Water abstraction and use patterns and their implications on downstream river flows: A case study of Mkoji Sub-catchment in Tanzania

Kossa R.M. Rajabu. Sokoine University of Agriculture. rkossa@email.com
Henry F. Mahoo. Sokoine University of Agriculture. hmahoo10@yahoo.co.uk
Hilmy Sally. International Water Management Institute. h.sally@cgiar.org

Abstract

This paper is based on a recent study undertaken in the Mkoji sub catchment (MSC) of the Great Ruaha River in Tanzania to investigate and analyse patterns of water abstraction and use and their implications on the downstream flows of Mkoji River. The study integrated social survey data, hydrologic data, water abstraction and water use data, remote sensing and GIS techniques. The impacts of dry season water diversions and upstream agricultural activities were evaluated in terms of the change of the flow hydrographs of the Mkoji River and its major tributaries. Results of monitoring water abstraction pattern of intakes have shown that there is significant change in water abstraction and use patterns as all the canals studied abstract water throughout the year, provided there is water in the rivers, irrespective of the conditions spelt in their water rights. Although all the schemes studied in MSC were abstracting, on yearly basis, less water than the amount spelt in their water rights, there is still over abstraction of water than needed for the size of areas and type of crops cultivated. The overall consequences are that many small rivers have now changed from being perennial to seasonal ones. Furthermore, rainfall trend analysis done in a recent study has shown that the available water resource has not been increasing over time. Thus while the available water resource has not been increasing over the time, water demands and uses have been and will likely continue to increase in MSC. The study concludes that if the prevailing conditions continue unabated, it is likely that more rivers will be drying up in the upstream areas resulting into wide-ranging social, economic, hydrological, and environmental consequences with impacts extending to downstream areas. Furthermore, water supply and demand in the MSC will be unbalanced, and risk of water deficit, and thus more conflicts, will be increased significantly. To mitigate this predicted water deficit, the study proposes a number of technological and institutional measures for meeting future water requirements.

Key words: Tanzania, Mkoji Sub Catchment, coefficient of water abstraction, water diversion, water abstraction pattern, flow hydrographs

Introduction

Water is the key resource in that without it other resources, natural and human, cannot be sustained. However, a steady increase both in population and agricultural and industrial activities has shown that water as a resource, is no longer available on an ad-lib basis (Usman, 2001) and water levels in many parts of the world are low and getting lower (SPORE, 1995). Water supply for agricultural, domestic, and industrial use, as well as for environmental use (rivers, habitat preservation, and fishing), has kept pace neither with population growth nor with growth of economic activities. Very often, we cannot find water in the right place, at the right time, in the right quantity and of the right quality. In his struggle for a better life, man has expended great efforts to tame the rivers for transportation, water supply, agriculture, and power generation. However, a wide range of these human uses and transformations of freshwater has the potential to alter, sometimes irreversibly, the integrity of freshwater ecosystems. Human activities that pose great threats to ecosystems include, among others:

1. ***Population and consumption growth*** - increases water abstraction and acquisition of cultivated land through clearing of forests;

2. ***Infrastructure development (dams, reservoirs, dikes, diversions etc)*** - alters timing and quantity of river flows, water temperature, nutrient and sediment transport;
3. ***Land conversion*** - it alters runoff patterns, inhibits natural recharge and fills water bodies with silt; and

4. ***Over-abstraction of water*** - depletes living resources and ecosystem functions and biodiversity (groundwater depletion).

Deliberate efforts are therefore needed to ensure that water is utilised efficiently, sustainably and to the fullest extent for the benefit of the present and future generations. The Mkoji River, a tributary of the Great Ruaha River in Tanzania, has not escaped this trend. The river has been severely fragmented by increasing diversions and irrigation canals, leading to the degradation of ecosystems. As a result of this, the water resources of the Mkoji sub catchment (MSC) are becoming increasingly stressed, and downstream flows have now reduced to zero during the dry season. It is due to the above facts that this study was undertaken in Mkoji sub catchment of the Great Ruaha River in Tanzania to investigate and analyse patterns of water abstraction and use and their implications on the downstream flows of Mkoji River.

A short description of the Mkoji Sub Catchment (MSC)

The Mkoji Sub-catchment is drained by the Mkoji River and is located in the southwest of Tanzania, between latitudes $7^0 48'$ and $9^0 25'$ South, and longitudes $33^0 40'$ and $34^0 09'$ East (Figure 1). It is a sub-catchment of the Great Ruaha River Catchment and covers an area of about 3400 km^2. Most of the sub-catchment lies within Mbarali and Mbeya Rural districts, while smaller portions of the sub-catchment lie within the Makete and Chunya districts in Iringa and Mbeya Regions respectively (Figure 2). According to the 2002 population census, Mkoji sub-catchment has a population of about 146,000 people with an average annual growth rate of 2.4%. The highest population density is found along the Tanzania-Zambia Highway and in the Southern highlands. Scattered villages are located in the plains. The sub catchment can be divided into three major zones as shown in Figure 2, which have the following important characteristics:

Zone A: Upper Zone (the highlands)

This zone is formed by the Southwest highlands of Poroto and Chunya with towns and urban areas. The Poroto and Chunya escarpment forms sources and tributaries of most of the major rivers in the MSC, thus the source of much of the sub catchment waters. This area is highly populated with high rainfall, deep soils and intensive agricultural production. In this zone, both rain fed and a bit of irrigated agriculture is practiced. The bimodal rainfall pattern and the type of soils allows for crop cultivation all year around. This is made possible through using residual soil moisture and growing of crops demanding low water input such as round potatoes, green peas and other vegetable crops.

Zone B: Intermediate (Middle) Zone

This zone is engaged with intensive rainfed and irrigated agriculture. It is characterized by a high concentration of traditional irrigation systems as well as improved traditional systems. The major crops under irrigation are rice (rainy season) and legumes, vegetables and maize in the dry season. With simple structures, farmers abstract water from the perennial small rivers flowing from the Poroto Mountains. Dry season irrigated agriculture is an important means of livelihood. Therefore this is an area of high competitive water demand and persistent water conflicts.

Zone C: Lower Zone (the plains)

This zone is engaged with intensive rainfed agriculture. The area is basically semi arid with alluvial and *mbuga* soils; and a high concentration of livestock particularly cattle, which had moved to the area from the Sukumaland. There are acute water shortages for even domestic uses, especially during the dry season.

Most of the lower zone of the sub-catchment, comprising the Usangu Plains, is semi-arid, whereas the upper zone (in the highlands) of the sub-catchment is semi-humid to humid. The rainfall regime in MSC is unimodal with a single rainy season starting from the third dekad of November and ending in the first dekad of April in the plains and third dekad of April in the highlands. In the high rainfall areas the dry season is shorter as the rainy season tends to continue up to May. The heaviest rainfall generally occurs in December- March (Table 1). The driest months are June to October. The highlands receive the highest annual rainfall. The mean annual rainfall at Uyole Agromet (which represents the highland) is about 1039 mm. The annual rainfall decreases towards the plains to about 840 mm at Igurusi (in the middle of MSC) and 617 mm at Mbarali Irrigation Scheme (representing the lower MSC area). The mean annual areal rainfall over the MSC is about 898 mm (3052 Mm^3 for the catchment). The rainfall amounts as well as the onset of the rainy season can vary considerably from year to year (average annual coefficient of variation is about 20%). The coefficient of variation is higher in the plains (i.e. 23 % at Igurusi) and it decreases towards the highlands (e.g. 18.2 % at Mbeya Maji). This variation often has a detrimental effect on crop production and other activities that depend on the reliable availability of water, especially in the drier areas. Trend analysis done in a recent study (FNPP, 2003) shows that rainfall in the studied stations in MSC is either decreasing or shows no significant change over the years.

Table 1. Rainfall characteristics of some selected stations (mm)

Sno.	Station Name	Month												Mean Annual Rainfall	Coefficient of Variation
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1	Mbeya Maji	204.2	179.2	174.1	95.7	13.1	1.8	1.6	0.2	3.0	13.5	62.6	194.6	943.6	18.2
2	Uyole Agromet	203.9	165.5	206.4	153.4	34.6	0.7	0.4	0.1	1.9	21.3	63.5	187.2	1038.9	19.9
3	Kimani	178.0	140.5	159.8	62.3	6.0	0.3	0.1	0.1	0.3	5.2	46.6	163.1	762.3	21.3
4	Mbeya Met	213.8	182.8	179.5	102.7	18.1	0.7	0.3	0.1	2.4	15.7	58.6	198.3	973.1	22.3
5	Mbarali Irr. Scheme	147.2	127.7	117.4	49.1	3.2	0.0	0.0	0.0	0.1	2.9	38.2	130.6	616.6	24.8
6	FAO Igurusi	210.0	163.1	152.1	84.5	17.5	0.6	0.0	0.0	1.3	3.2	43.3	166.2	841.8	23.0

Potential evaporation varies considerably within MSC. There is a tendency for decreasing evaporation with increasing altitude. The pan evaporation is 2430 mm/year at Igurusi (middle zone) and decreases to 1890 mm/year in Mbeya (representing the upper zone). The yearly variation is smaller and steady (coefficient of variation is 7% at Igurusi). The lowest evaporation is experienced in February (during the wet season) and increases during the dry season (from August to December), reaching a maximum in October/November. Significant moisture deficits are evident in the months of March to December. The annual total moisture deficit (evaporation minus rainfall) is of the order of 1585 mm.

The Mkoji River, which has given name to the sub-catchment, is the main river draining through the whole sub-catchment. It originates from the northern slopes of the Poroto Mountains from where it flows to the Usangu Plains, collecting en route water from the Makali and Itambo rivers before joining the Great Ruaha River. Other important rivers that drain the Mkoji Sub-catchment are Meta, Lunwa, Lwanyo, Mambi, Mswiswi, Ipatagwa, Mlowo, Mwambalizi and Gwiri (Figure 3). Surface water is the main source of water for both agricultural and domestic purposes. Ground water use is confined to domestic use only (including brick making). Demand for water in the MSC is driven by a number of competing uses. These include domestic supplies, irrigated agriculture, livestock, fishing, brick making and environment maintenance. Of these, water for irrigation is the key use, since it is the largest anthropogenic consumptive use, and the most obvious point at which management actions can have significant impact.

There are two types of irrigation schemes in MSC. These are:

a) Traditional systems, which comprise of village irrigation based on the diversion of perennial or seasonal flows, used mainly for the production of paddy, vegetables and other relatively high value crops. These are self-sustaining systems, which are an important means of livelihood-generation for a large number of people in MSC. The most important feature of these schemes is that they have been initiated, financed and developed by the farmers themselves, without any external assistance. They are not only farmer-managed, they are farmer-owned.

b) Improved traditional systems, which comprises of schemes that have received government or donor assisted interventions to improve the water control structures. There are claims that these systems have enhanced differences between top-enders who have benefited from improvements and tail-enders that have lost a measure of water predictability and supply.

Figure 1. Location of Mkoji sub-catchment within the Rufiji River Basin in Tanzania

Figure 2. The Mkoji Sub-catchment zones

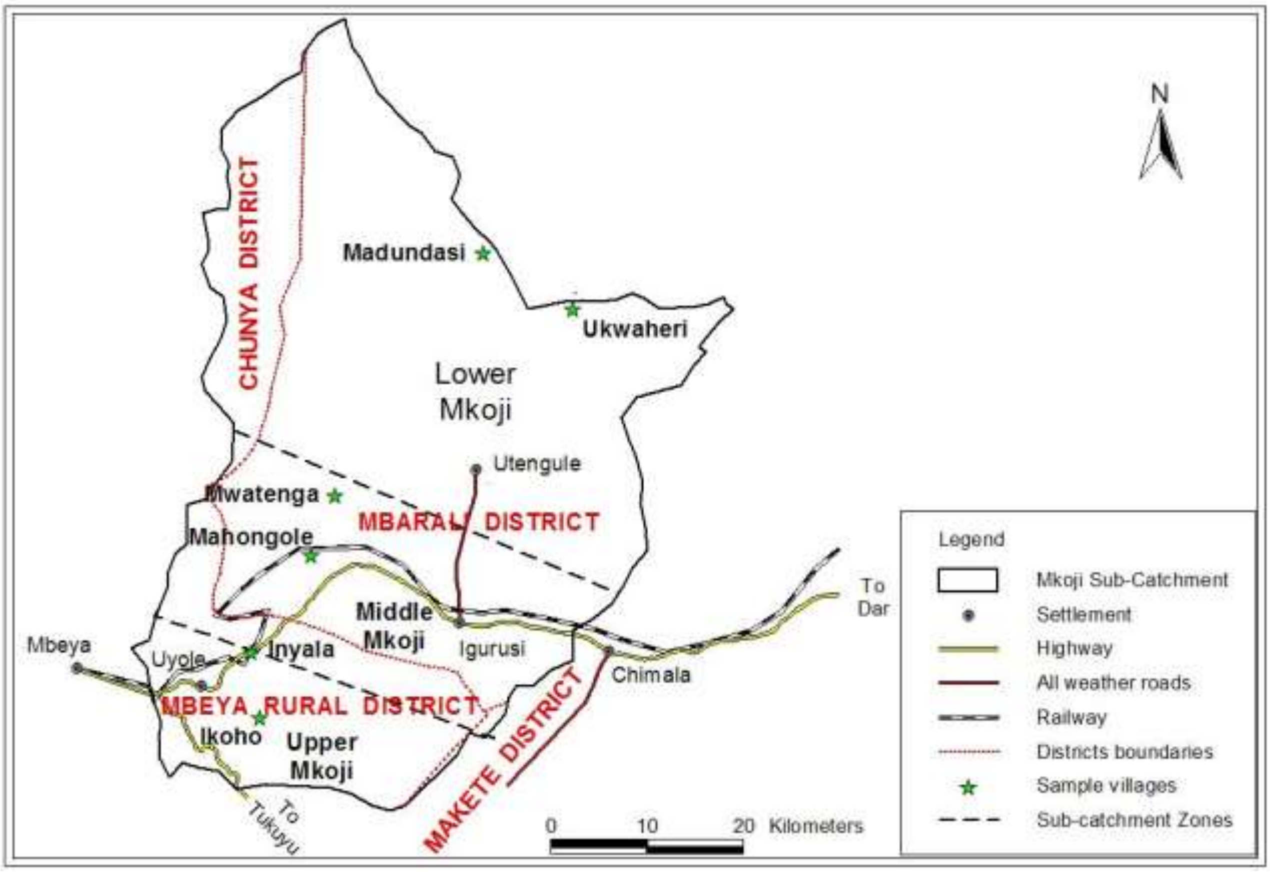
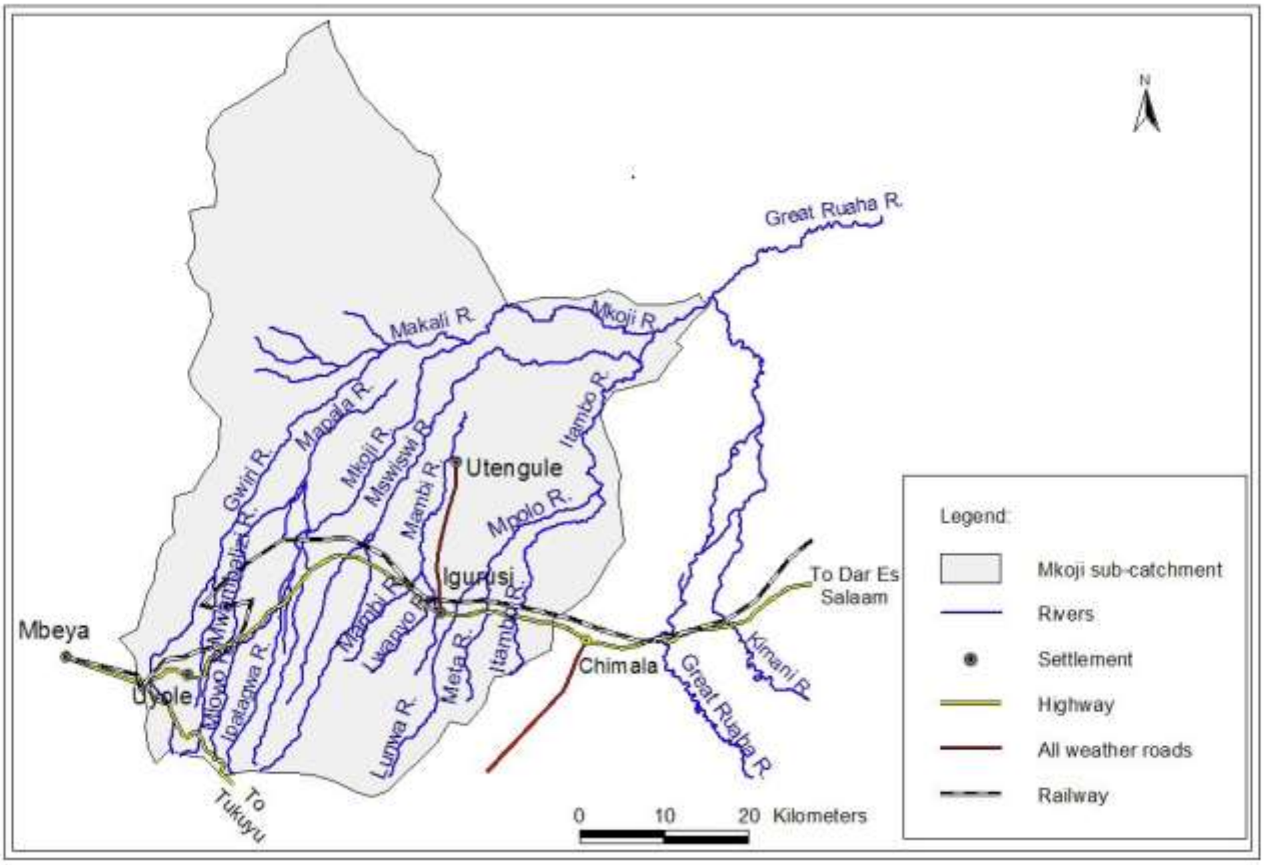


Figure 3. Mkoji Sub-catchment – Water Resources



Research approaches and methods

In this study both primary and secondary data and information was collected and used in the assessment. Data on household characteristics and water use was collected using a structured questionnaire, informal discussions with key informants and transect walks in and around the study area. Key informants were people that were knowledgeable in water resource availability, dynamics and use in their village and sub-villages. Irrigated areas were obtained by analysing remotely sensed images and by mapping the areas using Geographical Positioning System (GPS) receivers. Additional gauging points were established in rivers (upstream and downstream of irrigation schemes) and in water abstraction canals to collect daily flow data. Selection of irrigation schemes that were studied was based on the criteria that: 1) There is easy accessibility of the abstraction and gauged points throughout the year; 2) Both wet season and dry season irrigated agriculture are represented; 3) Traditional as well as improved traditional intakes are studied; and 4) Irrigation canals are selected from both the upstream and mid stream of the respective rivers. Spot discharge measurements were also undertaken using current meters, especially in the ungauged rivers. Seepage tests were undertaken during the wet and dry seasons in some sections of the irrigation canals so as to understand the extent of the problem. In order to supplement data obtained from measurements of physical variables, key informants were consulted about their experience and observation of flow changes in the Mkoji River and its tributaries over the years.

Secondary data and information was obtained from various databases, reports and other publications. Historical rainfall, evaporation and other climatic data from representative climatic stations were collected from Rufiji Basin Water Office (RBWO), Directorate of Water Resources, Sustainable Management of Usangu Wetland and its Catchments (SMUWC) and Tanzania Meteorological Agency databases.

Table 2. Description of irrigation schemes studied

Sno	Scheme Name	Type of intake	Water Source	Water right (m^3/s)		Potential area[1] (Ha)	Developed area[1] (Ha)	Remarks
				Wet season	Dry season			
1	Ipatagwa I Irrigation	Improved	Ipatagwa R.	1.000 (Nov-May)	0.100 (June-Oct)	700	542[2]	Irrigation
2	Ipatagwa II Irr. Project (Mkoji	Improved	Mkoji R.	0.300 (Nov-May)				Paddy irrigation
3	Irrigation Scheme at Majenje (Luanda	Improved	Lwanyo R.	0.180 (Dec-May)	0.040 (June-Nov)	500		Irrigation
4	Kongolo Mswiswi	Local	Mswiswi R.	0.360 (Dec-June)		600	180	Paddy irrigation
5	Irrigation at Inyala (B)	Improved	Mlowo R.	0.180 (May-Aug)	0.025 (Sep-Nov)	90	60	Irrigation
6	Moto Mbaya Irr.	Improved	Mlowo R.	1.200	0.300	800	600	Irrigation
7	Iyawaya Irr.	Improved	Uta R.	Not available	Not available	75	30	Irrigation, domestic
8	Abadaa Irrigation Scheme	Local	Abadaa Spring	Not available	Not available		22[3]	Irrigation

[1] Source: Mbeya Zonal Irrigation Unit – Master Plan, 2003
[2] Source: Smallholder Irrigation Improvement Project (SIIP)
[3] Obtained from GPS mapping

Results

Types of diversion structures in use

Both traditional and modern water diversion structures exist in the study area. There are about 108 water abstraction points in MSC, with only 20 of them having improved headworks. Traditional diversions are temporary in nature, needing to be re-built each year. They are built of wooden poles, rocks, gunny bags, clay soils and stones. Their major deficiencies are: (1) Inadequate water control hence excessive wastage of water; (2) Insufficient water supply during drought; and (3) Excessive water diversion during floods. Further to that, traditional schemes have no gates at all and water is abstracted and flows continuously throughout the day, even if it is not needed. To make matters worse, most traditional schemes have poorly maintained or no drainage systems at all to return the excess water back into rivers. The problem is very acute in flat terrain where excess water is just left to flow and spread in the plains. The overall result is that there are enormous losses of even the little amount of water available.

Most of the improved intakes were built in the 1980s onwards and were geared towards smallholder farmers. For example, Majengo, Mswiswi and Moto Mbaya intakes were built during the Usangu Village Irrigation Project (UVIP) in the mid 1980s. During early 2000s, other irrigation schemes were either developed or improved in the MSC. They include Inyala A & B, Iyawaya and Imezu Mkombozi irrigation schemes. Furthermore, in 2002, two more irrigation projects (Ipatagwa I & II and Luanda Majenje), funded by the World Bank under the Smallholder Irrigation Improvement Project (SIIP) component of the River Basin Management Project, were opened. Currently, Shamwengo irrigation scheme is undergoing improvements of its headworks and the main canal. Thus, one can say that since the eighties, there has been an increase in the number of improved intakes in MSC, the total abstraction capacity has steadily risen, and more importantly, the ability to abstract water during the dry season has increased. However, a good number of the improved irrigation schemes have their intake and/or spillway gates vandalised or not working properly (e.g. Ipatagwa, Moto Mbaya and Inyala B) making it difficult to regulate and control water abstraction.

While improved intakes are desired to control water abstractions and reduce unnecessary water losses through leakages at the intakes, selfish farmers can also abuse the intakes. Rivers in MSC have very small flows (less than 1 m^3/s) during the dry season. Therefore most of the improved intakes are capable of diverting the whole flow of the river permitting greater control of water to top-enders. Thus, while farmers with improved intakes are pleased to have great control of water and use less time and labour to maintain their intakes, the downstream farmers are deprived of water, particularly during the dry season. Survey of household water use has shown that over 80% of downstream household heads believe that construction and improvement of irrigation intakes in the upstream areas is responsible for the observed drying of rivers and shortage of water for domestic uses during the dry season.

Patterns of water abstraction by irrigation canals in the study area

One of the major objectives of the study was to investigate water abstraction patterns (rate, duration, season and frequency of abstraction) by canals. The irrigation canals studied fall under three main categories, depending on the season of abstraction. The seasons of abstraction are:

1. Wet season (mainly for paddy cultivation) (e.g. Mkoji and Kongolo Mswiswi canals);
2. Dry season (mainly for dry season cultivation of vegetables, legumes and maize) (for example Inyala B, Iyawaya and Abadaa canals); and
3. Throughout the year (e.g. Ipatagwa, and Luanda Majenje canals).

The abstraction period and the amount of water allowed to be abstracted are clearly indicated in the water rights issued (for authorised canals with Water rights). Table 3 shows the pattern of water abstraction by the irrigation canals. The results show that all the canals studied abstract water throughout the year, provided there is water in the rivers, irrespective of the conditions spelt in their water rights. The same trend can be found in most of the other canals, which were not studied.

Table 3. Mean daily irrigation canal abstractions[1] (l/s)

Canal Name	Year	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ipatagwa	2003	333.72	324.17	364.68	381.82	361.70	328.39	224.73	188.31	150.80	122.81	116.70	139.60
	2004	231.50	249.20	378.27	920.84	552.49	306.48	160.66	138.36	70.97	59.15	56.06	
Mkoji	2003	68.14	63.19	76.48	92.18	73.54	84.26	54.71	28.02	17.30	17.33	20.77	31.30
Moto Mbaya	2003	170.42	116.04	114.31	163.86	112.68	134.64	95.66	45.03	23.17	12.16	17.72	25.34
	2004	38.78	91.96	433.20	923.69	325.94	234.96	95.30	125.92	150.96	115.64	109.75	
Kongolo Mswiswi	2003	120.21	150.69	90.16	98.79	102.84	133.11	94.63	84.87	67.48	58.63	53.40	48.97
	2004	100.89	93.02	95.76	133.51	177.66	121.02	118.76	94.79	92.94	71.86		
Luanda Majenje	2003	109.67	126.47	101.27	151.48	89.82	45.27	62.26	40.88	45.82	43.03	15.71	40.32
	2004	105.39	203.67	210.85	180.30	190.02	152.22	89.82	82.84	66.88	48.19		
Inyala B	2004				0.35	38.00	38.00	47.98	79.29	65.45	38.22	32.18	
Iyawaya	2004				73.85	48.63	31.53	33.09	23.14	22.65	26.54	29.46	
Abadaa	2004	10.92	8.72	8.70	7.67	16.79	18.94	19.83	18.52	18.71	18.47	18.81	

[1]Obtained by summing mean daily discharges and dividing by the total number of days in the month

In general the abstraction pattern of irrigation canals is such that:

(i) Where a large area is under paddy cultivation, maximum abstraction occurs in April. Other months with relatively large abstractions are March and May. The reason for this is that during this period water requirement by paddy is at the maximum and also water availability in rivers is at the maximum;
(ii) When the area under dry season irrigated agriculture is larger than the area under paddy cultivation (for example Kongolo Mswiswi and Luanda Majenje canals), maximum abstractions occur in January/February (due to irrigation of early maize crop planted in November and transplanting of paddy) and June/July (start of dry season irrigated agriculture);
(iii) When the area is totally under dry season irrigated agriculture (for example Abadaa and Inyala B canals), maximum abstractions occurs in the months June through to November because the area is under intensive irrigated agriculture throughout this period; and
(iv) Where there is multiple use of water such as domestic, livestock, and agriculture (e.g. Iyawaya canal), maximum abstractions depend on the availability of water in rivers.

Relationship between irrigation canal abstractions and granted water rights

Table 4 shows the ratios of the amount of water abstracted to the water rights. The table shows that although all the schemes studied in MSC were abstracting, on yearly basis, less water than the total amount spelt in their water rights, there is still over abstraction of water than needed for the size of areas and type of crops cultivated. The water rights aim to control the amount of water used by water users and to halt or reduce over-abstraction of water. The water rights for irrigation use are based on flow rates (e.g. 0.5 m^3/s) and are issued taking into consideration the long-term mean flows in respective rivers. However, in some cases the rights are simply water duties, based on potential areas (potential command area multiplied by hydro module - 2.0 l/s/ha), and not developed area or crop water requirement of a particular cropping pattern. When just a portion of the potential area is developed due to financial limitations, the granted water right is not adjusted to match with the developed area. Furthermore not all the developed area is cultivated each year because of unreliable rainfall and hence river flows. Thus the water rights, in most of the irrigation schemes are much higher as compared to the cultivated areas, making it easy to over-abstract water (as compared to the areas under cultivation) without exceeding the limits set in the water rights.

Table 4. Ratios of the amount of water abstracted to the water rights

Sno.	Scheme Name	Mean daily abstractions (m^3/s)	Mean daily water right (m^3/s)	Average ratio of abstractions to the water right (%)
1.	Ipatagwa	0.268	0.609	44.00
2.	Luanda Majenje	0.097	0.107	90.24
3.	Kongolo Mswiswi	0.100	0.213	47.01
4.	Mkoji	0.051	0.175	29.05
5.	Inyala B	0.043	0.103	41.46
6.	Moto Mbaya	0.160	0.730	21.90

Relationship between the amounts of water diverted from the sources and the cropped areas

Table 5 shows the relationship between the amount of water diverted from the source and the cropped area during the dry and wet seasons. Major crops grown under irrigation in MSC include paddy, maize, dry beans, tomatoes and onions. The results show that Abadaa irrigation scheme, which abstracts water for dry season irrigated agriculture performed better than the other schemes in as far as water abstraction and use is concerned. The average abstraction rate (hydro module) is 0.928 l/s/ha as compared to 1.753 and 3.759 l/s/ha for Kongolo Mswiswi and Luanda Majenje irrigation schemes that also practice dry season irrigated agriculture. If you consider maize (a major dry season crop grown in all the schemes with an average growing period of 120 days), the above abstraction rates translate to 852, 1628 and 3897 mm of water respectively. These values are higher than the gross crop water requirements for maize in MSC, which have been estimated at 435 and 521mm for the upper and middle MSC respectively (FNPP, 2003). The low hydro module for Abadaa scheme is due to, among other things, the fact that the command area is concentrated in one core area and thus water need to be only conveyed to a relatively short distance (about 1.8 kilometre) to reach the farthest field. On top of that, seepage losses are also negligible as water travels only a short distance and the soil type (sandy clay to sandy clay loam) found at the scheme allows only slow to moderate seepage rates, if any.

Luanda Majenje irrigation scheme shows very inefficient water abstraction and use. There are two factors, among others, that contribute to this 'unwise' abstraction and use of water. The first factor is that the fields under dry season irrigated agriculture are very much scattered over a large area. Consequently water had to be conveyed to small fields, which are far apart. The second factor is high seepage losses due to fractures and burrows along the canal water way. Seepage tests conducted in October 2003 shows that in some sections of the main canal seepage losses were as high as 0.024 l/s per meter length. In order to overcome this problem, the two gates at the intake (one on the canal and the other allowing water to flow back into the river) are closed completely during the night. This allows water to pond behind the weir. When the canal gate is opened in the morning, the high water head created allows water to flow to the farthest field in a relatively shorter time and in reasonable amounts. This advantage is only short-lived and after about two hours the flow of water resumes to its normal rate. However, this practice increases seepage losses due to increased wetted area, given the presence of fractures and burrows along the canal way.

Kongolo Mswiswi scheme abstracted more water for paddy irrigation (2.688 l/s/ha) instead of 0.976 l/s/ha (SMUWC, 2001), which is normally taken as the gross water requirement for paddy in the Usangu Plains (MSC inclusive). The reason could be the fact that it is the upstream most intake in Mswiswi River and so water availability is not a limiting factor during the rainy season. The other reason is that the intake is a traditional one made of wooden logs, tree branches, trashes and soil, making it very difficult to control or regulate the amount of water being abstracted, especially during the rain season. The scheme also faces the problems of having a dirty irrigation canals, just as is the case with other irrigation canals. Periodic canal cleaning and maintenance is crucial for optimum performance of irrigation schemes. Of all the irrigation schemes studied, canal cleaning is not done on a regular basis. Scheduled canal cleaning and maintenance is undertaken only about once a year. Cleaning of canals is done before the onset of the wet season (for schemes irrigating during the wet season) and after the end of the wet season (for schemes practicing dry season irrigated agriculture). Otherwise canal maintenance is undertaken in between those two periods only if the canal system is somehow damaged or completely blocked by excessive siltation or weed infestation.

Table 5. Relationship between amount of water abstracted and cropped area

Sno	Scheme name	Period of abstraction (Months)		Mean daily abstraction (l/s)[1]	Cropped area (ha)	Hydro module (l/s/ha)
		Wet season	Dry season			
1	Abadaa scheme		May-Nov	18.58	22.6	0.928
2	Kongolo Mswiswi scheme		July-Nov	71.80	45.73	1.753
3	Kongolo Mswiswi scheme	Dec-June		110.12	40.97	2.688
4	Luanda Majenje scheme		July-Nov	41.54	11.05	3.759

[1]Obtained by summing mean daily abstractions and dividing by the total number of days in the period

Effects of upstream abstractions on downstream flows

Table 6 shows the average daily dry season river flows in MSC before any abstractions. The table shows that rivers in MSC have very low dry season flows and the total available water resource in MSC for the whole of the dry season is **39.36 Mm³**. Table 7 shows the average dry season abstractions from Lwanyo, Mswiswi, Mkoji and Mlowo rivers. Table 8 shows dates of drying and flow resumption for some rivers in the Mkoji sub catchment as recorded in the downstream gauges. Figure 4 shows the comparison of flow hydrographs at gauging stations located upstream and downstream of major irrigation abstractions in Mkoji River.

Table 7 shows that for all the four rivers studied, the average upstream dry season flows were higher in 2004 as compared to 2003, which was a very dry year. Mswiswi River recorded the lowest coefficients of abstractions (CA) as compared to the other rivers, which recorded CAs of 90% and above. The reason for this is that during the peak of the dry season (August to November), there are rotational schedules among all irrigation intakes as well as other water users in Mswiswi R. The rotation is on daily basis. There are therefore days in the week when irrigation abstractions are required to stop and all the available water in the river is left to flow to downstream villages of Simike, and Luhanga to meet domestic as well as livestock water requirements. However, this amount of water does not flow further than Luhanga village. Therefore downstream of Luhanga village, Mswiswi River also dries up from June, like other MSC rivers. Lwanyo and Mlowo rivers had coefficients of abstractions of almost 100% in 2003 and over 95% in 2004. This indicates that there are no rotational schedules that take into account downstream water requirements (e.g. for domestic use). The same scenario is also reflected by over 92% abstraction coefficients for Mkoji River in the months July to November in 2003 and 2004.

In summary, all the rivers draining the Mkoji Sub-catchment, during the dry season, are perennial upstream of the Tanzania-Zambia Highway. However, a few kilometres downstream of this highway, all these rivers dry up from the month of June and can be described as seasonal. This is mainly due to dry season irrigated agriculture, which uses all the water that would have kept them flowing during the dry season (losses of water through seepage, evaporation and deep percolation are considered to be negligible). The distance from the highway to the points where the rivers dry up varies from river to river and is a function of the number, type, capacity and location of water abstraction intakes in a particular river. Mkoji River therefore does not contribute any water to the base flow of the Great Ruaha River.

Table 6. Average daily dry season river flows (m^3/s) in MSC – from daily gauging and spot discharge measurements (Year 2004)

Sno	River Name	Month					
		Jun	July	Aug	Sep	Oct	Nov
1.	Itambo at Itamboleo	0.014	0.010	0.009	0.007	0.006	0.002
2.	Meta at Mapuga	0.107	0.109	0.078	0.088	0.121	0.105
3.	Lunwa at Igurusi	0.891	0.567	0.419	0.315	0.304	0.266
4.	Lwanyo at Igurusi	0.253	0.201	0.149	0.116	0.078	0.056
5.	Mkoji at Shamwengo	0.174	0.098	0.069	0.049	0.051	0.032
6.	Mswiswi at Wilima	0.650	0.411	0.304	0.307	0.197	0.268
7.	Mambi at Kalanzi	0.541	0.301	0.289	0.212	0.164	0.125
8.	Inyala (Hayuya) Spring at Inyala	0.027	0.022	0.012	0.011	0.010	0.004
9.	Gwiri at Malamba	0.196	0.082	0.095	0.084	0.078	0.066
10.	Ipatagwa at Great North Road	0.643	0.522	0.451	0.439	0.420	0.402
11.	Mwambalizi at Itewe	0.135	0.095	0.061	0.037	0.041	0.034
12.	Sawa at Itewe	0.015	0.007	0.007	0.006	0.004	0.004
13.	Mlowo at Idunda	0.239	0.179	0.133	0.111	0.089	0.071
14.	Uta at Iyawaya	0.039	0.033	0.031	0.022	0.024	0.028
15.	Abadaa Spring at Idunda	0.038	0.026	0.025	0.016	0.018	0.020
16.	Others	0.354	0.264	0.214	0.165	0.149	0.139
	Total flow (m^3/s)	4.316	2.927	2.346	1.985	1.754	1.622
	Monthly volume (Mm^3)	11.19	7.84	6.28	5.15	4.70	4.20
	Total dry season volume (Mm^3)						39.36

Table 7. Comparison of dry season discharges at gauged points upstream and down stream of irrigation schemes in Mkoji sub-catchment rivers

Month	Mean daily discharges[1] (m^3/s)															
	Lwanyo U/S	Lwanyo D/S	Amount abstr.	CA[2] (%)	Mswiswi U/S	Mswiswi D/S	Amount abstr.	CA (%)	Mkoji U/S	Mkoji D/S	Amount abstr.	CA (%)	Mlowo U/S	Mlowo D/S	Amount abstr.	CA (%)
May-03	0.369	0.004	0.366	99.025	0.836	0.391	0.445	53.230	0.190	0.074	0.116	60.939	0.618	0.001	0.617	99.838
Jun-03	0.259	0.002	0.257	99.270	0.245	0.152	0.093	38.015	0.102	0.009	0.092	90.821	0.439	0.000	0.439	100.000
Jul-03	0.210	0.002	0.208	98.950	0.184	0.104	0.079	43.170	0.082	0.003	0.079	96.902	0.400	0.000	0.400	100.000
Aug-03	0.176	0.002	0.175	99.121	0.167	0.062	0.105	62.995	0.041	0.003	0.038	92.557	0.327	0.000	0.327	100.000
Sep-03	0.151	0.000	0.151	99.776	0.134	0.084	0.050	37.533	0.037	0.000	0.037	99.957	0.279	0.000	0.279	100.000
Oct-03	0.086	0.000	0.086	99.929	0.105	0.043	0.062	59.480	0.024	0.000	0.024	100.000	0.206	0.000	0.206	100.000
Nov-03	0.065	0.000	0.065	99.999	0.253	0.083	0.170	67.052	0.027	0.000	0.027	100.000	0.188	0.000	0.188	100.000
Average	**0.188**	**0.001**	**0.187**	**99.439**	**0.275**	**0.131**	**0.144**	**51.639**	**0.072**	**0.013**	**0.059**	**91.597**	**0.351**	**0.000**	**0.351**	**99.977**
May-04	0.643	0.034	0.609	94.640	1.292	0.488	0.804	62.230	0.377	0.169	0.207	55.003	1.254	0.102	1.152	91.865
Jun-04	0.358	0.014	0.344	96.200	0.730	0.223	0.507	69.405	0.170	0.040	0.130	76.427	0.823	0.009	0.814	98.850
Jul-04	0.196	0.001	0.194	99.297	0.580	0.121	0.458	79.066	0.100	0.005	0.095	95.381	0.624	0.002	0.622	99.636
Aug-04	0.151	0.007	0.144	95.492	0.469	0.081	0.388	82.654	0.073	0.000	0.073	100.000	0.522	0.000	0.522	100.000
Sep-04	0.091	0.007	0.084	92.055	0.415	0.084	0.332	79.881	0.060	0.000	0.060	100.000	0.503	0.000	0.503	100.000
Oct-04	0.068	0.007	0.061	89.895	0.331	0.027	0.305	91.888	0.037	0.000	0.037	100.000	0.487	0.000	0.487	100.000
Nov-04									0.039	0.000	0.039	100.000	0.457	0.000	0.457	100.000
Average	**0.251**	**0.012**	**0.239**	**94.596**	**0.636**	**0.171**	**0.465**	**77.521**	**0.122**	**0.031**	**0.092**	**89.544**	**0.667**	**0.016**	**0.710**	**98.622**

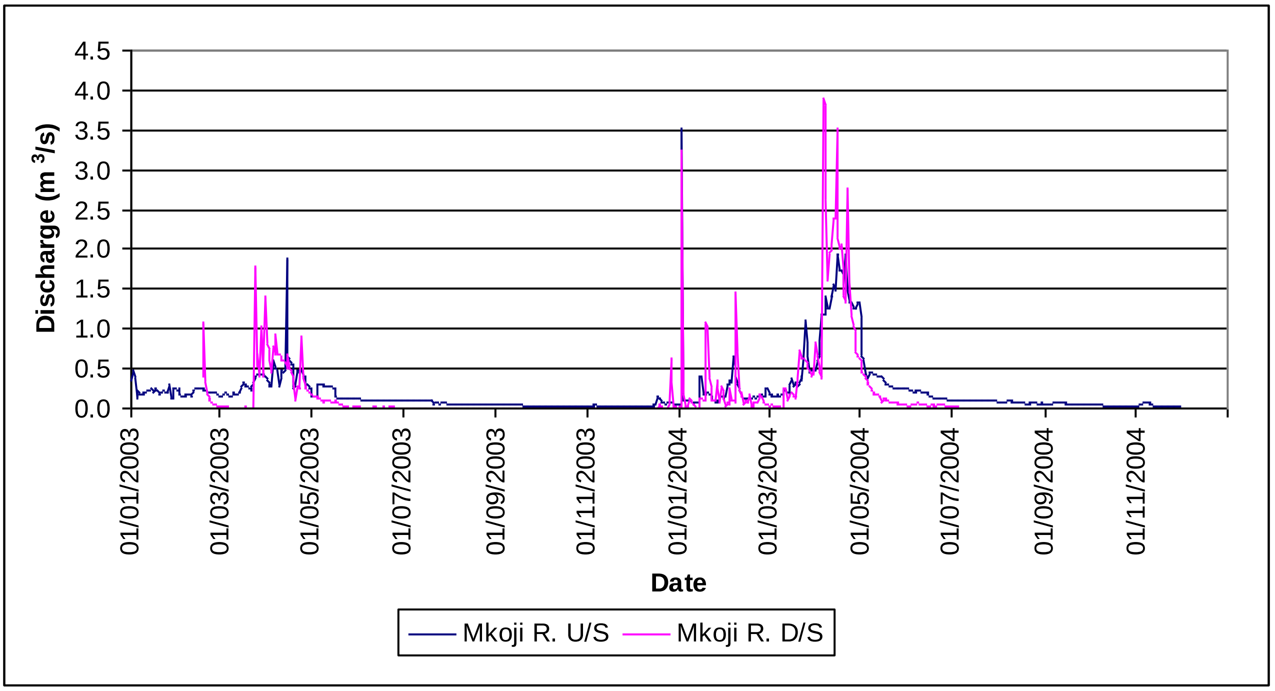
[1] Obtained by summing mean daily discharges and dividing by the total number of days in the month

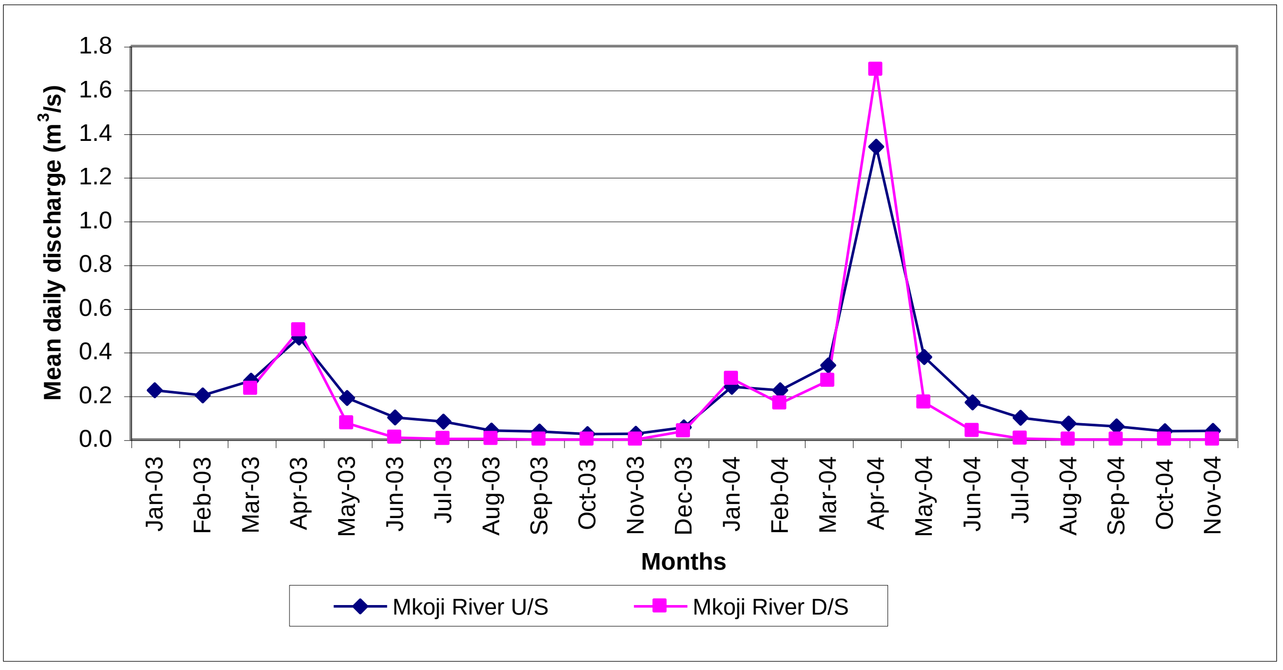
[2] Coefficient of Abstraction

Table 8 Dates of drying and flow resumption for some rivers in the Mkoji sub catchment

Sno	River name	Start of zero flow	Resumption of flow	Zero Flow days	Remarks
1	Lwanyo	03/11/2003	14/12/2003	41	
					The river never dried in 2004
2	Mswiswi	2003		3	The river never dried continuously due to rotational water abstraction schedules
		2004		2	
3	Mkoji	07/09/2003	18/12/2003	102	
		02/08/2004	01/12/2004	121	
4	Mlowo	06/06/2003	15/01/2004	198	
		18/07/2004	4/12/2004	136	

Figure 4 Mkoji River: Daily and mean monthly flow hydrographs at gauged points upstream and downstream of irrigation abstractions





Conclusion

The current National Water Policy (GoT, 2003) acknowledges that irrigated agriculture provides protection against drought and it is also the most important way of ensuring the availability of food reserves. Furthermore, this type of agriculture contributes to the reduction of poverty since it can facilitate many people to cultivate high value crops such as vegetables and fruits. The policy further asserts that efforts should be made to ensure reliable supply of water in all the competing uses important for the national economy, like agriculture, domestic use, hydropower generation, mining and industry. How can these competing policy objectives be realized in a situation like the one found in MSC? One way of achieving this is by increasing water use efficiency and water productivity. In Tanzania, there have been efforts to increase efficiency of water use in the traditional irrigation schemes, which is generally presumed to be low. The RBMSIIP (2001) project and other donors have been implementing a number of interventions in the MSC aimed at improving the indigenous irrigation schemes. Some of these interventions included:

- Improvement of irrigation water intakes and main water conveyance and drainage systems;
- Assisting farmers to form and register Water Users Associations and get statutory water rights;
- Training Extension Officers and farmers on proper water management and crop husbandry practices; and
- Promoting production of high value crops in order to realize high returns to land, labour and water inputs.

However, the study has shown that there are other factors, apart from water use efficiency, that impact on availability of water to downstream reaches of river systems. One of these factors is non-adherence to conditions spelt in the water rights, which are also problematic. Results of monitoring water abstraction pattern of intakes have shown that there is significant change from anticipated water abstraction and use patterns. All the canals that were studied abstract water throughout the year, provided there is water in the rivers, irrespective of the conditions spelt in their water rights. Furthermore, there is still over abstraction of water than needed for the size of areas and type of crops cultivated.

The second factor is the increase in the number of water abstraction points, in particular improved intakes. Out of the 108 water abstraction intakes in the Mkoji sub catchment, 20 schemes have improved (concrete) intakes and weirs. Nine of the improved intakes have been constructed during the period 2000 to 2004 and more improved intakes are planned to be constructed to “improve” water management. While improved intakes are desired to control water abstractions and reduce unnecessary water losses through leakages at the intakes, selfish farmers are abusing these intakes. Since rivers in MSC have very small flows (less than 1 m^3/s) during the dry season, most of the improved intakes are capable of diverting much of the available flow of the rivers thereby permitting greater control of water to top-enders. Thus, while farmers with improved intakes are pleased to have great control of water and use less time and labour to maintain their intakes, the downstream farmers are deprived of water, particularly during the dry season. To worsen the situation further, a good number of improved (due to vandalism) and all traditional intakes lack proper functioning gates to control abstraction of water. Consequently water is abstracted and flows continuously throughout the day, even if it is not needed resulting into enormous losses of even the little amount of water available.

The overall consequences of the above factors are that many small rivers have now changed from being perennial to seasonal ones. Thus while the available water resource has not been increasing over the time (from rainfall trend analysis), water demands and uses have been and will likely continue to increase in MSC. Thus the study concludes that if additional steps are not undertaken and intensified to control and regulate water abstraction during critical periods, downstream water users will continue to suffer from water shortages for even essential needs such as domestic water use resulting into increased conflicts over water and destruction of irrigation systems structures. On top of that more rivers will be drying up in the upstream areas and therefore contribution of MSC to the dry season flows of the Great Ruaha River will continue to be zero.

To mitigate this predicted water deficit, remedial measures and options for meeting future water requirements need to be undertaken and incorporated into future water development plans in the study area. The measures can either be technological or institutional ones. In most semiarid areas, like much of the Mkoji Sub Catchment, there is limited scope for increasing the available water resources by constructing large civil engineering works (e.g. dams and large reservoirs). This is because of the high social, environmental, and financial costs associated with large civil engineering works. However, in many semiarid areas there is considerable scope for developing additional water resources by constructing wells and boreholes in down stream areas that can cater for domestic water requirements. Likewise, intensification of the use of rainwater harvesting technologies (e.g. construction of charco dams) can go a long way in minimising the problem of shortage of water for domestic as well as livestock use, particularly during the dry season. Regular auditing or assessment of water availability in rivers and uses in irrigation canals by the respective basin authority should be done during critical periods in both the dry and wet seasons. The auditing should include closing of unauthorised abstractions and regulating water abstraction by authorised schemes to much with their actual water requirements and water availability in rivers. Although the exercise was carried out last year (2004) in MSC by the Rufiji Basin Water Office, the office is facing manpower, transport and financial resources to effectively monitor water abstraction and use. These resources need to be increased significantly soonest.

With regard to irrigation, current theory suggests that irrigation during the dry season implies a loss of recycling capacity (or loss of water to the atmospheric sink), as water evaporated during the dry season does not enhance rainfall. However, in MSC, dry season irrigated agriculture is an important livelihood activity as it provides security against famine, and is a major source of income. Therefore one cannot impose an outright ban on dry season irrigated agriculture. The only viable option is to reduce irrigation command areas (concentrated in one core area to reduce conveyance water losses) during the dry season and also during the dry years so as to enable the little water available reach downstream areas to meet domestic, livestock and environmental water requirements. With regards to institutional measures, all irrigation schemes should be enforced to construct, properly operate and maintain water control gates and drainage systems. Introduction of water allocation schedules among intakes and conduction of training and awareness campaigns on sustainable water use and conservation could also go a long way in ensuring wise use of water. Last, but not least, water rights should be reviewed to conform to the current actual irrigated areas and water requirements.

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