	L/S, KM^2	M^3/S	L/S, KM^2
3AA4	257	0.854	3.32	0.042	0.16
3BA10	101	0.557	5.51	0.095	0.94
3BA17	16.7	0.110	6.59	0.014	0.84
3BA18	68.1	0.351	5.15	0.030	0.44
3BA29	161	0.313	1.94	0.054	0.34
3BA32	1940	7.22	3.72	2.1	1.1
3BA40	136	0.329	2.42	0.022	0.16
3BB10	38	0.426	11.2	0.093	2.5
3BB11	37.7	0.269	7.14	0.014	0.37
3BB12	237	1.96	8.27	0.12	0.51
3BC8	271	3.27	12.1	0.58	2.1
3BC12	346	3.58	10.3	0.69	2.0
3BC13	41.9	0.717	17.1	0.14	3.2
3BC15	116	1.95	16.8	0.35	3.0
3BC19	18.5	0.482	26.1	0.080	4.3
3BD2	53	0.463	8.74	0.11	2.1
3BD5	283	2.87	10.1	0.26	0.90
3BD8	55.9	1.42	25.4	0.052	0.93
3CB2	96	2.01	20.9	0.50	5.2
3CB5	312	3.16	10.1	0.59	1.9
3CB6	31.2	0.673	21.6	0.13	4.3
3DA2	5590	23.2	4.15	3.1	0.56
3KG1	4980	3.47	0.697	0.24	0.048
3MH4	1.3	0.013	10.0	0.010	7.5
3MH10	3700	1.42	0.384	0.030	0.008

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL RUNOFF		95% DURATION RUNOFF	
		M^3/S	L/S, KM^2	M^3/S	L/S, KM^2
4AA1	90	1.34	14.9	0.36	4.0
4AA4	119	0.985	8.28	0.17	1.4
4AA5	501	5.28	10.5	0.95	1.9
4AB5	473	2.23	4.71	0.57	1.2
4AC3	282	12.2	43.3	3.7	13
4AC5	180	3.89	21.6	1.5	8.3
4AD1	429	12.8	29.8	4.2	9.8
4BB1	254	4.50	17.7	1.2	4.6
4BC2	2650	40.8	15.4	13	4.8
4BE1	414	11.6	28.0	3.3	7.9
4CA2	517	9.54	18.5	3.0	5.8
4CA15	52	1.44	27	0.22	4.2
4CB4	331	7.41	22.5	1.7	5.0
4CB5	32	1.52	47.5	0.49	15
4CB7	20	1.20	60.0	0.36	18
4CC5	1570	20.1	12.8	3.4	2.2
4DA10	353	12.2	34.6	4.6	13
4DC2	347	13.4	38.6	5.0	14
4DC3	197	5.15	26.1	1.9	9.6
4DD1	1970	28.1	14.3	8.0	4.1
4EA1	124	4.86	39.2	2.1	17.
4EA6	613	13.7	22.3	4.6	7.4
4EA7	1830	38.7	21.2	11.	5.8
4EB1	122	3.82	31.3	1.2	9.5
4EB4	108	3.68	34.1	0.93	8.6
4EB5	115	4.18	36.3	0.91	7.9
4EB6	368	4.76	12.9	1.3	3.6
4EB7	299	5.59	18.7	0.20	0.67
4EB9	49	1.18	24.1	0.30	6.1
4EB11	534	7.62	14.3	3.6	6.7
4ED3	9520	107	11.2	31	3.2
4F8	92	5.22	56.7	0.48	5.2
4F10	880	14.4	16.4	3.7	4.2
4F13	17400	279	16.0	76	4.4
4F18	757	16.6	22.0	2.1	2.8
4F19	1700	14.1	8.30	5.2	3.1
4G1	31700	199	6.28	54	1.7

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL RUNOFF		95% DURATION RUNOFF	
		M^3/S	L/S, KM^2	M^3/S	L/S, KM^2
5AA1	577	2.42	4.21	0.70	1.2
5AA5	157	0.904	5.75	0.16	1.0
5AB3	319	1.02	3.20	0.35	1.1
5AB4	135	0.468	3.47	0.22	1.6
5AC3	878	0.485	0.552	0.21	0.24
5AC4	2400	0.372	0.155	0.075	0.031
5AC6	448	0.190	0.424	0.46	1.0
5AC8	3294	3.46	1.05	0.40	0.12
5BB2	405	1.39	3.43	0.38	0.94
5BC2	83	1.13	13.6	0.28	3.4
5BC4	1865	4.66	2.50	0.67	0.36
5BC6	98	0.962	9.82	0.24	2.5
5BC8	256	1.57	6.13	0.25	0.98
5BE1	68	0.788	11.6	0.13	1.8
5BE2	61	0.663	10.9	0.11	1.7
5BE3	14.4	0.073	5.07	0.006	0.38
5BE4	62	0.692	11.2	0.14	2.3
5BE5	36	0.336	9.33	0.19	5.3
5BE6	64	0.258	4.03	0.14	2.2
5BE7	184	1.51	8.21	0.32	1.7
5BE11	41	0.613	15.0	0.19	4.6
5BE12	26	0.382	14.7	0.085	3.3
5BE20	860	5.09	5.92	0.99	1.2
5BE21	329	2.88	8.75	0.40	1.2
5D5	4561	7.54	1.65	2.1	0.47
5E3	15300	26.6	1.74	2.2	0.14

RIVER BASIN RUNOFF CHARACTERISTICS

R.G.S	CATCHMENT AREA IN KM^2	MEAN ANNUAL RUNOFF		95% DURATION RUNOFF	
		M^3/S	$L/S, KM^2$	M^3/S	$L/S, KM^2$
4H1	25	0.409	16.4	Q=0>10%	

A P P E N D I X   B

Gauging stations for which
monthly flow duration analysis
has been carried out up to 1972

GAUGING STATIONS FOR WHICH MONTHLY FLOW DURATION ANALYSIS HAS BEEN CARRIED OUT UP TO 1972

Stations included in the Annexes

DRAINAGE AREA					
1	2	3	4	5	1-5
1CC 1	2 B 5	3BA32	4AC 3	5AB 3	
1DB 1	2 B 7	3BD 2	4BB 1	5AC 8	
1DD 1	2 B 9	3BD 5	4BE 1	5BC 2	
1EB 2	2 C 7	3CB 2	4CA15	5BC 4	
1FC 1	2EC 2	3CB 5	4CC 5	5BE11	
1GG 1	2EE 7	3MH 4	4DC 2	5BE12	
1HA 4	2EE 9		4DC 3	5BE20	
1HB 5	2FA 2		4EA 1	5BE21	
1JA 2	2GC 5		4EB 1	5 D 5	
1JA 5	2 K 1		4EB 4		
1JF 4	2 K 3		4EB 5		
1JF 6	2 K 6		4EB 6A		
1KA 8			4EB 9		
1KB 1			4EB11		
1KB 7			4 F 8		
1KC 3			4 F18		
1LA 3			4 F19		
1LB 2					
18	12	6	17	9	62

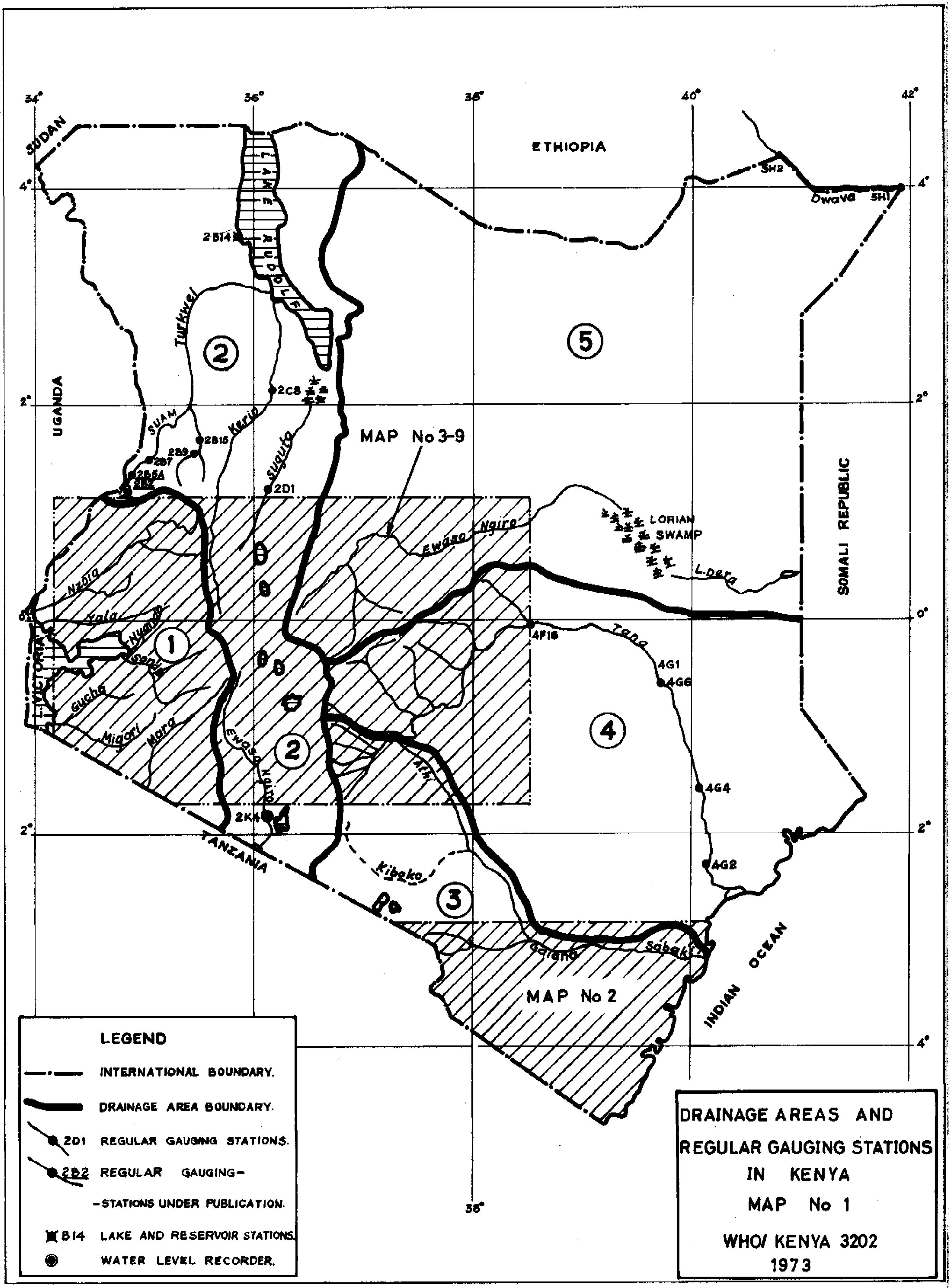
Stations not included in the Annexes

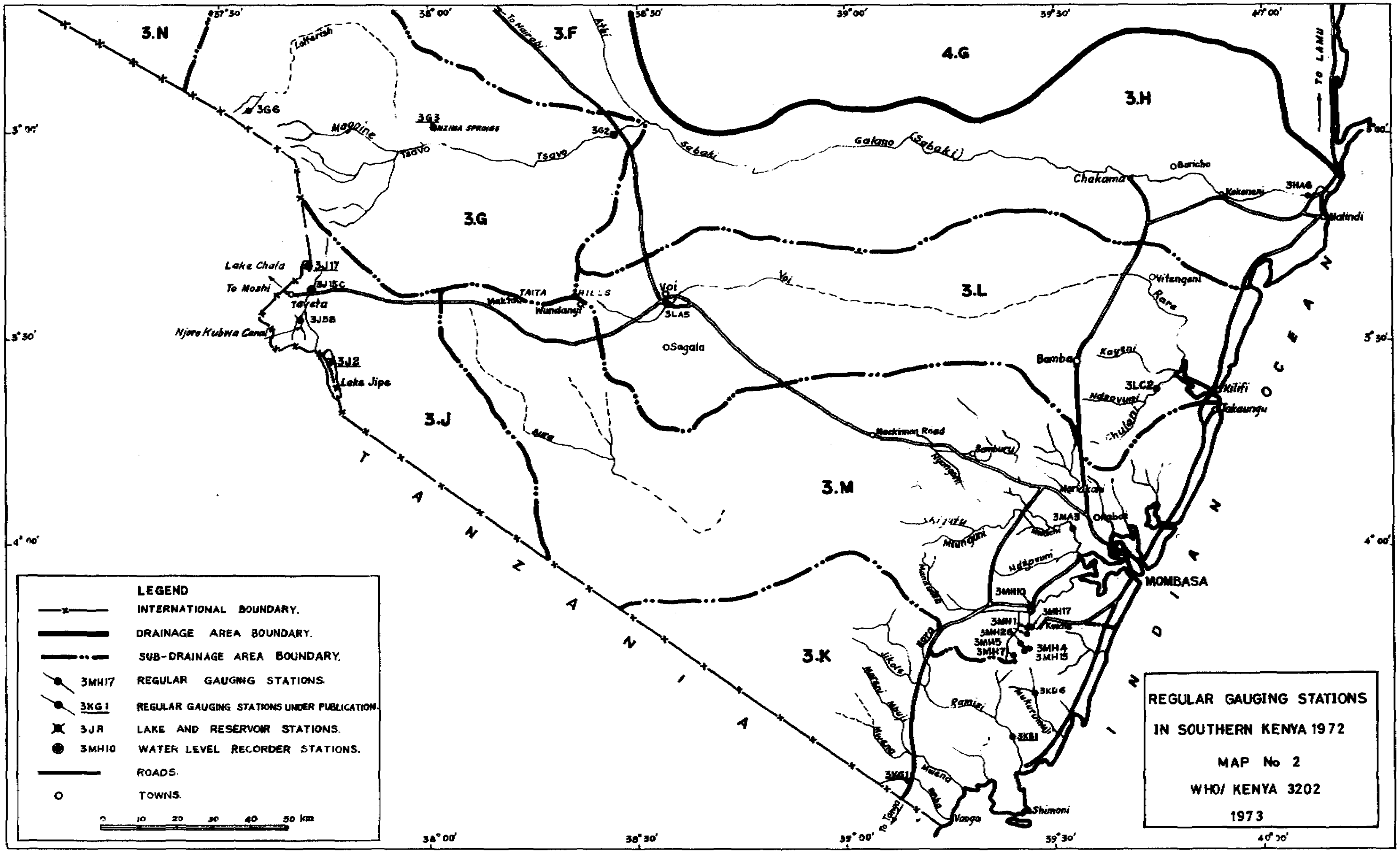
DRAINAGE AREA					
1	2	3	4	5	1-5
1AH 1	2 B15	3AA 1	4AB 6	5AA 2	
1BD 2	2 C 8	3AA 6	4DA 2	5AA14	
1CB 1	2EC 1			5AC14	
1CB 2	2EE 4			5BA 1	
1CD 1	2FC 9			5BB 5	
1HA10	2FC10			5BC 5	
1JC13	2GC 7			5BC 6	
1GD 1	2CD 7			5BD 2	
1GD 4	2 H 3			5 D 4	
1GD 7				5 D 7	
1GD 8					
1GE 1					
12	9	2	2	10	35

A P P E N D I X   C

Maps

Map No 1	Drainage Areas and Regular Gauging Stations in Kenya, 1972
Map No 2	Regular Gauging Stations in Southern Kenya, 1972
Map No 3	Regular Gauging Stations in Central Kenya, 1972
Map No 4	Low Flow Runoff - 95% Flow Duration Map in l/s per km^2
Map No 5	Mean Annual Runoff Map in l/s per km^2
Map No 6	Low Flow Discharge - 95% Flow Duration in m^3/s
Map No 7	Mean Annual Discharge, in m^3/s
Map No 8	Mean Annual Rainfall Map
Map No 9	Forested Area Map


ETHIOPIA
SUDAN
UGANDA
SOMALI REPUBLIC
TANZANIA
INDIAN OCEAN
L. VICTORIA
L. RUDOLF
34°
36°
38°
40°
42°
4°
2°
0°
MAP No 3-9
MAP No 2
Turkwel
SUAM
Kerio
Suguta
Nzoia
Yala
Nyando
Sondu
Gucha
Migori
Mara
Ewaso Ngiro
Athi
Kiboko
Galana
Sabaki
Tana
Ewaso Ngiro
LORIAN SWAMP
L. Dera
Dwava
2B14
2C8
2B15
2B9
2B7
2B5A
2B2
2D1
2K4
4F16
4G1
4G6
4G4
4G2
5H2
5H1
LEGEND
INTERNATIONAL BOUNDARY.
DRAINAGE AREA BOUNDARY.
2D1 REGULAR GAUGING STATIONS.
2B2 REGULAR GAUGING-STATIONS UNDER PUBLICATION.
B14 LAKE AND RESERVOIR STATIONS.
WATER LEVEL RECORDER.
DRAINAGE AREAS AND
REGULAR GAUGING STATIONS
IN KENYA
MAP No 1
WHO/ KENYA 3202
1973


REGULAR GAUGING STATIONS
IN SOUTHERN KENYA 1972
MAP No 2
WHO/ KENYA 3202
1973
LEGEND
INTERNATIONAL BOUNDARY.
DRAINAGE AREA BOUNDARY.
SUB-DRAINAGE AREA BOUNDARY.
3MH17 REGULAR GAUGING STATIONS.
3KG1 REGULAR GAUGING STATIONS UNDER PUBLICATION.
3JR LAKE AND RESERVOIR STATIONS.
3MH10 WATER LEVEL RECORDER STATIONS.
ROADS.
TOWNS.
0 10 20 30 40 50 km
3.N
3.F
4.G
3.H
3.G
3.L
3.J
3.M
3.K
37°30'
38°00'
38°30'
39°00'
39°30'
40°00'
3°00'
3°30'
4°00'
TANZANIA
INDIAN OCEAN
MOMBASA
Voi
Taveta
Lake Chala
Lake Jipe
To Moshi
Njoro Kubwa Canal
3G6
3G3
3G2
3J17
3J15C
3J5B
3J2
3LA5
3LC2
3HA6
3MA3
3MH10
3MH17
3MH4
3MH15
3KD6
3KB1
3KG1
Tsavo
Galana
Sabaki
Chakama
Malindi
Kilifi
Takaungu
Bamba
Mackinnon Road
Wundanyi
Sagala
Vanga
Shimoni
To Lamu
To Nairobi
To Tanga
Athi
Yoi
Ramisi