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Author(s): Samuel K. Mutiso and Russell D. Thompson
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Article

By Samuel K. Mutiso and Russell D. Thompson

Most African governments are aiming to provide a supply of clean and safe water for rural people by the year 2000. Faced with a rapid population growth rate of four percent per annum (the highest in the world) and limited high-potential agricultural land, the Kenyan government recognizes the need to examine the problems and prospects of developing the water resources of the marginal, semiarid areas for agricultural and domestic use. Wise management of the scarce resources of these areas entails an understanding of the factors which influence supply and demand of water and is a matter of urgency. Few studies exist on total or per capita water consumption in rural areas. This paper presents the results of a recent survey of rural agricultural and domestic water consumption in the Machakos district, an ecologically marginal area of Kenya.

MACHAKOS DISTRICT

The Machakos district lies about 25 km east of Nairobi (Figure 1) and is the home of 1.3 million Akamba people. The district is marginal from an agricultural point of view; the major limiting factor being inadequate surface and groundwater resources. Population increase in the high-potential areas of the district (mainly the central hill masses) has created a population/agricultural resource imbalance in these areas. As population continues to increase, and high-potential areas become less available, the district's medium-potential land (marginal and semiarid environments) is being considered for food production.

Between 1969 and 1979, the population in the Machakos district increased by 44.6 percent. The estimated number of inhabitants in 1985 totalled 1 287 400; by the year 2000 this figure will have reached 2 341 500. It is apparent that population distribution is influenced by the ecological conditions associated with rainfall and soil types. In the Machakos district 98 percent of the population live in the rural areas and population densities of up to 600 people per km^2 are found in the ecologically favorable northern part of the central hill masses (1).

Current population projections make it possible to estimate the district's future water demand, although it is difficult to assess both agricultural and livestock water demand at the individual farm level. Trends in the growth of population and livestock indicate that water demand in the district will grow from 16.5 million $m^3 \cdot yr^{-1}$ in 1985 to 47 million $m^3 \cdot yr^{-1}$ in the year 2000. However, since available and proposed water supplies are estimated to yield only 4.3 million $m^3 \cdot yr^{-1}$ in 1985 and 17.2 million $m^3 \cdot yr^{-1}$ in the year 2000, this will result in shortfalls of 12 to 30 million $m^3 \cdot yr^{-1}$ (2).

Analysis of climatological statistics for East Africa (3), and hydrological data from two main gauging stations on the Athi River (4), show that on average rainfall in the Machakos district is 9.4 million $m^3 \cdot yr^{-1}$. However, losses through evaporation and runoff amount to 0.86 million $m^3 \cdot yr^{-1}$ and 0.64 million $m^3 \cdot yr^{-1}$, respectively. Hence, the total direct loss due to evaporation and runoff is about 1.5 million $m^3 \cdot yr^{-1}$ resulting in a surplus of 7.9 million $m^3 \cdot yr^{-1}$. This figure should be seen against the estimated demand of 47 million $m^3 \cdot yr^{-1}$ in the year 2000. This implies that even if all available water resources (both surface and underground) were harnessed, they would not fulfil the per capita needs of the district in the year 2000. There is, therefore, a need to explore the possibilities of "importing" water from neighboring Tsavo-catchment areas such as Kilimanjaro and Chyulu. Kenyan government plans to harness water from the upper reaches of this catchment are well underway, and will undoubtedly alleviate the water-shortage problem in the relatively flat and semiarid areas of the southern half of the district.

PRESENT PATTERN OF WATER USE AND SUPPLY SOURCES:

Rural Water Demand

Results from a 1986 field survey indicate that the average daily water consumption per household is 104 liters (minimum 20 liters and maximum 320 liters). Assuming 5.48 persons per household (5), the daily per capita water consumption is 19.0 liters, which is lower than the average daily demand for the district described in the Design Demand Manual of the Ministry of Water Development (6). According to the manual demand in rural areas is 25 liters per capita per day when the source is a communal water point; 50 liters per capita per day when sources are individual water connections; and 75 liters per day per livestock unit, i.e. 2.5 cows, 20 goats/sheep or 1.25 camels.

Most of the farmers interviewed (104 questionnaires) were not able to provide accurate assessments of the amount of water used for irrigation and livestock. For example, 25 percent of the farmers practicing both traditional gravity-canal and sprinkler irrigation systems stated that they allowed a free flow of water to their fields from 5.30 a.m. to 7 a.m. or sometimes even until 12 noon. Additionally, estimates of agricultural water use were made difficult by the fact that land was irrigated during periods of the year when rain-fed agriculture was not possible. This irregular use of water for irrigation is evident from Table 1. It is obvious that most irrigation takes place between June and September. This period represents the dry season between the "long rains" (Uua) and "short rains" (Nthwa).

It is apparent that more reliable and accurate methods of assessing water for agriculture and livestock in the rural areas of Kenya are urgently required.

Sources of Water Supply

In view of the rapid population increase in the marginal and semiarid areas of Machakos district, and the corresponding demand for water to satisfy agricultural and domestic water needs, it is becoming increasingly important to determine and carefully control all available water resources.

The availability and hence supply of rural water is influenced by many and varied biophysical and socioeconomic factors such as climate, geology, hydrology, capital, and distance from homestead to the water source. Because of the complexity of these factors, it is not possible to discuss in detail their individual contribution to the availability of water as a resource for rural development. Consequently, emphasis is given to those factors which directly or indirectly influence the availability and supply of agricultural and domestic water.

Table 2 shows that streams are the source of water for 71 percent of the farmers who irrigate their land. It should be kept in mind that there are only four major streams in the district and that three of these have seasonal flow characteristics.

Similarly, Table 3 indicates that streams are also the main source of domestic water supply, although it is apparent that there is an increased dependence on wells, ponds and roof catchments.

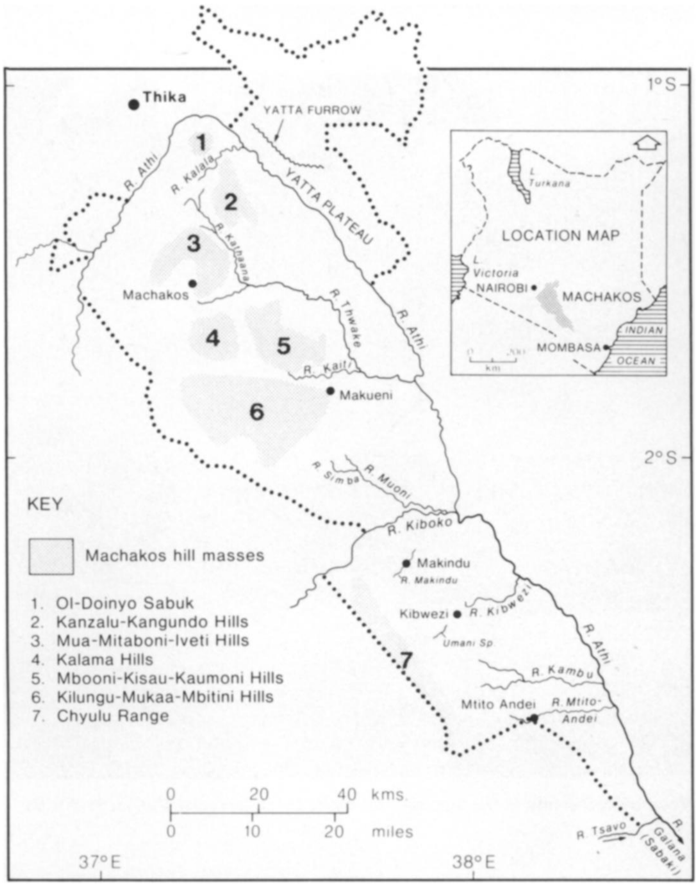

Figure 1. Machakos district—location map (1).

Water supply from a well in the Machakos district. Photo: S. Mutiso.

Table 1. Periods of irrigation.

Months	Response rate No.	%
January–February	4	10
March–May	–	–
June–August	16	40
August–September	20	50
October–December	–	–
TOTAL	n = 40 (N = 104)	100

N = number of interviews

Table 2. Source of irrigation water.

	Response rate No.	%
Stream	22	71.0
Well	5	16.1
Dam/Pond	3	9.7
Borehole	1	3.2
Roof catchment	–	–
Rock catchment	–	–
Digging the sand-beds	–	–
Piped water	–	–
TOTAL	n = 31 (N = 104)	100

Table 3. Source of domestic water supply.

	Response rate No.	%
Stream	61	54.0
Well	28	24.8
Dam/Pond	13	11.5
Roof catchment	7	6.2
Rock catchment	4	3.5
Digging the sand-beds (same as stream)	–	–
Other	–	–
TOTAL	n = 113 (N = 104)	100

Analysis of the data from the 104 questionnaires produced a negative correlation ($r = -0.418$) between the daily amount of water consumed per household and the distance between the homestead and water source. This suggests that distance influences the amount of water consumed in the home. The further the water source is from the homestead the less water is consumed. The Machakos people walk an average distance of 1.07 km to fetch water for domestic and agricultural use. The distance is minimal for those with tap water or a well at home, but in the drier south and southeastern part of the district people may have to walk up to 7 km.

Obviously, a supply of good-quality water, within a reasonable distance is a matter of urgency. At present, the population/water ratio in every division in the district is more than 11 500 persons per water source. Since most of the projects are small, serving less than 5000 persons, this ratio implies that the majority of the district's population has little or no access to a developed, reliable water facility (7). Furthermore, availability of water in sufficient quantities is only one aspect of the supply problem since the quality of the water is also of concern.

Regional Water Availability Characteristics

In regard to water availability and supply it is necessary to establish the water balance for the area as a whole. Water balance is determined by measuring the continuity of water flow in order to establish the balance between total input, total output and change in storage over a given period of time (year, season, month, or a number of days) for a specific drainage basin or area. The outflow is the most difficult component of the water balance to compute, especially that portion of outflow that involves subsurface seepage. This is due to the fact that it must be indirectly estimated from measurements of groundwater levels, permeability, etc. (8).

Nonetheless, computing water balance provides qualitative information on the water-resource potential, including the spatial and temporal distribution of untapped water resources, possible resource exploitation, and optimal utilization. Thus, water balance is the first step toward integrated rural water-resources development and should be given high priority in resource assessment of semiarid lands.

Rainfall Characteristics

In the Machakos district the most critical water-balance component influencing agricultural yields is rainfall since its amount, intensity, and distribution have great bearing on agricultural production. In most semiarid areas of Kenya (and indeed in East Africa), rainfall is characterized by low total amounts, strong seasonal concentration (around "short rains" or "Nthwa" October to December, and "long rains" or "Uua" March to May) and high temporal and spatial variations from year to year and season to season. Since the agricultural calendar is normally based on expected rainfall, these variations may have serious effects on the cultivation of crops. For example, a late onset of rainfall will often result in loss of seed while earlier than usual rainfall will cause farmers to sow early and a following dry interval may destroy the crop (9). In normal circumstances, about 750 mm of rainfall per annum is considered necessary for most forms of crop production. When rainfall ranges between 500 and 750 mm crops such as sor-

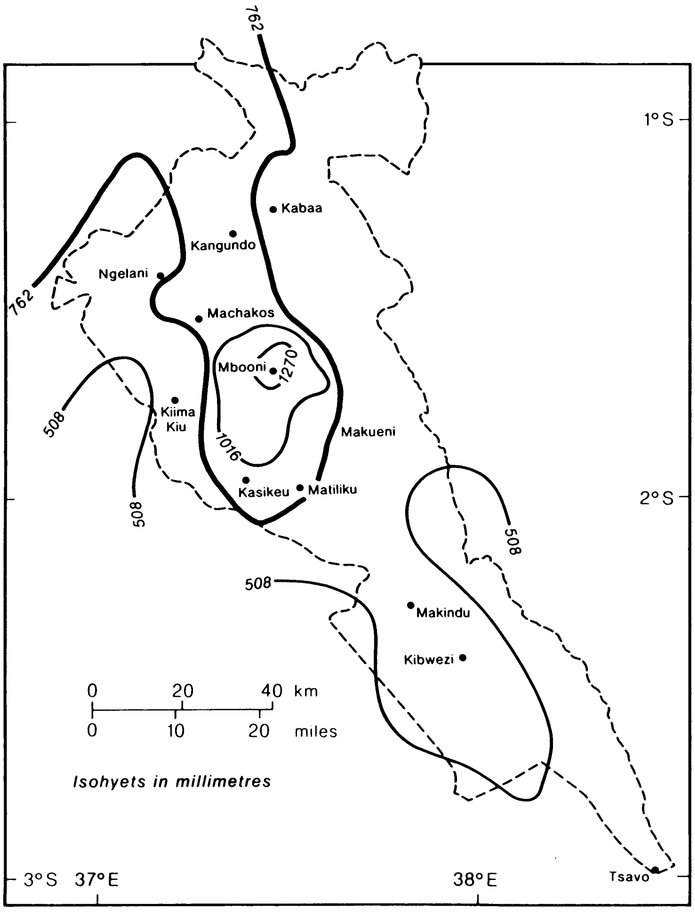

Figure 2. Machakos district—mean annual rainfall (mm) (1).

Water conservation in the Machakos district using terraces. Photo: S. Mutiso.

ghum may still be grown but since the risk of drought is large most agricultural activities are devoted to a mixed type of farming based on crops and animal husbandry. However, where annual rainfall is below 500 mm, only pastoral activities can be carried out unless other sources of water are available, such as boreholes, reservoirs or rivers.

In terms of spatial distribution of mean annual rainfall in excess of 750 mm, only one-third of the Machakos district receives these amounts. This is illustrated in Figure 2 by the 762 mm *isohyet* which encloses the ecologically favorable central hill masses of the district. Porter (10) and Mutiso (1) remark that there is a positive relationship between rainfall and elevation in East Africa. Precipitation increases with altitude with such regularity that a simple regression equation allows fairly precise calculation of rainfall from elevation. In terms of temporal distribution the marked seasonal nature of rainfall (i.e. the Nthwa and Uua) is most closely related to the equinoctial storms associated with the overhead passage of the Inter-Tropical Convergence Zone (ITCZ). Furthermore, the reliability of rainfall estimations decreases as the amount of rainfall decreases.

It is apparent that the most serious problem in using mean annual or mean monthly rainfall to determine the agricultural potential of a given area is that mean values conceal extreme events and do not take into account runoff losses, evapotranspiration, and the distribution of rainfall during the growing period. Other problems associated with the calculation of a detailed and reliable water balance for the Machakos district are due to the lack of an even distribution of rainfall stations. Most stations are situated directly on and west of the central hill masses. At some stations there is a lack of care and continuity in collecting rainfall data as well as a lack of reliable data from which evapotranspiration, soil-water deficit and hence the available water capacity for plant requirements can be computed. Such data, as Woodhead (11) points out, are "basic to catchment research and they have considerable bearing upon the feasibility of irrigation projects."

Water in Rivers and Aquifers

Surface runoff and groundwater components of the water balance are determined by the geology of the district. Rivers in the northern part of the district, which do not receive water from volcanic areas, soon dry up after termination of the rains. The only permanent runoff in this area is in the Athi, Thika and Tana Rivers, which drain the northern part of the district and are fed by baseflow from volcanic rocks. Approximately 80 percent of the Machakos district lies within the Athi River Basin and 20 percent of the runoff drains toward the Tana River. The total drainage area of the Athi River exceeds 22 000 km^2 (2). Conversely, rivers in this area which derive their supply of water from basement-system rocks have an intermittent flow, with periods of flood and periods of dryness. It is noticeable that rivers such as the Kalala that have a few small tributaries from the edge of the volcanic area, flow for a longer period after the rains, compared to rivers that lack tributaries in the volcanics.

Fairburn (12) states that boreholes in the basement rocks have not been successful owing to the abundance of impervious granitoid gneisses and massive biotite gneisses in the area. This factor is also emphasized by the Institute of Applied Geosciences (1) which reports that "approximately 33 percent of the boreholes in the basement rocks are dry, i.e. they have a yield of less than 1 $m^3 \cdot hr^{-1}$. The equivalent figure in the volcanics is only 22 percent. The average yield for a successful borehole is nearly 6 $m^3 \cdot hr^{-1}$ and more than 69 percent of these boreholes have a yield of 2–10 $m^3 \cdot hr^{-1}$." Consequently, because of their considerable influence on investment and operation costs, such as depth and water-rest level, there is a need for a detailed analysis of other borehole data.

In terms of surface runoff in the southern part of the district, the Machakos, Kilungu and Mbooni hill masses also have a few perennial streams whose flow is extremely intermittent at low altitude. Saggerson (13) points out that surface water is present in three main streams that drain the volcanic region, namely the Kiboko, the Kambu and the Kibwezi. Apart from these rivers, no other main watercourses cross this part of the Chyulu-Kiboko lava field and it is evident that most of the rain that falls on the lava disappears rapidly underground. The water infiltrates the lava and is sufficiently retarded so that a constant flow of water is present at Simba, Kiboko, Makindu and Umani springs, which are situated along the northern margin of the lava fields. These perennial springs and streams offer a potential for piped and gravity-fed water schemes for domestic and livestock uses in the lower altitudes of the area.

Finally, few significant streams exist in the extreme southern part of the district, including the Kibwezi division. Sanders (14) reports that "apart from the Tsavo and Galana (lower south) which are fed from catchments outside the area, most of the rivers are insignificant sand-choked channels carrying running water for only short periods. The discharge of Tsavo River fluctuates less than that of the Galana, as throughout the year it is supplied by a relatively steady escape of waters from the lavas of the Chyulu range of Kilimanjaro." This southern part of the district is also drained by two tributaries of the Athi River, the Mtito Andei and Kiboko.

Problems of Groundwater Quality

In terms of the district's water quality, available data indicate that the composition of the groundwater in the district has never been evaluated vis-a-vis the geological setting of the boreholes and depth of the water-bearing layers. Hence, only general chemical characteristics of groundwater, as summarized by the Institute of Applied Geosciences, are given (2). Data from 51 boreholes show that the total dissolved solute (TDS) content of groundwater varies from 230 $mg \cdot L^{-1}$ to 7040 $mg \cdot L^{-1}$, and that 27 boreholes have TDS values exceeding 500 $mg \cdot L^{-1}$ (the World Health Organization recommended limit value). The fluoride content in the water ranges from 0.0 to 16.2 $mg \cdot L^{-1}$, although for 55 percent of the samples, it is above 1.5 $mg \cdot L^{-1}$ (the permissible World Health Organization limit value), and for 20 percent, it exceeds 5 $mg \cdot L^{-1}$. Since the World Health Organization recommended limit value of 500 $mg \cdot L^{-1}$ for TDS in groundwater used for drinking is exceeded in the majority of the boreholes, and the permissible fluoride limit of 1.5 $mg \cdot L^{-1}$ is also exceeded in more than half of the samples, it is evident that the quality of drinking water is a problem in the Machakos district.

WATER RESOURCES ASSESSMENT NEEDED

A systematic study of all available water resources in the district is a matter of high priority involving the assessment of water resources through geological, hydrological, and meteorological surveys and water-balance studies. A survey of the spatial distribution of successful boreholes, with data on their yield, water quality and rest levels, is particularly important. Similarly, investigations should be related to "how water storage projects in the highlands affect the lowlands, which depend on them for groundwater recharge or seasonal flow" (15), and how land tenure influences the spatial distribution, access and actual water use in the district (16).

In addition to the ground surveys, which are often time consuming and expensive, "it is important to note that the spatial, spectral, temporal and radiometric qualities of remotely sensed data, ranging from low-level aerial photography to Advanced Very High Resolution Radiometer (AVHRR) and the National Oceanic and Atmospheric Administration (NOAA) series of meteorological satellites, are technically and economically feasible for the assessment of the water resources of Africa" (17).

It is apparent that surface water potential is mainly confined to the central hill masses (Figure 1), namely the Mua-Mitaboni-Iveti hills (Iveti south and Kathiani divisions); Kilungu hills (Kilome division); the Mbooni hills (Mbooni division); Kangundo-Kanzalu hills (Kangundo division); the Ol Donyo Sabuk hill, Matungulu location (Kangundo division) and the southern volcanics of the Chyulu hills. The domestic water supply can also be increased by careful assessment and exploitation of water resources from the Tana and Thika rivers in the Yatta division. Water from the Yatta furrow could also be extended through gravity canals and pipelines to the adjacent areas. The Athi and Thwake river basins in the northern, eastern and central parts of the district are another water-supply potential. Springs, subsurface sand dams, wells/boreholes, rock and roof catchments are other sources of domestic water supplies that should be both fully exploited and carefully conserved.

CONCLUSIONS AND RECOMMENDATIONS

The central theme of this paper has been the identification of the problems associated with the supply and demand of both agricultural and domestic water in the marginal semiarid areas of the Machakos district. Water is the crucial governing factor for agricultural development in these areas. For proper development, management, and planning for optimal utilization of water resources, it is necessary to establish the water balance for the district. It is also essential to explore and map the geological formations which are likely to yield more groundwater, and to identify factors that constrain efficient exploitation and supply of water to rural people. The District Development Plan (7) states that "where earth dams without piping exist, as in Makueni division, or where other sources hardly exist, attempts should be made by the District Development Committee to initiate piping projects from dams and also develop a policy of ensuring that, as far as possible, large dams which have gravity piping components are incorporated in their plans. Where technically feasible, new pumping schemes should be avoided to alleviate the problem of having to rely on fuel to supply to the users." Obviously, meaningful planning should not only be concerned with land and water *per se*, but should also relate to the environmental perceptions, desires and aspirations of the rural people.

The socioeconomic benefits of carefully planned rural water schemes are bound to improve the living standards of rural people. Benefits will include decreased distances and time spent in fetching water (especially by women, who are primarily responsible for water supply in the rural areas); more time devoted to food production and soil-water conservation measures; increased rural small-scale industries; decreased waterborne and related diseases; increased dry-season farming and availability of more water for livestock and people; and decreased migrations of agropastoralists in search of water and pasture for their animals.

Finally, rural water resources should be used in such a way that quality is maintained and conflicts avoided. Water used for one purpose upstream can have a disastrous impact on water quality down stream. For example, coffee factories are usually located close to streams and unplanned water use in these factories may pollute the stream water, and threaten the interests of downstream water users. The use of the water resources should be integrated into a framework of development for the entire basin so that a maximum number of people will gain maximum benefit from improvements.

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Mr. Sam Mutiso is a lecturer at the University of Nairobi and is completing doctorate research in agricultural geography at the University of Reading. Dr. Russell Thompson lectures in climatology at the University of Reading. Their address is: Department of Geography, University of Reading, P.O. Box 227, Reading, Berkshire, RG6 2AB, UK.