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The Impacts of Water Abstraction in Tropical Rivers: A Case of South West Upper Tana Basin, Kenya.

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Abstract
The study to determine the impacts of water abstraction in South West Upper Tana Basin which is part of the larger Upper Tana basin was undertaken in four major rivers, Thika, Kimakia, Kiama and Chania. Data for this study was obtained from the Kenya Meteorological department (KMD), Water Resources Management (WRA) and questionnaire surveys. The questionnaires were administered in the period between January 2018 and December 2018 to determine the impacts of water abstraction in both dry and wet seasons. Regression and correlation analysis was used to determine the nature and strength of relationships between different variables. The results of the study indicate that the main impacts of water abstraction are hydrological, environmental and socio-economic. The hydrological impacts include reduced water levels, changes in stream morphology, decreased turbidity and reduced siltation. Socio-economic impacts include increased income from crop production and conflicts while environmental impacts were mainly changes in riparian vegetation. The study established that the best combination of impacts of water abstraction in the South West Upper Tana Basin were changes in water turbidity, decline in water levels, improved crop yields, changes in channel morphology and siltation with a coefficient correlation r of 0.57 and coefficient of determination R^2 of 0.52. To mitigate these impacts, there is a need for better enforcement of legislations on water abstraction and the monitoring of the river basins to curb water over-abstraction. Public awareness campaigns and involvement of stakeholders could also minimize these impacts.
Keywords: Water abstraction, hydrological impacts, socio-economic impacts, environmental impacts, South West Upper Tana Basin (SWUT).
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1. Introduction

Rivers are important hydrological systems of the planet earth since they support livelihoods in the planet (Manatunge et al., 2008). The distribution of these freshwater sources is, however, erratic and unreliable (Saleh et al., 2005). Thus, man has endeavored to modify them through construction of dams, diversion of waters and abstraction of water for various uses (Jim and Truls, 2005). Due to the increasing population and the need for irrigation water, water for hydroelectric power and domestic purposes, water abstraction is set to increase in the near future (Finer and Jenkins, 2012). It is estimated that over 60% of the Worlds Rivers are diverted (IWMI, 2007). Additionally, water abstraction from rivers for irrigation, industrial and domestic use has doubled in the recent past (MEA, 2005).Water abstraction for the fore mentioned uses is in some parts of the world approaching or has exceeded the amount of renewable water available (IWMI, 2007). This has resulted in hydrological modifications of most of the rivers.

The need for governments to provide adequate supply of drinking water has resulted in the construction of large water abstraction projects to supply water in large cities (Dahm et al., 2013). These projects have far reaching consequences locally and regionally. Some of the documented impacts include, emergence of large waterway networks, conversation of previously dry and unproductive lands to agriculturally productive areas and reduction in the areal extent of large lakes (Accreman et al., 2000; Beeton 2002; Helled_en and Tottrup, 2008). It is, however, important to note that, at sub-catchment level especially in Africa, the impacts of water abstraction are largely unknown. This is because very few studies have been undertaken to unravel the impacts of water abstraction in Africa.

The impacts generated by any water abstraction project depend on the type and nature of the project. For instance, large dams generate major hydrological impacts such as changes in water chemistry, changes in water turbidity, changes in channel morphology and changes in water temperature (Poff and Allan, 1995; Friedl and Wuest, 2002; Olden and Naiman 2010). These hydrological changes may impact on the riparian vegetation and the riverine biodiversity (Haxton and Findlay, 2008; Aristi et al., 2014).

In the South West Upper Tana basin, there are many low magnitude water abstractions that are necessitated by the need to provide water for rural and urban water supplies, agricultural or irrigation water, industrial and recreation purposes. Most of the water abstractors in this basin are not licensed and there is poor monitoring of the abstractions by the relevant authorities. These unregulated abstractions have brought major impacts, largely because there are no tools and strategies to address the cumulative impacts. This study seeks to unravel these impacts and recommend ways of promoting integrated water resource management in the basin. This will guide the authorities and other stakeholders in establishing a framework for sustainable water abstraction in the basin.

2. Description of the study area

2.1 Location

The study area is located in central Kenya in the counties of Muranga and Kiambu. It lies between latitudes 034' S and 1 7' S and longitudes 36 E and 37 27' E. The total surface area of the basin is 2558.8 Km2. The highest point in the basin is 2190 m above sea level while the lowest point is 1340 m above sea level (Muranga Integrated Development Plan, 2018). The main rivers in this basin (Thika, Chania, Kiama and Kimakia) originate from the West in the Aberdare Mountain ranges and flow eastwards. Chania and Thika rivers intersect at Ngethu and flow downstream as Chania River while Thika intersect with Kiama River at Gatanga and flow downstream as Thika River (Kimenju, 2018). The rivers then join at Ndururumo to form the main Thika River which flows to Tana River (Figure 2.1).

2.2 Climate

Temperature in the study area is influenced by altitude with the higher altitudes experiencing a maximum temperature of 18 C and minimum temperature of 6 C. The low altitude area experience maximum temperature of 26 C and minimum temperature of 16 C. Rainfall in the area is influenced by the relief factor of Aberdare Mountain ranges and the monsoon winds that occasionally blow from the Indian Ocean (Otieno et al., 2000). There are two rainny seasons in the area, between March and May (long rain season) and between October and December (short rain season). Each of these seasons is preceded by a dry season which is caused by the persistent North Easterly monsoons (See also Okoola, 1996; Onduru and Muchena, 2011). The highest rainfall in the study area is 1800 mm/yr (received in high altitude areas) and the lowest rainfall is 700 mm/yr (received in low altitudes) (Otieno, 2000).The area has a mean annual potential evaporation of 2300 mm in the lower altitudes and 1200 mm in the higher altitudes (Leisher, 2013).

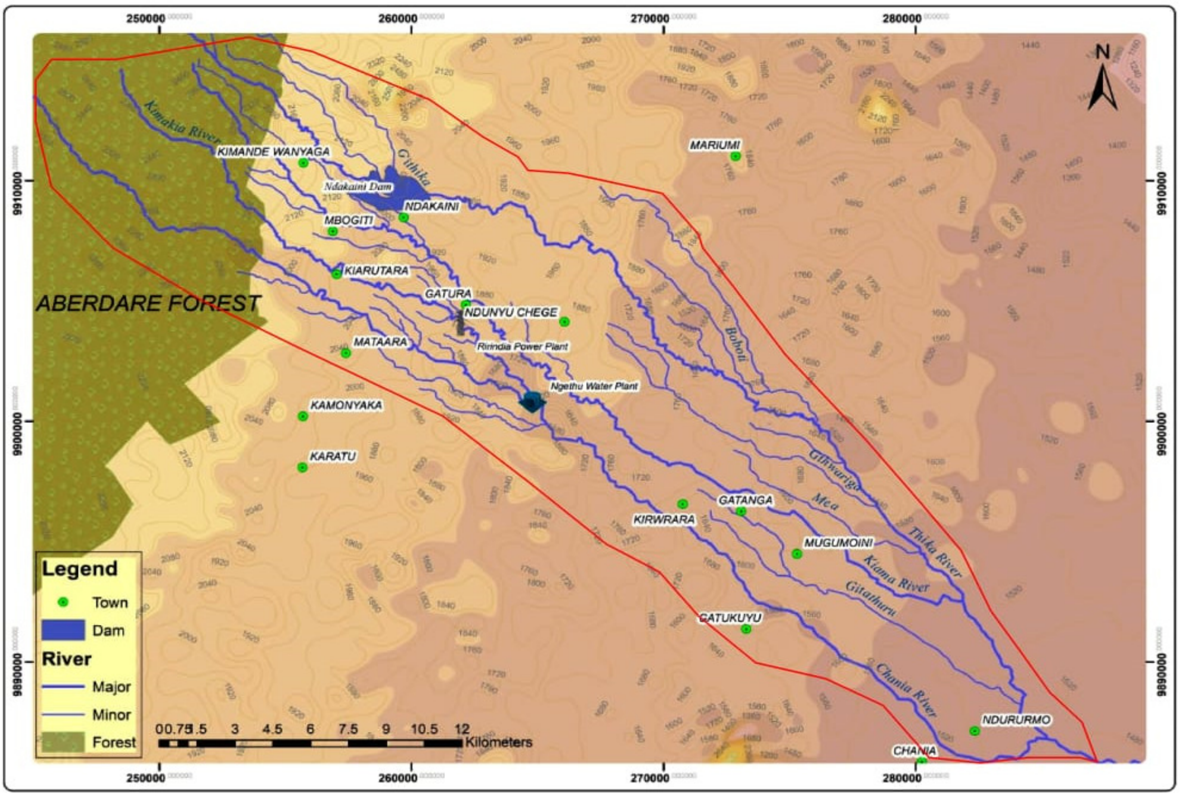

Figure 2.1: The main rivers in the SWUT basin

2.3 Soils

The main soils in SWUT basin are andosols, cambisols and nitosols. The distribution of soils in the area is influenced by altitude and rainfall. In the high altitude areas, above 1800 m asl, soils are dark in colour because they have high quantities of organic matter. In the low altitude areas, below 1800 m asl, rainfall has great influence on the soils. For instance, areas that receive high amounts of rainfall have red soils with some traces of clay (Athi Water Services Board, 2014).

2.4 Geology
The geology of the study is characterized by a rock basement system of the Achean type (AWSB, 2014). Volcanic rocks of the pleicestone age dominate the Aberdare region which on the western part of the study area (Kimenju, 2018). On the eastern side, the basement system is found while on the southern side, rock outcrops of the pre-cambrian rocks are found (Leisher et al., 2016).

2.5 Population
Population of the SWUT basin is estimated to be 163, 597(KNBS, 2010). The female population of 82,610 is higher than the male population of 80,987. This is so because most men migrate to the nearby urban centers to seek for employment. The area has a population density of 276 persons /Km^2 (MCIDP, 2018). The western parts have the lowest population density since most of the area is forested and protected land.

2.6 Socioeconomic activities
60% of the people in the study area are farmers (MCIDP, 2018).Tea and coffees are the main cash crops grown in the area (TNC, 2015). However, the production of coffee has dwindled over the last few years due to emergence of more profitable horticultural crops and real estate business (Kitheka et al., 2019). Food crops such as cabbages, bananas, potatoes, tomatoes and pineapples are also grown. Dairy, beef and pig farming is also widespread in the basin (Agwata, 2006). Forestry and wildlife is practiced in the upper parts of the study area in Kieni, Gatare, Kimakia and Aberdare forests (Agwata, 2006). There are also small urban centres and markets such as Kirwara, Gatura, Gatunyu and Kangari.

3. Methodology
3.1 Water abstraction data
Field based measurements were used to obtain water abstraction data in the study area. The study area was sub-divided into four (4) transects which were defined by the four major rivers (Kiama, Kimakia, Chania and Thika). For each transect, a total of 25 households were randomly selected and a questionnaire administered to make the total of questionnaires used to be 100. This was repeated daily for a period of 12 months (January 2018 to December 2018). The data collected enabled for the calculation of daily, monthly and annual water abstraction rates. The mean monthly abstraction rates were calculated as follows;

$\bar{Q}_{abs(m)} = \sum_{i=1}^{i} Q_{abs(d)}$ ……………………………………………………………equation 1

Where $\bar{Q}_{abs(m)}$ is the total monthly water abstraction rate (in litres) and $Q_{abs(d)}$ is the daily water abstraction rate. The annual water abstraction rate is the sum of the monthly water abstraction rates $\bar{Q}_{abs(m)}$ calculated as follows;

$\bar{Q}_{abs\ (a)} = \sum_{i=1}^{i} \bar{Q}_{abs(m)}$ …………………………………………………………equation 2

Secondary data was also obtained from Water Resources Authority (WRA) archives.

3.2 River discharge data and water level
River discharge data was obtained from the Water Resources Authority (WRA) for river gauging stations RGS 4CA15, RGS 4CB5 and RGS 4CA19. This enabled the study to determine the changes that have occurred as a result of water abstraction in the rivers. Water level measurements were taken daily for a period of 12 (twelve) months. This allowed the study to note the changes in water level in each month of the year.

3.3 Water quality data
The parameters used to describe water quality in this study were turbidity, siltation and nutrient level concentrations. This data was obtained from WRA archives. To determine the relationship between turbidity, siltation and nutrient level concentrations and water abstraction, regression curves were plotted.

3.4 Determination of sample size
Population for this study included households that abstract water from the four rivers in SWUT basin. The sample size was determined as follows;

$n = \frac{z^2 pq}{e^2}$……………………………………………………equation 3

Where;

N is the sample size, P is the estimated proportion of an attribute present in the population (0.5),q is 1-p, z^2 is abscissa of the normal curve that cuts off an area α at the tails (value of z obtained from the statistical table). This yielded a sample size of 96.04 rounded off to 100 households.

3.5 Socioeconomic data
Socioeconomic data for this study was mainly collected using questionnaires. A total of 100 (hundred)

questionnaires were administered randomly in the four transects (rivers) in the basin (see section 3.1 above). Data collected through the questionnaires include the impacts of water abstraction on farmers (agricultural production), riparian vegetation and income level of the people in the basin. This data was analysed by comparing each variable with water abstraction through plotting a regression curve.

3.6 Data analysis

Data analysis techniques used in this study include descriptive statistics, parametric tests, regression analysis, correlation analysis and Analysis of Variance (ANOVA). Descriptive statistics used include mean, cross tabulation and percentages. Simple and multiple regression analysis were used to determine the nature of statistical relationships between variables such as the relationship between water abstraction and income from crop sales, water abstraction and turbidity, water abstraction and siltation, water abstraction and riparian vegetation and water abstraction and nutrient concentrations. Simple linear regression was calculated as;

Y= a+bX+e……………………………………………………………………………equation 4

Where Y is the independent variable, a and b are the numerical constants, X is dependent variable which was water abstraction and e is the error term.

Multiple linear regression analysis was calculated as follows;

$y=\beta o+\beta 1X1+\beta 2X2+\cdots+\beta kXk+\varepsilon$……………………………………………………equation 5

Where Y is the dependent variable (water abstraction), $X1$, $X2$,…, are the independent variables for instance income from crops, farm size, household size, amount of fertilizer used, type of crop grown and technology used. $\beta 1$, $\beta 2$,…, βk are Beta coefficients and "k" is the number of independent variables. ε is the random error taken to be a random variable with variance ($\sigma 2$) and mean 0 (See also Chirchir, 2014).

4. Results and Discussions of the Study

4.1 Influence of water abstraction on river discharge

The results of the study indicate that increase in water abstraction rate leads to subsequent decline of water level in rivers. Figure 4.1 shows the variations in water levels in the four rivers in SWUT basin. Water level in the four rivers decrease in the period between April and September from 0.78 m to 0.24 m, 0.83 m to 0.41 m, 1.01 m to 0.5 m and 0.83 mto 0.4 m in Thika, Chania, Kiama and Kimakia rivers respectively. The water level also decrease in the period between November and February from 0.79 m to 0.38 m, 0.99 m to 0.41 m, 1.5 m to 0.38 m and 0.89 m to 0.41 m in Thika, Chania, Kiama and Kimakia rivers, respectively. These are the periods when water abstraction rates are also very high. Figure 4.2 shows water abstraction rates in the SWUT basin. The period of maximum water abstraction rate of about 107, 200 l/d, 63, 400 l/d, 95, 500 l/d and 66, 900 l/d in Thika, Chania, Kiama and Kimakia rivers, respectively is between the months of September and January. These are the same periods with low water levels. Water abstraction rates increase during these periods because farmers abstract more water for crop production. The analysis of the relationship between water level and water abstraction yielded a correlation coefficient (r) of 0.51 and coefficient of determination (R^2) of 0.46 both of which are significant at 95% confidence level (P=0.05). These results agree with (Mokaya, 2015), who established that increased water demand during dry season led to decline in water level in Nyakomisaro river. This is also consistent with Mromba (2012) who noted a significant relationship between water abstraction and stream discharge.

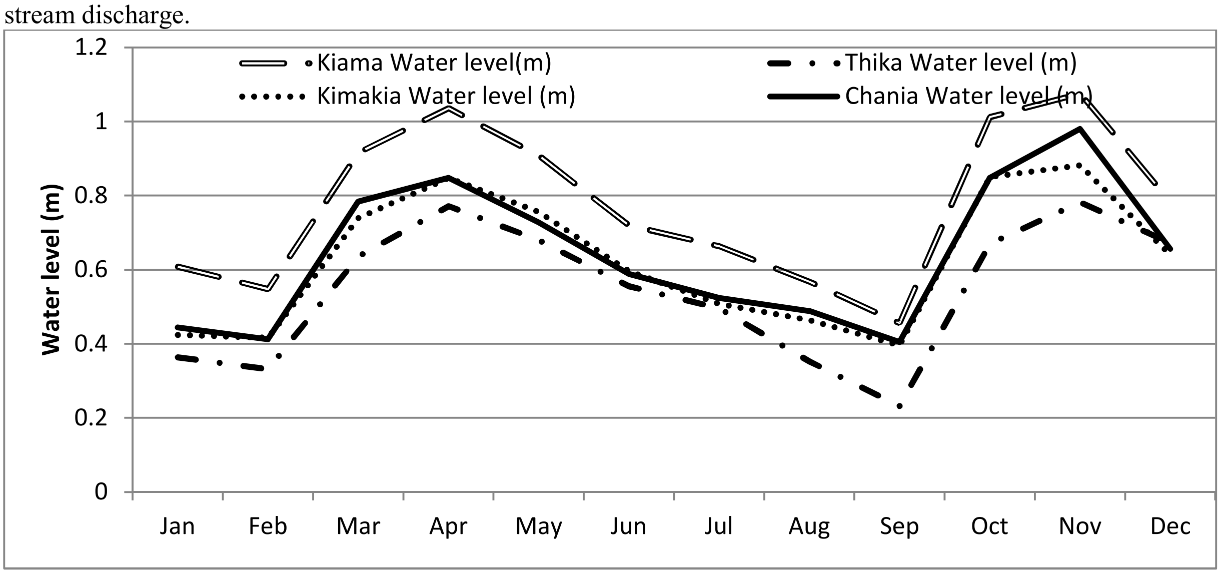

Figure 4.1: Water levels in Thika, Kiama, Chania and Kimakia sub basins in 2018

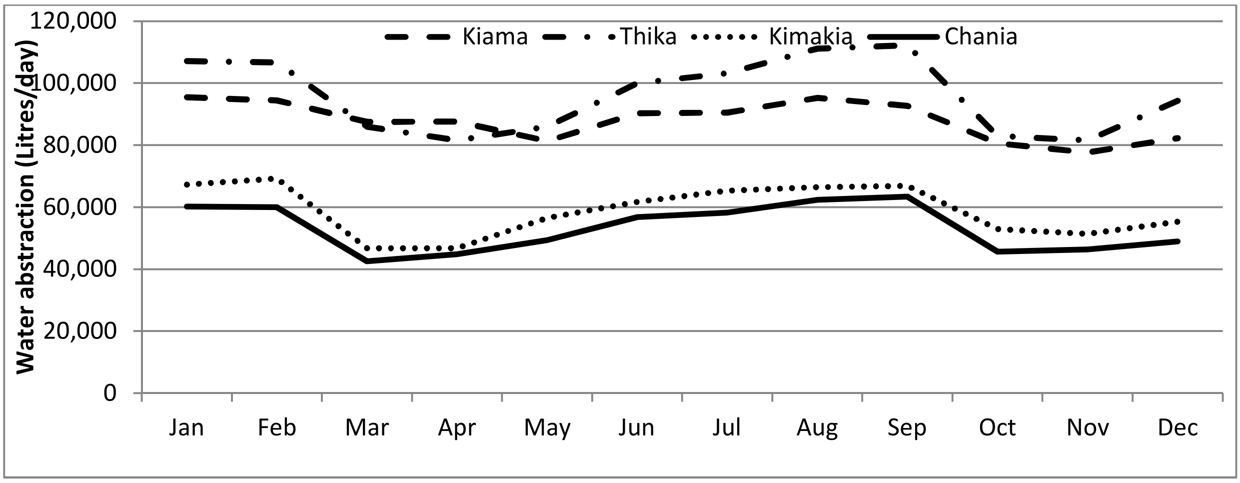

Figure 4.2: Water Abstraction rates in Thika, Kiama, Chania and Kimakia sub basins in 2018

4.2 Relationship between water abstraction and water turbidity

There are significant seasonal variations in water turbidity in the four rivers in SWUT basin. Turbidity increases in the periods between September and November and between February and April (Figure 4.3). Low turbidity levels are in the periods between May and September and between November and February. Water abstraction in the basin also increases during the same periods. Decrease in water turbidity as water abstraction rate increases could be attributed to the fact that low flows decrease the amount of suspended sediment loads. The relationship between water abstraction and water turbidity yielded a correlation coefficient (r) of 0.81 and coefficient of determination R^2 of 0.75. This is a significant relationship since 75% of the variations in turbidity in SWUT basin can be explained by water abstraction. The findings also agree with Lane et al., (1999) who noted that there was a decrease in water turbidity in Mississippi river due to the diversion of the river. These results also concur with those of Moldan and Ceny, 1994; Manohar et al., 2014; Wambugu, 2018.

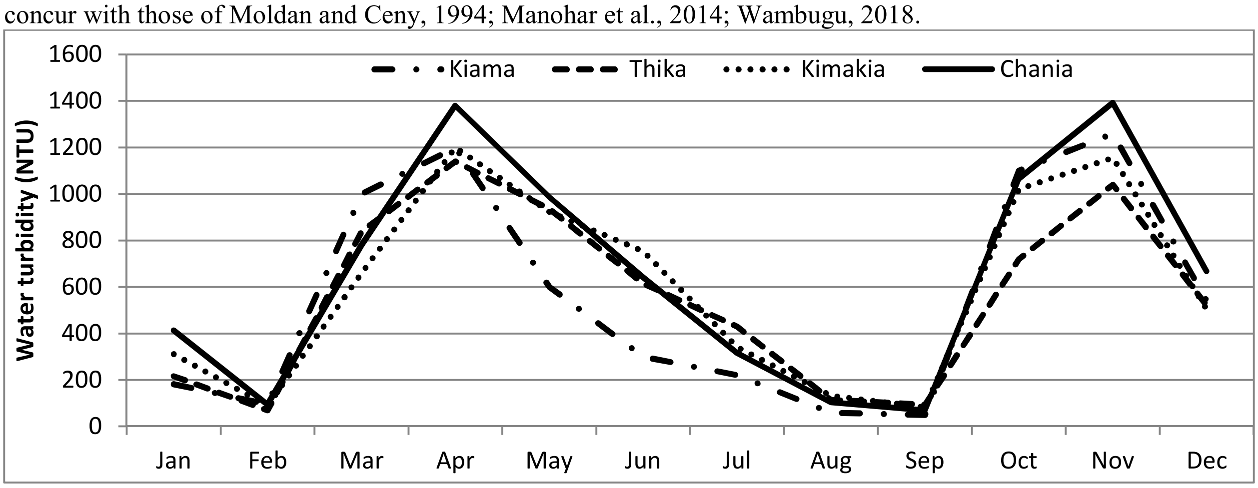

Figure 4.3: Seasonal variations of water turbidity in South West Upper Tana Basin

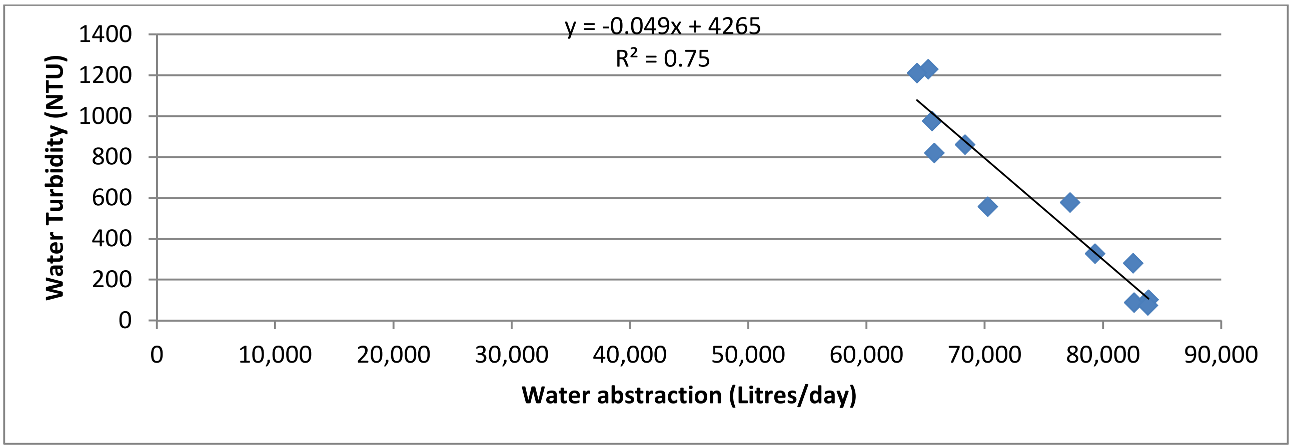

Figure 4.4: Relationship between water abstraction and turbidity in South West Upper Tana Basin

4.3 Influence of water abstraction on eutrophication and siltation

There is a significant seasonal variation in siltation and eutrophication in the SWUT basin. Eutrophication happens when there are high nutrient levels in rivers. These nutrients include phosphorus, nitrates and nitrites (Schilling and Wolter, 2001; Manohar et al., 2017). The nitrate levels in SWUT basin vary from 0.4 mg/l to 2 mg/l during rainy season and 4 mg/l to 14 mg/l during dry season. The nitrate concentration levels decrease during periods of high water abstractions (between January and February and between July and August). This can be attributed to the concentration of nutrients during the dry period when fertilizers from nearby farms are washed into the rivers since there is no return flow (See also Kithiia, 2006, 2008, Okoth and Otieno, 2000 and Mavuti, 2003). These findings also agree with Mattias (2010) who established that water abstraction for agricultural use led to increase in nitrate and phosphorus compounds in water.

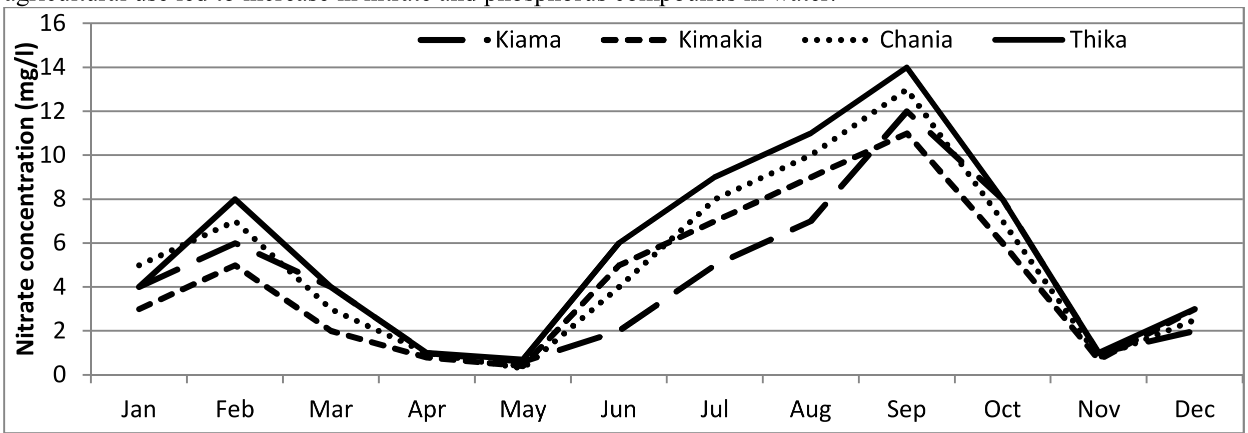

Figure 4.5: Seasonal variations of nitrate concentrations in South West Upper Tana Basin

The study established that, most (63%) of the water abstraction canals take between 1 and 3 months to fill up with silt. The main reason why these canals take long to fill up is due to the fact that water abstraction reduces sediment loads in the rivers. Only 20% of the canals fill up with silt within the first week after rains while 13% of the canals take more than 3 months to fill up with silt. This is an indicator that water abstraction in the basin has decreased sediment loads in rivers.

Table 4.1: Siltation of water canals in South West Upper Tana basin

Sub-Basin	Time taken for diversions to fill up (Percentage)						
	1 week	2 weeks	3 weeks	1 month	2 months	3 months	More than 3 months
Chania	30	5		45	5	10	5
Kimakia	17	5	6	22	17	11	22
Thika	14		5	18	27	18	18
Kiama	40	8	28	8	8	8	

Source: Mwendwa, 2018

4.4 Influence of water abstraction on agricultural production

This study established that majority of the water abstractions in SWUT basin are for irrigation agriculture. It was established that farmers with higher acreage of land under irrigation obtain more yields than those with smaller farm sizes. Crop sales increase with increase in water abstraction. High crop sales of >Kshs 400,000 and water abstraction >3000 l/d for each farmer are limited. The maximum Income realised from crop sales and water abstraction were Kshs 500,000 and 4000 litres while minimum income realised from crop sales and water abstraction was Kshs 2000 and 100 litres respectively. Most of the respondents indicated that they have benefited from high crop yields due to water abstraction. 43% of the respondents use the income generated from sale of crops to pay school fees while 34% use the income to maintain their families. 13% of the income is used to grow businesses while 10% is invested in other sectors (Table 4.2). The larger the farm size the more water is abstracted for irrigation from the river (C.f Gichuki et al., 1998; Ericksen, 2011). There are a variety of crops grown in the study area including tomatoes, cabbages, kales, French beans, flowers, tea, coffee and potatoes. Most of these crops are grown under irrigation due to the changing rain patterns in the study area (see also IFAD/UNEP/GEF, 2004; AWSB, 2014). The relationship between water abstraction and crop sales yielded a coefficient of determination (r) of 0.78 and coefficient of determination R^2 of 0.73 (Figure 4.6). These were statistically significant at 95% confidence level (P=0.05).This shows that the volume of water abstracted can explain 73% of variations in crop sales in SWUT basin. The relationship between crop sales and farm size yielded a correlation coefficient (r) of 0.84 and a coefficient of determination R^2 of 0.70. These were statistically significant at 95% confidence level (P=0.05). These findings are consistent with Spelman (2009) who noted that farm size and the type of crop grown by the farmer significantly influence water abstraction for irrigation use. Similarly, Michailidis et al., (2010) established that irrigation agriculture contributes the highest water abstraction rates in developing countries. The results also agree with Qadir et al., (2010) who noted that water abstraction for agriculture improves crop production.

Table 4.2: Benefits of income from crop sales in the SWUT basin

Sub basin	Benefits of income from crops (%)			
	Maintaining family	Growing business	Pay fees	Investments
Kiama	35	15	40	10
Thika	37	9	43	11
Kimakia	32	13	45	10
Chania	33	15	42	10
Mean	34.25	13	42.5	10.25

Source: Mwendwa, 2018

The increase in agricultural production in SWUT has led to a rise in use of fertilizers to improve crop yields. It was established that the main types of fertilizers used by farmers in the study area are Diammonim Phosphate (DAP), TSP and NPK. These fertilizers are rich in nitrogen and phosphorus which cause eutrophic conditions when washed into the rivers evidenced by change of water colour from clear to green due to high concentrations of green algae (chlorophyta) (see also (Matsui and Takigami, 2001,WHO/EU, 2002).

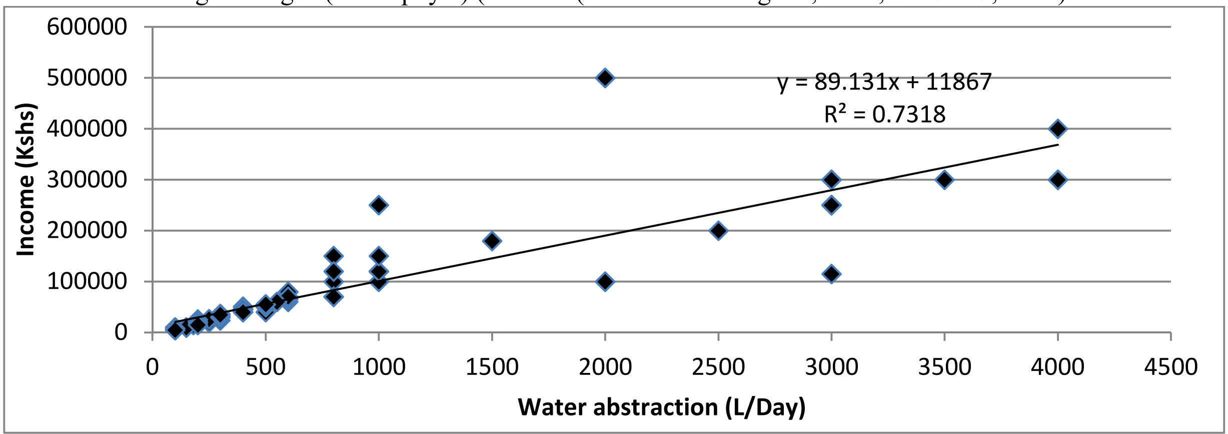

Figure 4.6: Relationship between crop sales and water abstraction in the SWUT basin

4.5 Social impacts of water abstraction

The study established that there has been 22% increase in water related conflicts as a result of water abstraction. Increased water demand due to increase in population and changing rain patterns as well as the decrease in water level in the rivers has led to increase in conflicts (see also ERM, 2007; Mokaya, 2015 and Bekele, 2013). This has resulted in the formulation of informal ways of solving those conflicts such as involving community elders. Elders listen to the conflicting parties and give resolutions that are binding to the parties (C.f Aeschbacheretal., 2005; Notter et al., 2007; Ngigi et al., 2007).These findings are consistent with Mutiga (2010) who established that water abstraction in the upstream of River Ewaso Ng'iro was the main cause of water use conflicts in the downstream.

4.6 Impact of water abstraction on environment

This study established that there has been a significant change in the riparian vegetation as result of water abstraction especially in the downstream of the rivers. In Kiama and Thika rivers, there has been introduction of water weeds due to the influence of Ndakaini dam. It was also established that some plants that grow along the river banks dry up especially in the dry season when water levels decline as result of water abstraction. These findings are consistent with Reinfelds et al., (2006) who established that reduction in water level as a result of water abstraction can alter the abundance of micro invertebrates and reduce river biodiversity (See also Procipio, 2010). The low flows in the dry season due to water abstraction lead to high water temperature which affect aquatic plants and animals (Mukhwana, 2016) (see also Bunn and Arthington, 2002; Milton and Dean,2010).

5. Conclusion

The study concluded that the main impacts of water abstraction in SWUT basin are hydrological, socioeconomic and environmental. Hydrological impacts include extremely low flows in the dry season, changes in stream morphology, reduced water turbidity, eutrophication and reduced siltation. High water abstraction rates during the dry season for irrigation agriculture leads to the low stream flows in SWUT basin. Water turbidity also decreases during the dry season because of reduced total suspended solids due to low velocity of the river. Eutrophication, which is evidenced by change of water colour to green due to presence of green algae, is also common during dry season. Socioeconomic impacts of water abstraction are improved income from crop sales and water related conflicts. Farmers who abstract water from the rivers obtain more yields from the farms since they don't necessarily rely on rainfall. The income obtained from sale of crops is utilised in paying school fees, maintaining the family and investments. Water related conflicts mainly occur in the dry season due to water over abstraction in the upstream which leaves the downstream users without enough water for irrigation. The environmental impacts of water abstraction in the study area are introduction of invasive species and drying up of riparian vegetation in dry season. Water weeds are common in River Thika and River Kiama because of the influence of Ndakaini dam. The study recommends that Water Resources Authority (WRA) should increase the frequency of visits to the river basins to monitor water abstractions in the area. The authority should also carry out public awareness campaigns and encourage stakeholder participation to ensure farmers are aware of the impacts of water over abstraction in the rivers. WRA should also ensure that Water Resource Users Associations (WRUAs) are properly constituted and functional to ensure the leadership can encourage sustainable water abstraction.

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