American Journal of Water Resources, 2018, Vol. 6, No. 5, 189-202
Available online at http://pubs.sciepub.com/ajwr/6/5/2

DOI:10.12691/ajwr-6-5-2

Effects of Water Abstraction on Burguret Flows, Kenya

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Received October 02, 2018; Revised November 04, 2018; Accepted November 20, 2018

Abstract The water flows of Burguret River, located on the slopes of Mt. Kenya in Burguret catchment, were assessed along the profile to determine the water abstraction status. Downstream water users are faced with challenges of low river flows or no flows during the dry season which leads to a lot of conflicts arising due to the water allocation in these areas. Methods used for assessment of water abstraction included field survey visit to ascertain abstraction points details, the water users' interviews in which convenience and random sampling methods were used. Flow duration curves, fdcs were developed from the observed river flow discharge to ascertain the water supply of Burguret River and finally Mike Hydro model was used to predict optimal flows for water allocation within Burguret catchment. Majority of upstream abstractions used gravity pipes and abstracted large amounts, 14,502 m^{-3}day (67%) of water compared to downstream users who mostly used portable pumps and abstracted 2,696 m^{-3}day (16%). The unofficial abstractions took place when abstractors exceed the allocated amounts. Burguret River can supply 21,953 m^{-3}day and 10,800 m^{-3}day during normal flows from the Naturalized and Observed fdcs respectively. The Nash Sutcliffe Efficiency, R^2 was found to be 0.71 and 0.61 during calibration and validation periods respectively. This showed that the model performed well and was used to adequately simulate scenarios which yielded results after optimal allocation and the river supply stood at 15,984 m^{-3}day which was good enough to ensure downstream and environmental flows are restored.

Keywords: *Burguret catchment, river water abstractions, flow duration curves, Mike Hydro Model*

Cite This Article: Irine Jeptum, Bancy Mbura Mati, John Mwangi Gathenya, and Michael Thomas, "Effects of Water Abstraction on Burguret Flows, Kenya." *American Journal of Water Resources*, vol. 6, no. 5 (2018): 189-202. doi: 10.12691/ajwr-6-5-2.

1. Introduction

Burguret river, a tributary of the Ewaso Ng'iro North river, emanates from the peaks of Mt. Kenya. Burguret catchment is a typical highland–lowland system, exhibiting to a high degree all the characteristics of such systems as great ecological diversity, steep vertical gradients, dominance of gravity-controlled processes, and a great sensitivity to human intervention, [1]. Burguret catchment covers 209km^2 which is 1.4% of the Upper Ewaso Ng'iro basin. The reserve flow is defined as the flow required to sustain downstream ecosystems and to meet basic human demand. In order to translate this into practice, three flow conditions were defined as shown in Table 1. Specific allocations can be made for the different flow conditions.

In reality however, abstraction takes places without regard to the conditions of water allocation. Irrigation water demand is highest during the dry season months when river flows are lowest. The value of water to individual users is linked to its location and quality, and the timing of its availability. Its location determines accessibility and cost, its quality whether it can be used at all, and if so, at what treatment cost. The timing of the availability of water dictates its reliability and value for power production, irrigation, environmental or domestic use.

Table 1. Flow conditions and permitted allocations [2]

Flow conditions	Threshold	Permitted Allocations
Reserve	Q<Q95	None
Normal	Q95<Q<Q80	Domestic and public uses
Flow	Q80<Q	Irrigation and other commercial uses

1.1. Burguret River Abstractions

In Burguret catchment water supply services are provided by community owned and managed water projects developed through a combination of local equity, government support and external grants. These water service providers use gravity-fed raw water piped schemes. Riparian land commands a premium price which reflects the economic potential of smallholder irrigation which further complicates the process of regulating river flows.

Water is allocated through a system of permits, but adequately fails to control abstraction since the abstraction limits are exceeded several times [3], due to lack of intensive enforcement of the water rules.

Runoff at any point in a river is contributed by runoff from the catchment area upstream of that point and discharge from groundwater bodies. Rivers and streams may be perennial, intermittent and ephemeral, [4]. Burguret River, for a long time has been a perennial but recently during severe conditions of dry season, its lower reaches dry up leaving no flows to the Ewaso Ng'iro River. This is partly attributed to the increased water abstractions in the upper reaches due to pressure of the water users to meet their horticultural developments and domestic use demands especially during the dry season, which have resulted to low flows in the lower reaches. Surface water allocation in Kenya is based on two complimentary concepts. The first relates to priority of water use and the second relates to availability of river flow. Domestic water has priority over irrigation water and the reserve flow has priority over all other uses of water [2].

1.2. Solving Conflicts within Burguret Water Users.

In Burguret sub catchment, there also exist conflicts among water users particularly the pastoralists and the crop farmers where the pastoralists in the downstream reaches can sometimes be forced to move further upstream the river where crop farming is dominant in search of pasture for their animals. The other major source of conflicts arises during low river flows when the downstream communities receive little or no water at all due to over abstraction in the upstream areas, [1]. Some of these conflicts have been partly addressed through communities forming water user's association along the river, which is Burguret Water Resource User Association, BWRUA that was formed in 1999 and registered in 2003. BWRUA is mandated to Promote: legal water abstraction; efficient, proper and sustainable water use; soil and water conservation practices within the catchment area; conservation of the water quality; dialogue between the water users and government in regard to water policy and enforcement of the Water Act; a reasonable water sharing plan of the available river flow that recognizes the priority ranking of water use; modifications to existing and new river abstractions be considered by the Association before being approved by the relevant government water boards and to provide a forum to discuss, prevent and resolve water use conflicts, [5]. BWRUA has greatly reduced these conflicts by amending the by-laws.

1.3. Objectives

1.3.1. Main Objective

Determine the effects of water abstractions on the flows of Burguret River.

1.3.2. Specific Objectives Were to

1. Identify the users of Burguret river water and its uses.
2. Determine the amount of water abstracted from Burguret River between 1995-2015 period
3. Determine which are the official and unofficial water abstractions from Burguret river
4. Predict optimal water allocation for maintaining sustainable flows in Burguret river

2. Materials and Methods

2.1. Study Area

Burguret River catchment covers an area of 209 km^2 which is 1.4% of the upper Ewaso Ng'iro Basin. The catchment has two main rivers with Burguret River being the major, the altitude of the catchment ranges from 4200m a.s.l at the upper parts to 1800m a.s.l on the lower end as it joins the Ewaso Ng'iro River, [6]. Burguret catchment lies within humid to semi-arid agro-climatic zones, it therefore experiences cool wet climate. The Figure 1 shows location of Burguret catchment within the three counties, Laikipia, Meru and Nyeri. Climate variability is determined by altitude and aspect due to its proximity to Mt. Kenya. It is located on the leeward side hence contributes to its low rainfall received. There are two rainy seasons, the long rains last from around April to June, and the short rains from September to December. The maxima's being the month of June and November respectively. Rainfall varies considerably from year to year in duration and intensity. Burguret RGS is equipped with R16 OTT type autographic water level recorder which provides information of measured river flows as daily discharge data.

2.2. Methods Used in Assessing River Water Abstractions and Quantities

2.2.1. Field Survey

Using the community study map, it was a good idea to conduct an initial reconnaissance visit in the study area with a few community members to verify features that rose in the focused group discussion. This helped in obtaining a general understanding of the state of natural resources (vegetation, soil, water), what degradation types and processes are associated with which land use types and management practices, also what are the main response measures and interventions being used, [7].

The reconnaissance visit / initial transect walk included a rapid assessment of the water resources and water users. The survey was carried out starting from the upper reaches of the Burguret river system and moving downstream to Marura swamp where the Burguret River joins Ewaso Ngiro River. The major information about these abstraction points included: geo-reference and ownership, principal water uses, water resources apportionment, authorizations and permits, description of abstraction works, peak capacities, measuring and controlling devices, abstraction quantities estimates and measurements.

2.2.2. Water Users' Interviews

Water users' interviews were conducted using a semi-structured type of questionnaire. The selection of the study samples to which the data relate was an important phase in the collection of data. Probability and convenience sampling methods were used in this study. In convenience sampling, the selection sample from the population was based on easy availability and accessibility. Probability sampling, for example random sampling involved much more preparation to avoid time and cost constraints, [8].

The two sampling methods are explained further below.

i) Convenience sampling

A closed type of questionnaire was designed for the water users. The samples (water users) along the Burguret River reach were chosen from the community water users projects which are well distributed along the river based on their location and others who were not in any water project, most of these water users occupied the downstream reach. Other interviews were with the floricultural and olericultural firms within the catchment, the hotels and Ol pejeta conservancy. This was mainly to ascertain the amount of water they abstract and their uses, it also captured their main agricultural activity and the type of abstraction works used and if there were any conflicts with regard to river water use and sharing.

ii) Random sampling

This sampling criterion was carried out for water stakeholders' within Burguret catchment. This method included focused group discussions, FGDs this comprised of the water river users association, WRUA officials and face to face interviews with water resource Authority, WRA and Laikipia wildlife forum, LWF officials on water resources, their management and any degradation to land resource components. Water resources degradation and effects of land degradation on water quantity and quality should be assessed in more depth in areas where this is reported to be a critical issue. In particular focus, the reduced water quantity / availability for consumption (human and animals) and other uses because of drought or over-exploitation of water sources, [9]. Water resources and environmental management problems often engage multiple stakeholders with conflicting interests, [10]. To achieve equitable and efficient water allocation requires the cooperation of all stakeholders in sharing water resources.

2.2.3. Methods Used to Assess the Quantities of River Abstractions

(a) Upstream and downstream flow meter readings

River flow measurements were made by use of electromagnetic flow meter reading. The flow meters were installed by Rural Focus Ltd at different points along the Burguret River. These included installation of six electromagnetic flow meters of which five were installed at community water projects and one at Tambuzi farm. The flow meter data were read manually for three water projects (Mureru, Burguret and Kamangura) that were still functional. The electromagnetic flow meters at Gatune and NGK failed to transmit any data and therefore normal manual meters were used to collect daily flow measurement. Tambuzi electromagnetic flow meter worked for quite a good period of time but also failed and at the time of study data collection it was not working, the manual meter hence was used to collect data of daily flow measurements.

b) Demand Based Estimation

Where abstractions quantity measurement was not possible especially for the small abstraction points, where a double gauging for instance did not yield dependable results, or where pumping information was not available, an estimate based on the demand was used. This involved the collection of information on the pump used for the system and using this information to determine the operating pumping capacity for the system. Additionally, the operating time table was collected to determine the daily hours of operation and the two used to compute an average rate of abstraction. Table 2 below adopted from the fact sheet, was therefore used in estimating the abstraction quantities for majority of small scale farmers and domestic uses.

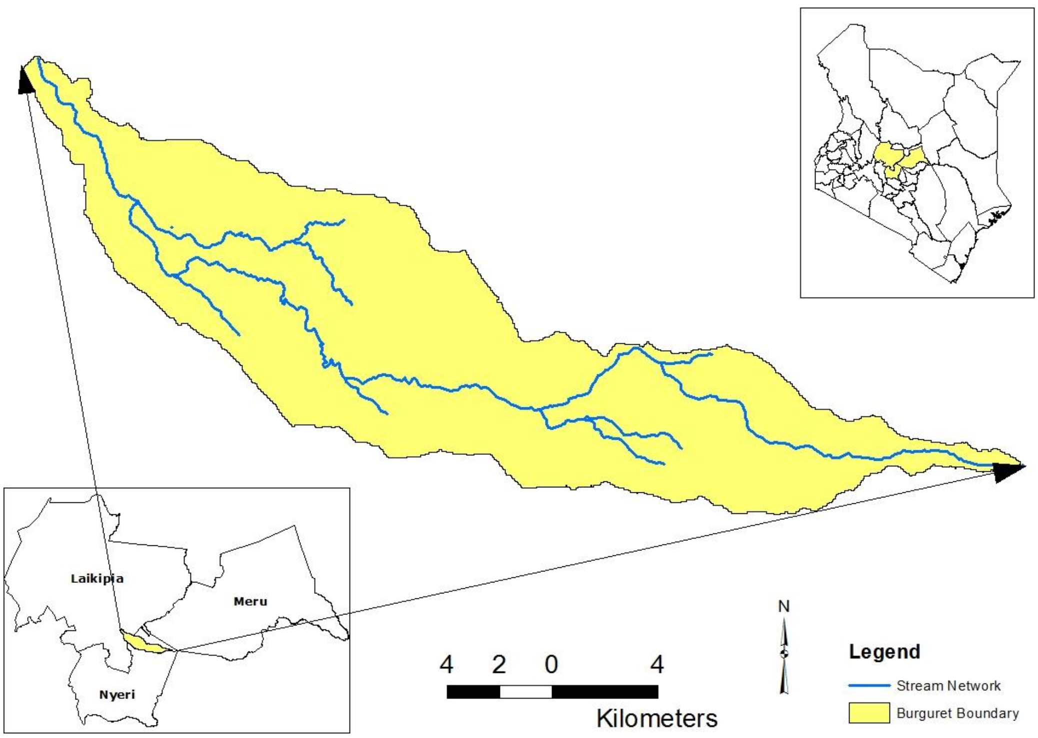


Figure 1. Map showing the location of Burguret River Catchment

Table 2. Class B PVC flows

Pipe size mm	Wall thick mm	Flow diameter mm	Max pressure m	Flow area m^2	Average flow l/s	Average flow m^3/hr	High flow m^3/hr
32	1.8	28.4	90	0.00063	0.63	2.28	6.84
50	1.8	46.4	60	0.00169	1.69	6.09	18.26
63	2.1	58.8	60	0.00272	2.72	9.78	29.33
75	2.4	70.2	60	0.00387	3.87	13.93	41.8
90	2.9	84.2	60	0.00557	5.57	20.05	60.14
110	3.5	103.0	60	0.00833	8.33	30.00	89.99
280	7.6	264.8	60	0.05507	55.07	198.26	594.77

2.3. Developing Flow Duration Curves, FDCs

FDC illustrates the percentage of time a flow occurred during a given period of record and provides important information with regard to flow characteristics of a river in an easy-to-understand format. In this context, FDCs are used quantify the flood flow, normal flow and reserve flows for irrigation, domestic and other commercial uses. The FDC was constructed by compiling the daily stream flow data for sufficient period of time record and percentiles computed using Excel function.

The naturalized FDC was computed from the observed discharge data at RGS 5BC6 for the period 1995 to 2000 when abstractions were significantly lower than today using Mike Hydro model. Mike Hydro model was run without the abstraction time series in place to generate the naturalized flow conditions for Burguret catchment, [11]. Naturalization was done in order to get a better understanding of river water availability, if there were not abstractions, [12]. This means that the effects of river water abstractions are discounted against the measured values to provide an insight into what would have been available were river water abstractions not being carried out. Measured river flows define the residual river water amounts after the effects of human use and abstraction. FDCs are highly dependent on temporal references chosen for analysis, daily discharges are mostly used in flow duration analysis but longer discharge intervals, weeks or months could be used to simplify the generation of a flow duration curve, [13,14].

The length and timing of the period of record used can also alter a flow duration curve drastically. Longer periods provide better representation of temporally averaged conditions within the catchment. If shorter periods are used, extreme climatic conditions such as much wetter or much drier than the averaged conditions can influence the results and consequently the applicability of a flow duration curve to a typical year, [15]. For this reason, it is good to construct multiple flow duration curves representing shorter periods and compare the results so as to establish an appropriate range of the flow duration curve. Table 3 below gives description of terminologies related to FDCs.

Table 3. Terminologies related to flow duration curves

	Description of flow (m^3/s)
Q10 (the 90 percentile flow)	The flow which was equaled or exceeded for 10% of the specified time
Q50 (the 50 percentile flow)	The flow which was equaled or exceeded 50% of the flow record
Q80 (the 20 percentile flow)	The flow which was equaled or exceeded for 80% of the flow record
Q95 (the 5 percentile flow)	The flow which was equaled or exceed for 95% of flow record

2.4. Predicting Optimal Flows and Allocations Using Mike Hydro model

Mike Hydro model software developed by Danish Hydraulic Institute, DHI is a multi-purpose, GIS-based river basin simulation package designed for analyzing water sharing problems and environmental issues at international, national and project scale. It builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The very user-friendly interface and the ability to quickly built models makes Mike Hydro suitable for quick policy oriented water resources planning at basin or sub-basin scale. Mike Hydro incorporates many multisectoral water demands such as domestic water supply, industrial water supply, irrigation, and hydropower generation, [11].

Mike Hydro represents the river basin mathematically. It contains the configuration of tributaries and main rivers, hydrology of the basin with respect to space and time, and various water demands. It provides a basin-wide representation of water availability, water rights, reservoirs, and transfer or diversion schemes. During dry periods when the river flow is low conflicts arises on how to distribute water available among the water users. Mike Hydro solves this problem by setting up priorities rules on a local or global scale with different priority levels, [11]. A set of rules that defines how the available water is allocated in case of water shortage is required. Two different options are available:

Supply by priority: Each of the Water users is getting their demand fulfilled in order of priority, i.e. each water user is assigned a priority and the demands will be fulfilled according to the assigned priorities and **Supply by fraction of flow**: Each Water user is assigned a fraction of the available water at the priority node. The sum of the assigned fractions must be equal to one.

In this study, supply by priority rule was chosen, the mode of assigning the priority was based on the type of abstraction works. In the downstream flow abstraction works, the design and operation of the abstraction works ensures that in the event of every low river flows, the downstream release gets the first priority over the abstraction flow. The remaining water resource that could be allocated was then shared by fraction by the upstream water users.

2.4.1. Mike Hydro Model Set up

The model set up in Mike Hydro software involved five steps, these were data preparation, catchment and sub catchment discretization, nodes and chainage definition, calibration and validation of the model and environmental water requirement based on the chosen scenarios.

Mike Hydro model was set by first uploading the DEM for Burguret catchment, the DEM had to be set to ASCII format which is the acceptable file format for MH model. Creating of ASCII was done using ArcGIS software. The rivers and catchments present in the uploaded DEM were then easily traced. The transparency of the river which is hidden in the DEM was adjusted to make it visible. The water users were then added based on their locations as per the GPS points of the water intake points and supply chainage added as per the location of water use. The river nodes and chainage shapefile was created in ArcGIS and imported to Mike Hydro model using the import shapefile option. The time series in .dfs0 format were then added onto the model.

Calibration and validation was done using the Mike Hydro NAM model by adjusting the nine parameters available for calibration of the rainfall runoff model. These parameters are described in the Table 4 below.

2.4.2. Model Input Requirements

The basic data requirements for the MH model consist of;

- Catchment parameters; this comprised of catchment area and name
- Initial conditions; this was based on the nine NAM parameters, these were adjusted during calibration
- Meteorological data; the basic meteorological data used was rainfall and evaporation time series and from 1995 to 2015.
- Stream flow data for model calibration and validation; the period of data from 1995 to 2000 for calibration and 2001 to 2004 for validation was used.
- Water users time series on the amount of water they abstract daily

In order to obtain a successful calibration, it was necessary to formulate numerical performance measures that reflect the calibration objectives, [16]. This was done by considering the calibration problem in a multi-objective where two different objective functions are considered, these were goodness of water balance and overall goodness agreement of shape of the hydrograph measured by relative volume error and Nash-Sutcliffe coefficient respectively.

2.5. Data Used

2.5.1. Digital Elevation Model, DEM

Digital Elevation Models play an important role in generating topographic parameters such as slope, drainage network and catchment area, a DEM with a resolution of 30m obtained from the Shuttle Radar Topography Mission (SRTM) dataset was used to represent topography, slope and catchment area in this study. Figure 2 shows this illustration and Table 6 the hydro-meteorological stations and RGS within Burguret catchment.

The time period used for the study was carefully chosen such that the missing data was significantly minimal.

Table 4. NAM model parameters

Parameter	Units	Description	Effects
Umax	mm	Maximum water content in surface storage	Overland flow, infiltration, evapotranspiration interflow
L_{max}	mm	Maximum water content in lower zone/root storage	Overland flow, infiltration, evapotranspiration, base flow
C_{QOF}	-	Overland flow coefficient	Volume of overland flow and infiltration
C_{KIF}	h	Interflow drainage constant	Drainage of surface storage as interflow
TOF	-	Overland flow threshold	Soil moisture demand that must be satisfied for overland flow to occur
TIF	-	Interflow threshold	Soil moisture demand that must be satisfied for interflow to occur
TG	-	Groundwater recharge threshold	Soil moisture demand that must be satisfied for groundwater recharge to occur
CK 1	h	Timing constant for overland flow	Routing overland flow along catchment slopes and channels
CK 2	h	Timing constant for interflow	Routing interflow along catchment slopes
CK_{BF}	h	Timing constant for base flow	Routing recharge through linear groundwater recharge

Table 5. Input data requirement for NAM Model

Variable	Type	Unit	TS Type
Daily Discharge	Discharge	m^3/s	Instantaneous
Daily Rainfall	Rainfall	mm	Step accumulated
Daily Evaporation	Evaporation	mm	Step accumulated

Table 6. Hydro-meteorological stations and RGS within Burguret River catchment

Stations	Altitude (m)	Longitude (S)	Latitude (E)
Burguret RGS	1932	0°06’41.84’’	37°02’17.40’’
Naro Moru Met station	3053	0°10’13.23’’	37°12’48.47’’
Munyaka Met station	2065	0°10’59.68’’	37°03’34.50’’
Matanya Met station	1843	0°03’54.82’’	36°57’20.28’’

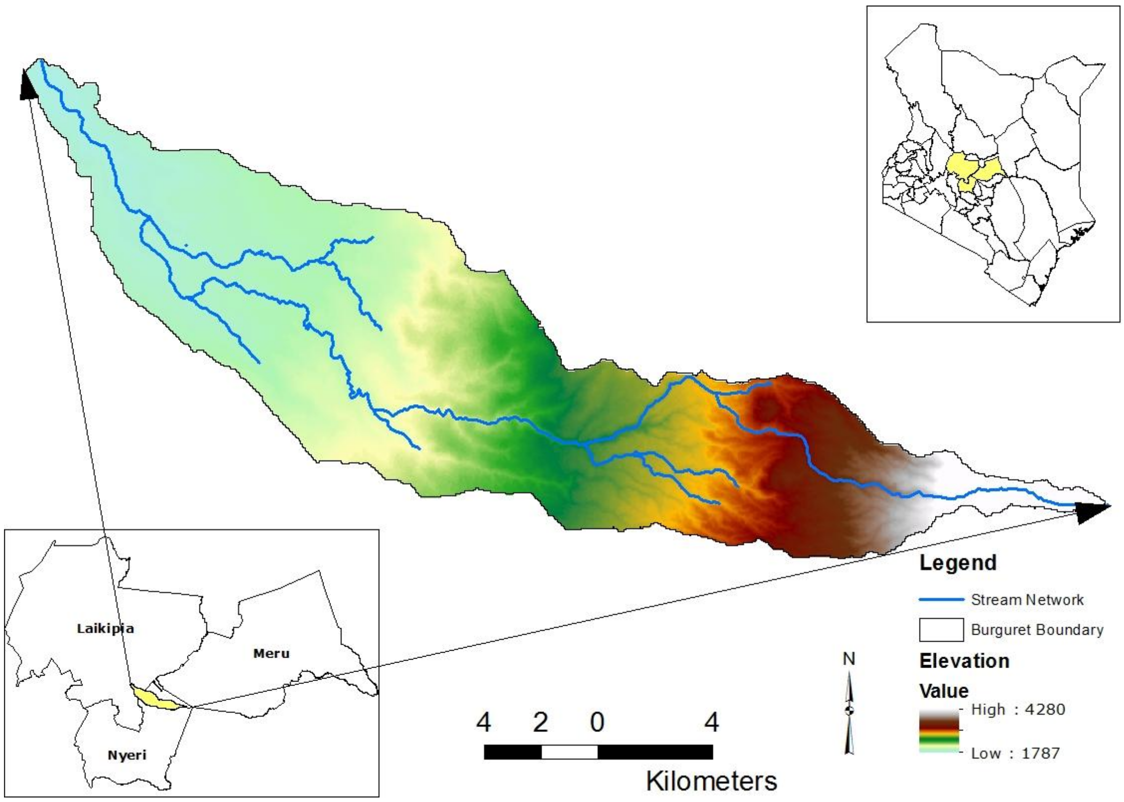


Figure 2. Digital Elevation Model for Burguret Catchment

2.5.2. Population Data

Population data was obtained from the KNBS for 1999 and 2009 Census,

2.5.3. Water Permits

The water permits data was obtained from the water resource authority, WRA office in Nanyuki.

2.6. Data Analysis

Data Analysis for Burguret sub catchment was carried out to identify the missing data and its percentage, appendix 1 illustrates the data findings. The period for simulation was carefully chosen to ensure minimal data gaps existed.

3. Results and Discussion

3.1. Water Abstraction on Burguret River

The density of the abstraction points is seen to increase towards the lower reaches. This is attributed to the land use system and majority uses portable pumps. The upper parts are predominantly forested while the lower parts are smallholder parcels under cultivation. Although the river is perennial, over-abstractions leads to drying up of the lower reach during the driest months of February and March, and under extreme conditions from July to September. Dependence on the Burguret river water extends beyond the catchment boundaries, such coverage currently stands at 19.2 Km^2 shared between three community water projects, [17]. There are six community water projects within the Burguret catchment: Gatune, Njoguini Gitero Kabati (NGK), Mureru, Burguret, Kamangura and Mkumbune.

3.1.1. Users of Burguret River Water Abstractions

The six community water projects are the major water abstractors in Burguret River, the overall goal of these community water projects is to supply domestic, livestock and small-scale irrigation water to households. The projects are mainly gravity supply schemes and most of the intake points are located in the forested area. Most of the beneficiaries of these water projects are the communities close to the upstream reaches of the river where this water is available and at the same time the gradient is high enough to allow good gravity flow of the water.

Old records, [18] show that Burguret River abstractions amounted to approximately 21,000 m^3/day or up to 98% of the natural dry season river flows. Six out of 112 abstractors accounted for 82% of the total abstracted volume, with the balance abstracted by 106 small abstractions made up primarily of portable pumps, [19]. The most recent list of abstractors on Burguret River as compiled by water resource authority, WRA 2012 and [2] were 72 and 133 respectively. This study assessed abstractions based on data collected in 2015 and found a total of 177 abstractors. The river water abstraction is currently under heavy pressure due to increasing human and livestock population as well as rapid horticultural development leading to increasing abstractions to meet irrigation demand. Increasing scarcity, high variability in time and space and inadequate access of river water during low flows has been cited as current water problems in the catchment.

Figure 3 shows Burguret major abstractions, small scale abstractions have been grouped and indicated to be located at the downstream reach.

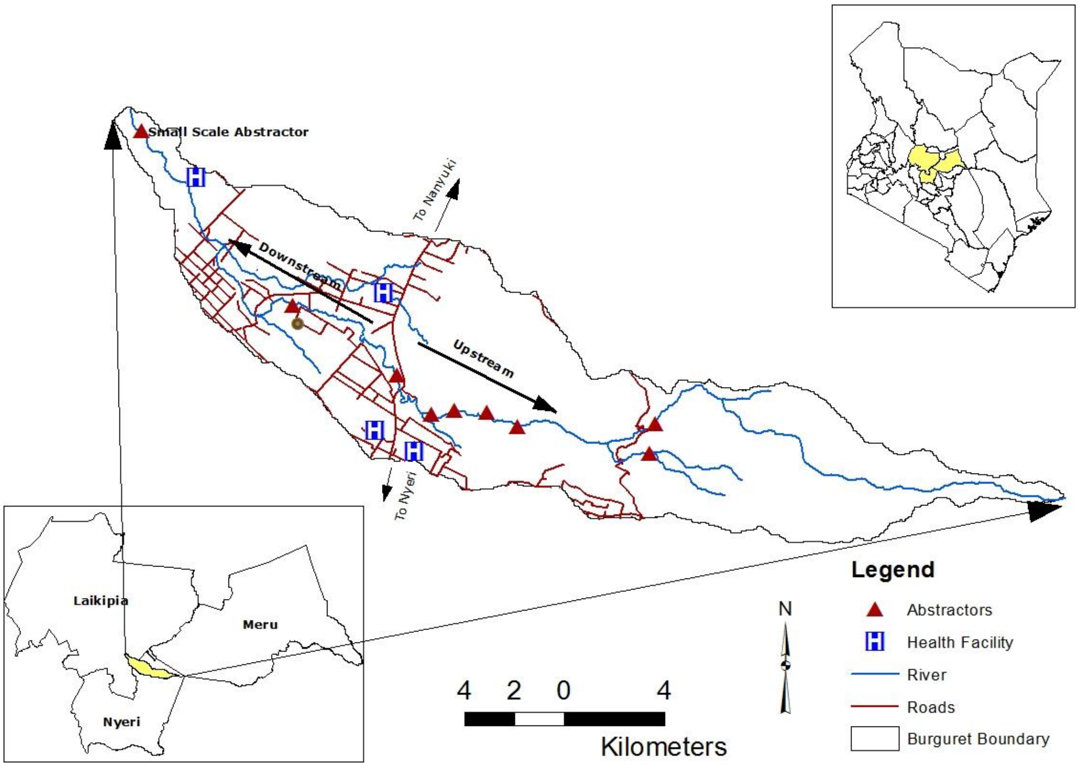


Figure 3. Map of Burguret Abstractions showing major abstractors and Centre's

This study identified 177 abstractors on Burguret River, ten being major abstractors while 167 small scale abstractors. The amount of water abstracted by small scale abstractors was mainly for domestic use and small scale irrigation purposes. Majority of these abstractors used portable pumps, their monitoring of water abstracted involved inquiring the average number of hours which the users would be operating the portable pumps during field visit and the amount abstracted estimated based on the pipe diameter used, time and the flows given in the adopted fact sheet table. Table 7 shows the resulting amount of water abstracted by the small scale abstractions.

3.1.2. Abstraction Monitoring

Table 8 indicates that the reliability of GSM data from the meters was in general not acceptable with only Kamangura, Burguret, Mureru and Tambuzi providing an acceptable level of reliability. Gatune and NGK did not embrace the electromagnetic flow meters as they were very accurate and the volumes abstracted were way above the permitted allocations hence the conflicts of more upstream abstractions that led to almost no flows at the downstream reach during low flows.

Table 7. Small Scale Abstractors

Pipe metric size (mm)	No. of abstractors	Average flow m^3/hr.	No. of hours used/day	Water abstracted m^3/day
25	1	2.28	1	2.28
40	107	6.09	2	1,303.26
50	49	9.78	2	958.44
65	7	13.93	3	292.53
80	2	20.05	2	80.20
100	1	30.00	2	60.00
Total	167			**2,696.71**

Table 8. Large Scale Abstractors

Abstractor	Basis for estimation	Water abstracted, m^3/day	Use
Burguret WP	GSM Meter	1,586	Domestic and subsistence irrigation
Mureru WP	GSM Meter	1,982	Domestic and subsistence irrigation
Kamangura WP	GSM Meter	1,244	Domestic and subsistence irrigation
NGK WP	Manual Meter	3,568	Domestic and subsistence irrigation
Gatune WP	Manual Meter	2,180	Domestic and subsistence irrigation
Tambuzi	Manual Meter	950	Commercial irrigation
AAA Growers	Manual Meter	1,784	Commercial irrigation
Mkumbune WP	Manual Meter	954	Domestic only
Mutuma	Pipe size	120	Domestic and commercial agriculture
Bantu hotel	Pipe size	130	Domestic and recreation
Total (10)		**14,502**	

WP-water project.

The 177 abstraction points abstract a total amount of 17,199 m^3 water per day. Distribution of water abstraction volumes among the existing abstraction points varies with the type of abstraction works as well as the intended use. This distribution has a high significance in terms of management requirements. A fairly uniform distribution means that the abstraction points should receive fairly equal attention in their management such us controlling and monitoring. A skewed distribution suggests that more attention should be given to those that are contributing more to the total abstractions.

3.1.3. Abstractors Holding Valid Permits

It was found that only 11 abstractors have their permits and authorized to abstract water from Burguret river as per the volumes shown on their permit as shown in Table 9 below. Majority of these abstractors are the community water projects, WP. (Table 9)

3.1.4. Abstractions Whose Permits were not Available

Allocation of water for irrigation is from flood flow which is defined by WRA to be flow that is exceeded 80% of the time, referred to as the Q80. The naturalized Q80 value for 5BC06 was to be 21,953 $m^{3/}$day. Table 10 shows the over abstracted water amounts.

The results (Table 10) demonstrate that abstraction rates are independent of the state of flow in the river. The results of no over abstraction recorded in medium scale abstractors illustrates that they adhere to the water abstraction rules, for the flower firm it has a dam to store its water during food flows while the fish firm returns all of its water to the river after use. The hotel within this category also can serve its population with allocated water and the water project has majority of its users with household metered connections which ensures great monitoring of water use. For the other water projects, the general condition is that abstraction operates at a fairly constant rate which is above the approved domestic allocation, regardless of whether the river flow drops below the Q80 discharge value.

For the water projects, over-abstraction in excess of the authorized volume for domestic use takes place on at least 95% of the low flow days. The over-abstracted amount is low for projects with large authorized domestic allocations and very high for projects with low domestic allocations due to their proximity to water through gravity fed pipes intake location. This essentially demonstrates that the permitting system is ineffective as a means to control abstraction. If water allocations and the permitting system are tools to minimize water use conflicts, then a more practical and effective approach is required. This study proposes water allocation framework that prioritizes the downstream water users be allocated first and the remaining upstream water users be given a fraction of the remaining amount of water available for allocation. This water sharing and allocation was done using Mike hydro model as shown in the next section.

Further to this, WRA should increase monitoring and enforcement activities to reduce over abstractions.

3.2. Burguret River Flows

Burguret River provides a continuous discharge throughout the year which is seen to be sustained as a result of a densely forested catchment as compared to adjacent catchments such as the Naro Moru which dries up during critically dry times. The stream flow for Burguret is given by the general hydrograph as shown in the Figure 4 below.

The average discharge for this period was found to be 0.62 m^3/s, this was the annual average flow available for Burguret river for the 20 years of the data collected.

3.2.1. Flow Duration Curves

Two indicators of river water discharge measurement were developed, these are the measured flow, which comprises of the discharges passing the point of measurement as determined from the gauge height records and the rating equations and the estimated natural flow through the gauging station. This natural flow is an indicator of what would be the expected flow if there were no human activities resulting in abstractions and use. It signifies the quantity of resource available for planning purposes. Therefore, it is the river flows adjusted to take into account the net abstractions and discharges upstream of the gauging station. The resulting naturalized and observed FDCs are shown in the Figure 5 below.

Table 9. Authorized water allocations for Burguret users

Abstractor Category	SW abstraction, m-3day	Applicants	Quantity of water, m-3day	Population served	Domestic	Irrigation
Small scale	50 - 500	3 WP	1,124	14,461	917	207
Medium scale	500 - 5000	Hotel, 1 WP, flower and fish firms	3,087	6,333	1,262	1,825
Large scale	> 5000	3 WP	14,973	9,135	1,905	13,068

SW-surface water, WP-water projects.

Table 10. Proportion of non-permitted abstractions for Burguret users

Abstractor Category	Applicants	Over abstracted amount, m-3day	Quantity of water, m-3day	Population served	Domestic	Irrigation
Small scale	3 WP	1,988	1,124	14,461	917	207
Medium scale	Hotel, 1 WP, flower and fish firms	Nil	3,087	6,333	1,262	1,825
Large scale	3 WP	3,517	14,973	9,135	1,905	13,068

WP-water projects.

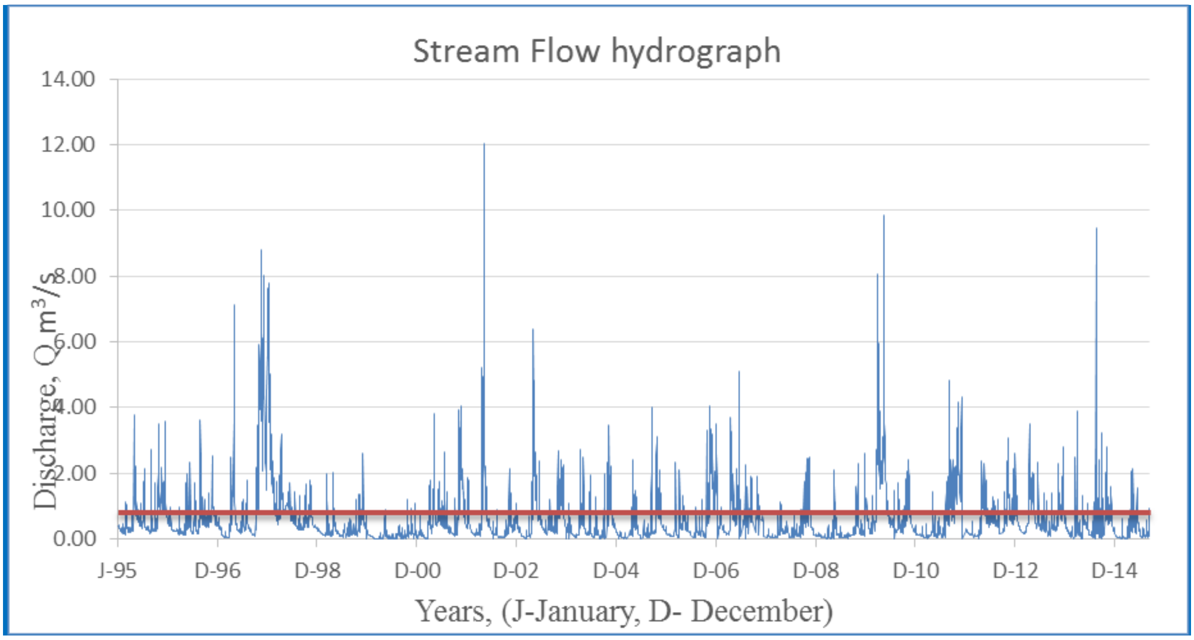


Figure 4. Observed Stream Flow Hydrograph at RGS 5BC6 with daily flow (blue) and mean flow (red)

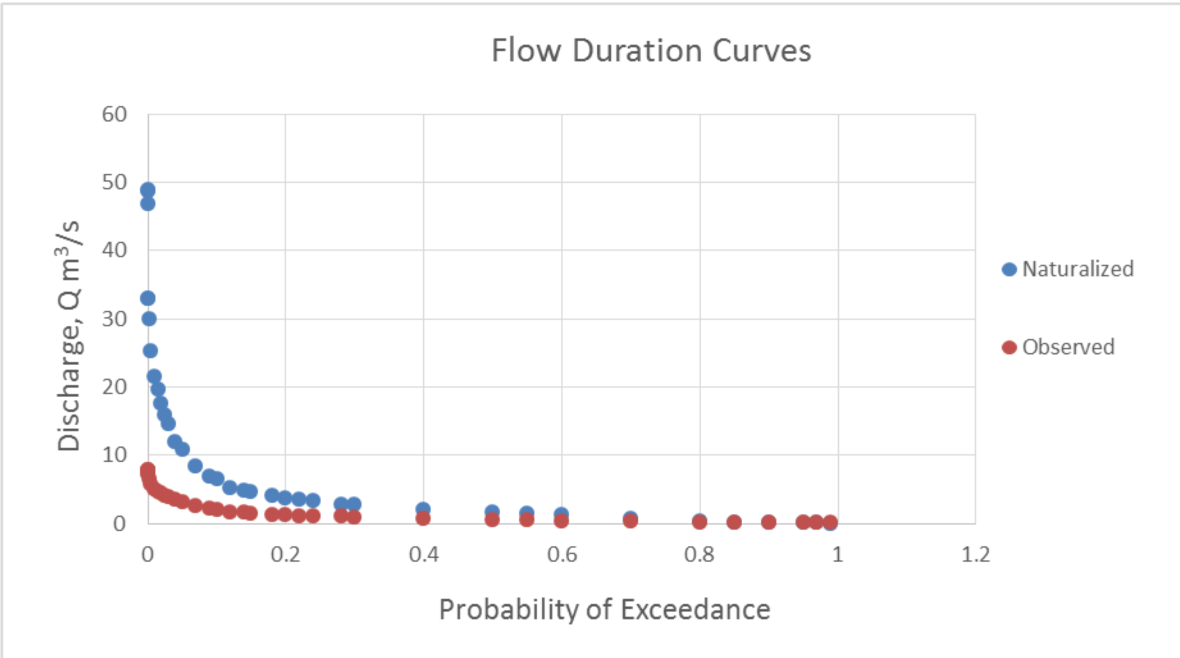


Figure 5. Flow duration curves

Flow rates between Q0 and Q10 are considered high flow rates, and Q0 to Q1 would be extreme flood events. Flows from Q10 to Q70 are considered 'medium' range of flows. Water Users can still abstract as much water as they need provided they have storage facilities. Flow rates from Q70 to Q100 are the 'low flows' and it is at this point that allocating the scarce water resource become difficult as this also happens during dry season. Each and every water user ought to adhere to the water allocation framework for the water users from the same river so as to avoid more conflicts amongst the water users. As flow rates move from Q95 towards Q100 this becomes the low-flow draught flows. Q95 values should hence be used with caution in view of the problems associated with both the measurement of very low discharges and the increasing proportional variability between the natural flow and the net impact of artificial influences, such as abstractions, discharges and storage changes as the river flow diminishes.

Table 11 shows the status quo of Burguret river, the abstraction of the water resource takes place especially during low flow season and it amounts to 17,199 m^3 /day in total as shown in the previous section of abstraction assessment. This clearly indicates that Burguret river doesn't meet the water demand need for all water users in the catchment during dry season despite its capability to supply the water and also satisfy the permitted water demand.

In the following section, Mike Hydro model is used to generate the best options for equitable water sharing among the users within the catchment considering Burguret river water abstractions demand and river supply.

Table 11. Water Resource available for allocation for Burguret river

Exceedance probability	Flow condition	Naturalized flow, m^3/s	Supply, $m^{-3}day$	Observed flow, m^3/s	Supply, $m^{-3}day$	Authorized Demand, $m^{-3}day$
Q_{95}	Reserve	0.0566	4,925	0.0478	4,147	
Q_{80}	Normal flow	0.3107	26,870	0.125	10,800	
Q_{50}	Flood flow	1.6944		0.5598		
$Q_{80} – Q_{95}$	Domestic use	0.2541	21,954	0.0772	6,670	3,554.64
$Q_{50} – Q_{80}$	Irrigation use	1.3837	119,578	0.4348	37,584	15,100

3.3. Burguret River Water Allocation Using Mike Hydro Model

The river nodes and tributaries to Burguret were created to form the river network and chainage required in setting the MH model, this was done using the ArcGIS and the shapefile imported on the Mike Hydro model, [20]. The resulting feature is shown in the Figure 6 below. The Nash Sutcliffe Efficiency, R^2 was found to be 0.71 and 0.61 during calibration and validation periods respectively. Values between 0.7 and 0.8 indicate that the model performs reasonably. Values between 0.8 and 0.9 tell that the model performs well and values between 0.9 and 1 indicate that the model performs extremely well, [21]. Therefore, in this study the coefficient of determinant shows that the model performed reasonably which was a good measure to proceed and test the model with other parameters for a period of four years, (2001-2004), which was different from the calibration period. The result being above average means that the model was good enough to be used in running scenario simulation for Burguret.

The major abstractors were then added to the Mike Hydro model setup following the method outlined in the methodology. The figure below shows the resulting model setup with major water users abstracting water in Burguret River.

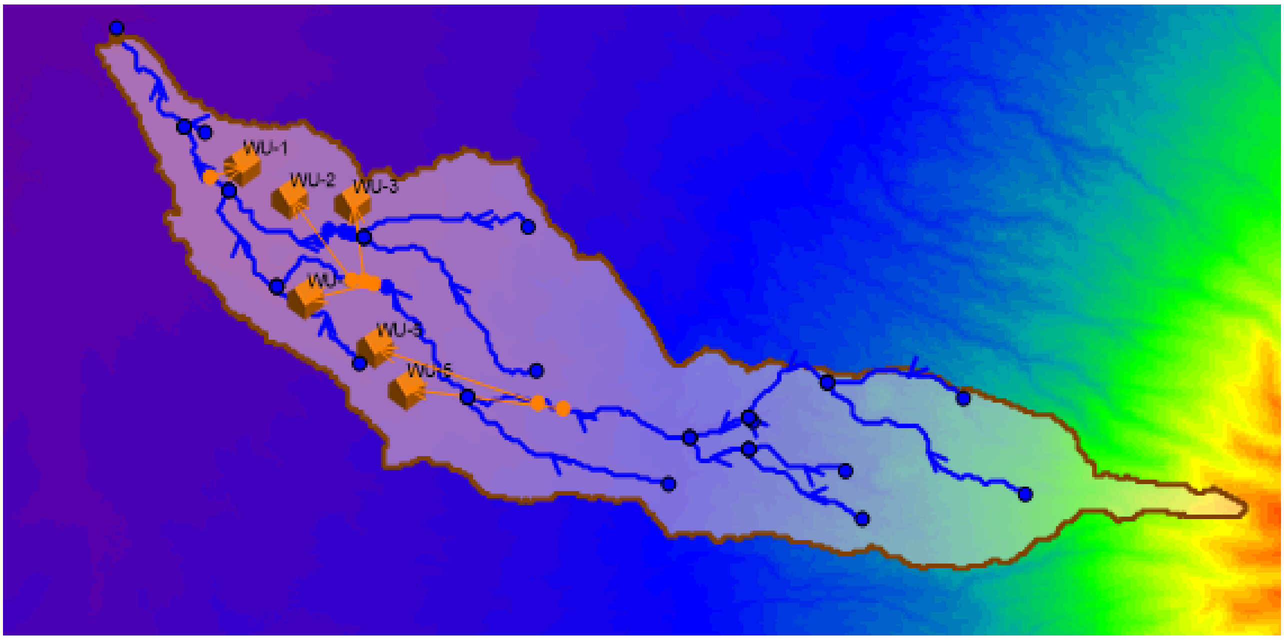
This is the Burguret main river in which simulation runs were based on. The Environmental Water Requirement, EWR was used as the indicator of allocation. The EWR was assessed based on the following three scenarios. The MH Model was set with all time series in dfs.0 format uploaded and run to simulate the flows at the abstraction points (nodes).

i) Scenario one: When there is no abstraction

This yielded the naturalized flows at all the abstraction points from which the EWR were determined based on the Q95 flow indices, the focus was on the EWR (Q95) at the river outlet. Figure 7 illustrates the resulting hydrograph of this scenario.

ii) Scenario two: When all abstractors are operational

This yielded the observed flows of the catchment when all the abstractions were operational. The simulated naturalized and observed flows differ greatly in that observed presented very low flows making it difficult for downstream water users to receive good flows during dry period. The resulting hydrographs of these scenario is shown in Figure 8.



Key
WU-1-Small Scale Abstractors
WU-4-Mureru water project users
WU-2-Burguret water project users
WU-5-NGK water project users
WU-3-Kamangura water project users
WU-6-Gatune water project users

Figure 6. Burguret River Major Abstractors

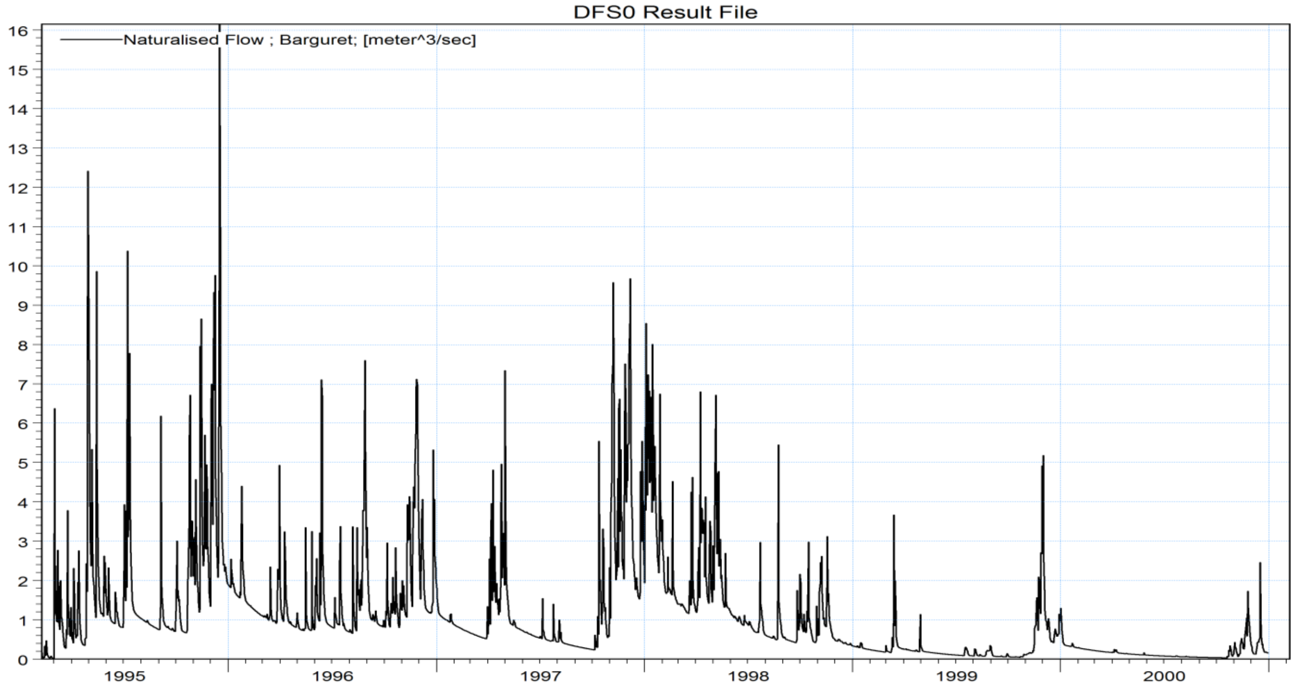


Figure 7. Naturalized flow Scenario

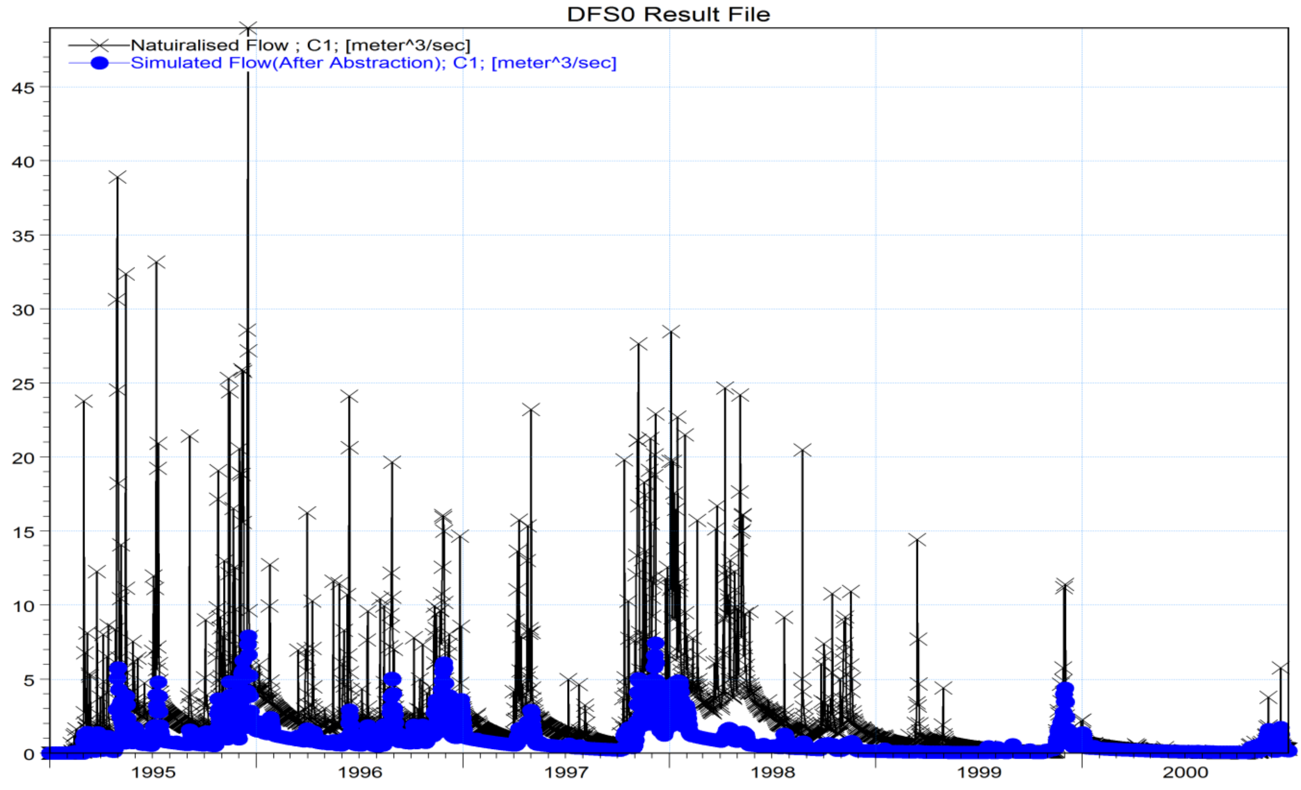


Figure 8. Naturalized and Observed flow with water abstractions in place

iii) Scenario three: When optimal options are considered

This yielded the flow after the control measures had been put in place. The control measures include the following Downstream water users were given the highest to receive water and the remaining fraction of the amount of water resource available for allocation shared by fraction among the upstream users. In this study, the small scale abstractors located at the downstream of the river reach were given the highest priority in the MH model. Despite being many their total volume of water is little compared to other abstractors. The remaining water available for allocation was shared by fraction according to their authorized amounts of water they should abstract as provided by WRA. This saw NGK and Gatune being at the upstream river reach receive very little allocation despite their huge non permitted abstractions. When all this priorities and allocation had been set, the MH model was run and the result obtained shown in Figure 9.

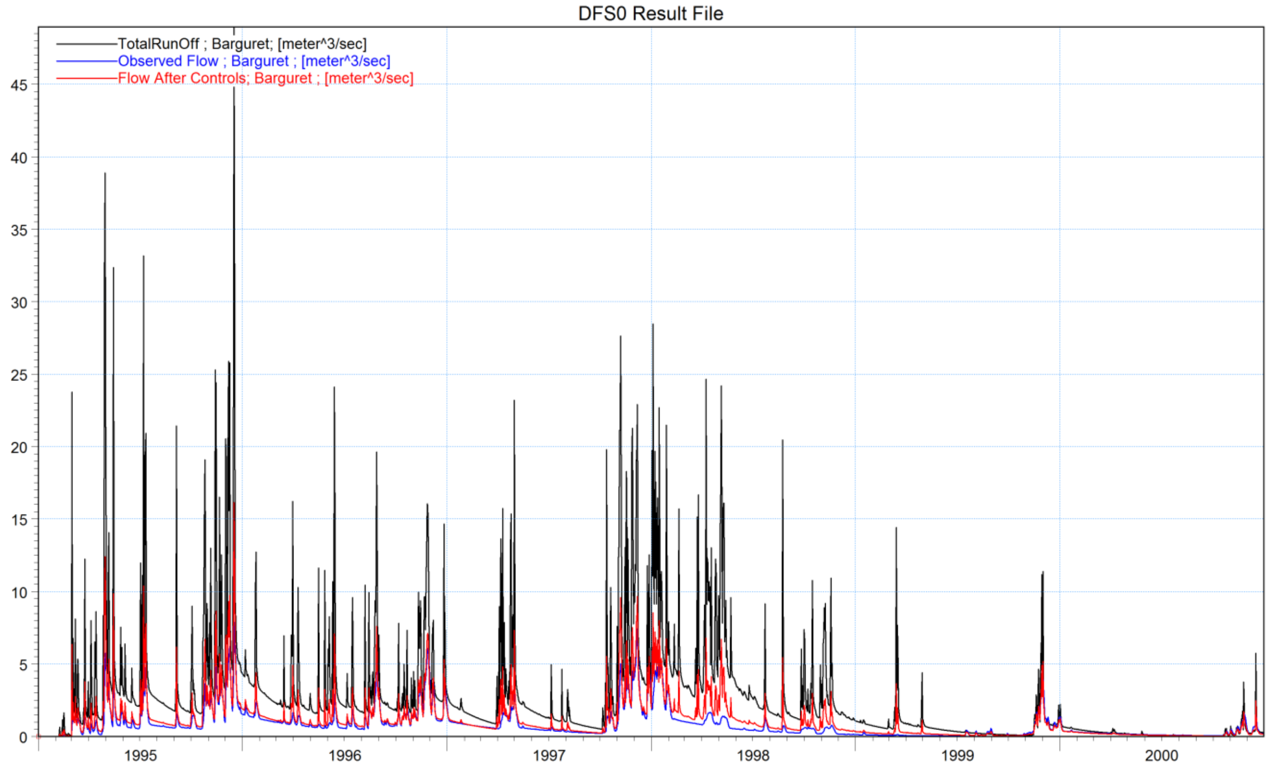


Figure 9. Flow after control measures

After all the abstractions had taken place the remaining available water resource was analyzed and used as a framework for any future allocations. The flow duration curves for all the scenarios are indicated in Figure 10.

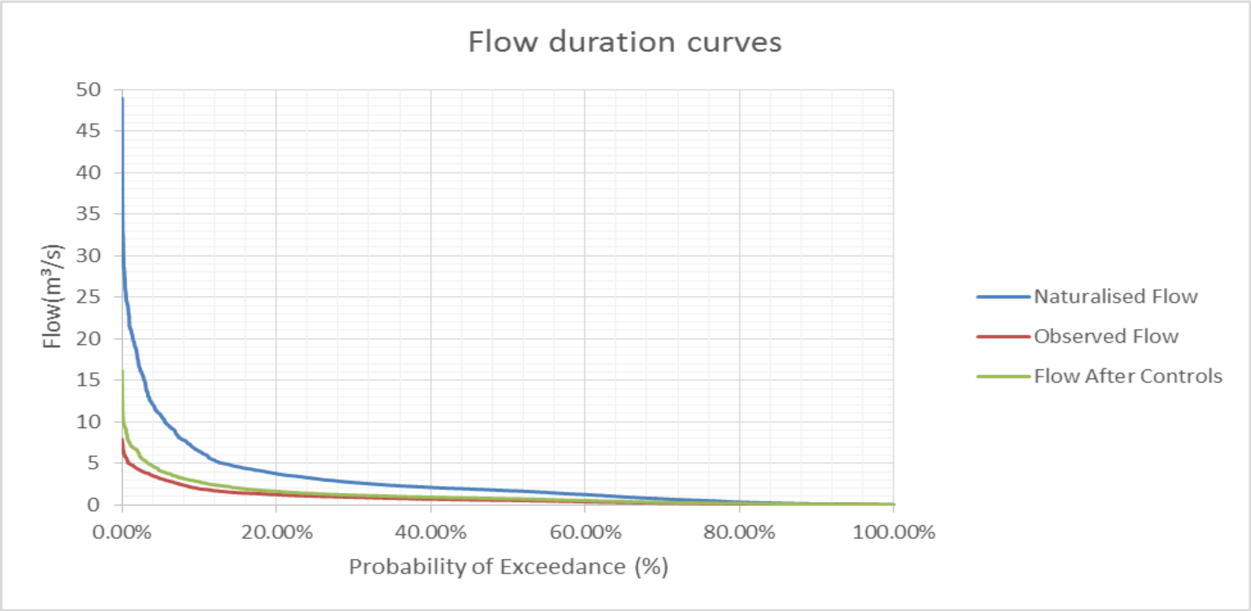


Figure 10. Flow Duration Curves after control measures

Table 12. Water Resource Available for Allocation after control measures for BRC

Exceedance probability	Naturalized m^3/s	Observed m^3/s	After Controls m^3/s	Supply, $m^{-3}day$	Flow condition
Q_{95}	0.074	0.048	0.056	4,838	Reserve
Q_{80}	0.353	0.125	0.185	15,984	Normal flow
Q_{50}	1.724	0.560	0.753	65,059	Flood flow
$Q_{80} – Q_{95}$	0.279	0.077	0.129	11, 146	Domestic use
$Q_{50} – Q_{80}$	1.371	0.435	0.568	49,075	Irrigation use

When all the control measures were taken into account, the amount of water available was seen to have increased above the observed value as shown in the Table 12.

4. Conclusions

Direct river abstractions for domestic and irrigation purposes, decreases the amount of water flowing downstream in Burguret River and has a more pronounced effect on streamflow during the dry season. The catchment had a total of 177 abstractors as at August 2015 when data collection was done for the study. Ten of this abstractors were large scale abstractors, abstracting a total of 15,502m^3/day. They comprise largely of the community water projects and the commercial firms who practice irrigation and other recreation services. The small scale abstractors were 167 situated majorly on the downstream reach of the river, abstract a total of more than 2,697m^3/day mostly using portable pumps. The river supply stood at 21,953 m^3/day and 10,800 m^3/day the Q_{80} value of naturalized and observed fdcs respectively. This clearly indicates that Burguret river doesn't meet the water demand need for all water users in the catchment during dry season despite its capability to supply the water. The study proposed that the downstream water users be given the first priority of water allocation and the remaining available water be shared by fraction among the upstream water users. This water sharing and allocation rule was achieved through use of Mike hydro model that simulated flows when this controls were in place, the predicted values saw that Burguret river could supply 15,984 m^3/day which is good enough for an allocation framework. When this sharing principle is adhered to, all of the Burguret residents will enjoy the water flows from Burguret river.

The natural flow conditions do result in extreme low flows, for example the years 1999and 2000 there was acute drought spell and can be seen in the Burguret hydrograph. Others include, most months of February/March and August/September that comprises the dry periods between long and short rainy seasons respectively. This condition may not arise from excessive abstraction, or modifications to the river hydrology due to the dams and reservoirs, but is actually a natural possibility based on rainfall patterns and catchment conditions.

Burguret River has the potential to supply its users only when the users strictly follow the rules, [22] that there can be NO abstraction of water for irrigation use during dry periods and where the water levels are below normal, Q80 values.

5. Recommendations

All downstream water users should be given the priority to satisfy their water demand and the remaining water amount from the river supply after controls be shared by fraction among the upstream water users. This sharing priority of the available water resource will ensure that downstream release and environmental flows are restored.

In as much as Burguret river water users are aware of the water use and water rules, more awareness should be done to the residents, through capacity building and enforcement, to better understand the water rules and uses. Most residents were afraid of the water administrators even when they have committed no wrong, they tend to run away at the sight of any water committee members whenever they are on site doing their duty of surveillance and monitoring.

A similar study should be carried out to determine the potential of ground water, its quality and quantity and determine how it can be well utilized to reduce overdependence on the river water use and probably lead to high productivity and profitability to the locals especially those unreached by the river water.

Acknowledgments

Danish Hydraulic Institute, DHI for availing the Mike Hydro software license.

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Appendix 1. Data Analysis

Data Item	Discharge	Rainfall			Temperature			Evaporation		
Station		1	2	3	1	2	3	1	2	3
Period	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015	1995-2015
Available data (days)	7385	6774	7541	7571	7605	7384	7589	7642	7510	7582
Missing data (days)	284	895	128	98	64	285	80	27	159	87
% missing data	3.7	11.7	1.7	1.3	0.8	3.7	1.0	0.4	2.1	1.1

1-Matanya, 2-Munyaka and 3-Naromoru hydro-meteorological stations.