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Temporal Variation of Sedimentation from Surface Runoff from Agricultural Land Uses in Sondu-Miriu Basin, Kenya

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Abstract: The study was conducted at two sites in Sondu-Miriu basin between November 2010 and May 2011, using runoff plots to determine the temporal variation of sediments, organic matter, solids and surface runoff from agricultural land uses. At Kabianga, lower sediment and surface runoff values were observed in natural vegetation while runoff was generally higher in April-May 2011 wet season. While there were significantly lower sediment concentrations and higher runoff volumes, organic content was significantly lower in April-May 2011. Principal Components Analysis correlated surface runoff and erosion to seasonal land use activities particularly during wet seasons depicting the influence of hydrology on surface runoff pollution. In Sondu, sediment concentrations were lower in natural vegetation. Surface runoff was higher in January-March 2011 in natural vegetation but lowest in cropped systems during April-May, 2011. Solids and organic matter were significantly higher in November-December 2011 ($p<0.05$). PCA linked surface runoff quality to changes in hydrological periods which influenced the nature, quality and quantity of material transported via surface runoff. PCA for River Sondu-Miriu at Kabianga suggested ionic pollution by dissolved substances ($r = 0.77$-0.99, $p<0.01$) and sediment load introduced via surface runoff during wet seasons. In Sondu, PCA associated ionic pollutants and sediment loads to hydrological changes relating to seasonality ($r = -0.75$-0.99, $p<0.01$). Temporal variations in surface runoff volumes, water quality and sediment load correlated significantly to hydroperiods in Sondu-Miriu basin. Hydrological changes impacted highly in agricultural land uses with reduced land cover which increased surface runoff accompanied by higher sediment loads.

Keywords: Hydrology, pollutants, principal component analysis, seasonality

INTRODUCTION

There is increasing awareness of the need to protect natural resources in order to meet present and future requirements. Since economies and environments are dependent on healthy soil and water, it is essential to ensure the sustainable use of these resources in the face of growing demand. Excessive or enhanced soil erosion due to poor land management can result in both on and off-site impacts detrimental to a wide range of receptors. Where soil erosion occurs, the soil resource can be severely depleted when the rate of erosion exceeds that of natural soil formation. This loss often corresponds to the most agriculturally important topsoil and any fertilizer or pesticide application, causing subsequent reductions in agricultural productivity. Soil erosion is a hazard traditionally associated with agriculture and often occurs in tropical and semi-arid areas (Collins and Owens, 2006).

Recent interest in soil erosion has increased awareness of off-site impacts. These impacts are predominantly associated with the movement of eroded soil and sediment particles and changes in surface and sub-surface water flows. Off-site problems are often more evident and include the loading and sedimentation of watercourses and reservoirs and increases in-stream turbidity. All these can disturb aquatic ecosystems and disrupt the geomorphological functions of river systems (Owens *et al*., 2005). Surface water pollution from organic and inorganic sediments generated from agricultural catchments is a serious threat to aquatic ecosystems and public health in many regions. If eroded soil carries nutrients, contaminants and pathogens, it can present serious problems of surface and groundwater pollution and eutrophication, threatening habitat and human health (Owens *et al*., 2005). Hence, there is need for proactive management of aquatic water quality in agricultural catchments. Most research efforts are however directed towards routine monitoring of water quality (Yillia, 2009) rather than tracking and managing the sources of pollution. Information on pollution levels and nature of pollutants is frequently required to identify the major contributing sources and path ways (Venter *et al*., 1997), to draw attention to the intrinsic value of soil as a resource and the need to prevent soil erosion and sediment transfer for soil and surface water protection (Van-Camp *et al*., 2004).

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Many studies have pointed out that the land-use pattern in a drainage basin affects the quality of the river water (Sliva and Williams, 2001; Tufford *et al*., 2003; Woli *et al*., 2004). The land use-water quality relationship is complex and is likely to be site-or region-specific (Baker and Richards, 2003). There have been relatively few studies on the relationship between river water quality in terms of sedimentation and surface runoff from agricultural land uses in tropical river catchments. Our objective was to determine the temporal variation of sedimentation from surface runoff generated from agricultural land use activities in Sondu-Miriu Basin. Levels of sediments in River Sondu-Miriu were also determined across three hydrological periods.

MATERIALS AND METHODS

Study area:

Topography and climate: There are about 10 major rivers flowing into Lake Victoria from the Kenyan side representing multiple sub-basins. River Sondu-Miriu (RSM) is the third largest river in Lake Victoria Basin, Kenya and drains a total of 3,508 km^2 in Sondu-Miriu Basin (SMB). The SMB lies between Nyando Basin on the northern side and Gucha-Migori Basin southward (NBI-Nile Basin Initiative, 2005). The elevation ranges between 1000 and 2000 m a.s.l. and extends between 35° 45'-34° 45' longitude and 0°15'-1°00' latitude (Fig. 1). The basin can be divided into three major climatic regions: humid, sub-humid and semi-humid. The long rainy season is between April, May and June. Short rains fall around October, November and December. However this seasonality is much clearer in the lower regions. The highlands receive a cumulative annual rainfall of approximately 1,835 mm which decreases to about 1,500 mm towards the lowlands. The lowlands have an average annual temperature of 26°C. Mean annual temperature ranges from about 18 to 30°C, respectively while relative humidity lies around 62% for most of the year. RSM is an important trans-boundary lotic system partly due to its volumetric water contribution and partly as a conduit for carrying pollutants into the Lake Victoria. Nationally, the river contributes to both domestic and industrial water supplies and recently in hydroelectric power production. It is also a source of agricultural and livestock water. Hence, RSM is exposed to both non-point and point pollution (NBI-Nile Basin Initiative, 2005).

Sampling and design of runoff plots: The study tested two factors: land use at three levels and runoff assessment at 2 levels (UP and BP) each replicated three times in two sites. Sites were selected based on previous work that had sub-divided the basin into three based on major soil types: lower, middle and upper catchment (Mungai *et al*., 2011). Water samples from RSM were collected at River Ainapkoi (S 00° 26', E 035° 08', 1712±14 m a.s.l) tributary at Kabianga and at the main RSM (S 00°23', E 035° 00', 1507±7 m a.s.l) in Sondu. Runoff plots in the upper basin were established at Kabianga High School farm (S 00° 26', E 035° 08', 1760±7 m a.s.l) at Kabianga and at the Nyakach Water treatment plant site (S 00° 22', E 035° 00', 1517±9 m a.s.l) in Sondu.

A two-way classification, Randomized Complete Block Design (RCBD), with three replications was established on each site. In each block, three treatment (natural vegetation, weedy fallow and cropped) units were set up. Natural vegetation at Kabianga was dominated by grassland (Kikuyu and fox tail grass). Sondu's natural vegetation was typically Kikuyu, Thatch and Red Oat grass interspersed with shrubs. Unbound Plots (UP) is not enclosed on any sides and each is fitted with a modified Gerlach trough at the sloping end to collect runoff. A Gerlach trough as developed by Gerlach (1967) is a simple metallic gutter, 0.5 m long and 0.1 m wide. It is closed at the sides and opens at the end facing the plots. Each trough was connected to a collecting tank by a pipe. The Bound Plots (BP) consists of an all-round polythene sheet boundary installed to avoid leakage effects. Runoff was collected through an outlet pipe into tanks set up at the sloping end. The boundaries were carefully installed and inserted deep enough and tall enough to prevent overtopping.

Gerlach troughs were used to collect sediment and surface runoff in the unbounded 2×2 m plots. On the cropped plots, Sweet sorghum (*Sorghum bicolor* (L.), Serena variety, was planted at a spacing of 75×20 cm. Phosphate fertilizer was applied at 96 kg P/ha as Triple Super Phosphate (TSP) at planting and 84 kg N/ha as Calcium Ammonium Nitrate (CAN) for top dressing. The same treatment applied for the 2×5 m bound plots. A 30-cm deep trench was dug on the upper end of each land use to prevent runoff from elsewhere interfering with the desired basin measurements. The distance from the trench to the Gerlach troughs was 2 m and long enough to allow the development of rills and interrills, which could cause significant runoff. A clinometer was used to determine slope which ranged between 2-10% in both sites. The distance between plots was 0.5 m while the replicates were 1 m apart.

Sampling and site measurements: Sampling was conducted from November, 2010 to May, 2011. Data was collected from runoff plots and River Sondu-Miriu bi-monthly in the rainy season and once a month during dry and short rains. Geographic location of sampling sites was captured using a 'GARMIN®' (Etrex-legend) hand-held GPS unit. Physical water parameters for the runoff plots were measured *in situ* including: temperature, conductivity (EC), Total Dissolved Solids (TDS) and pH using 'HACH' (*Eco* 40) multi-meter. Dissolved Oxygen (DO) was determined with 'HACH' (*HQ*40*d*) multi-meter. Water samples were taken after every rainfall event causing significant runoff (≈25

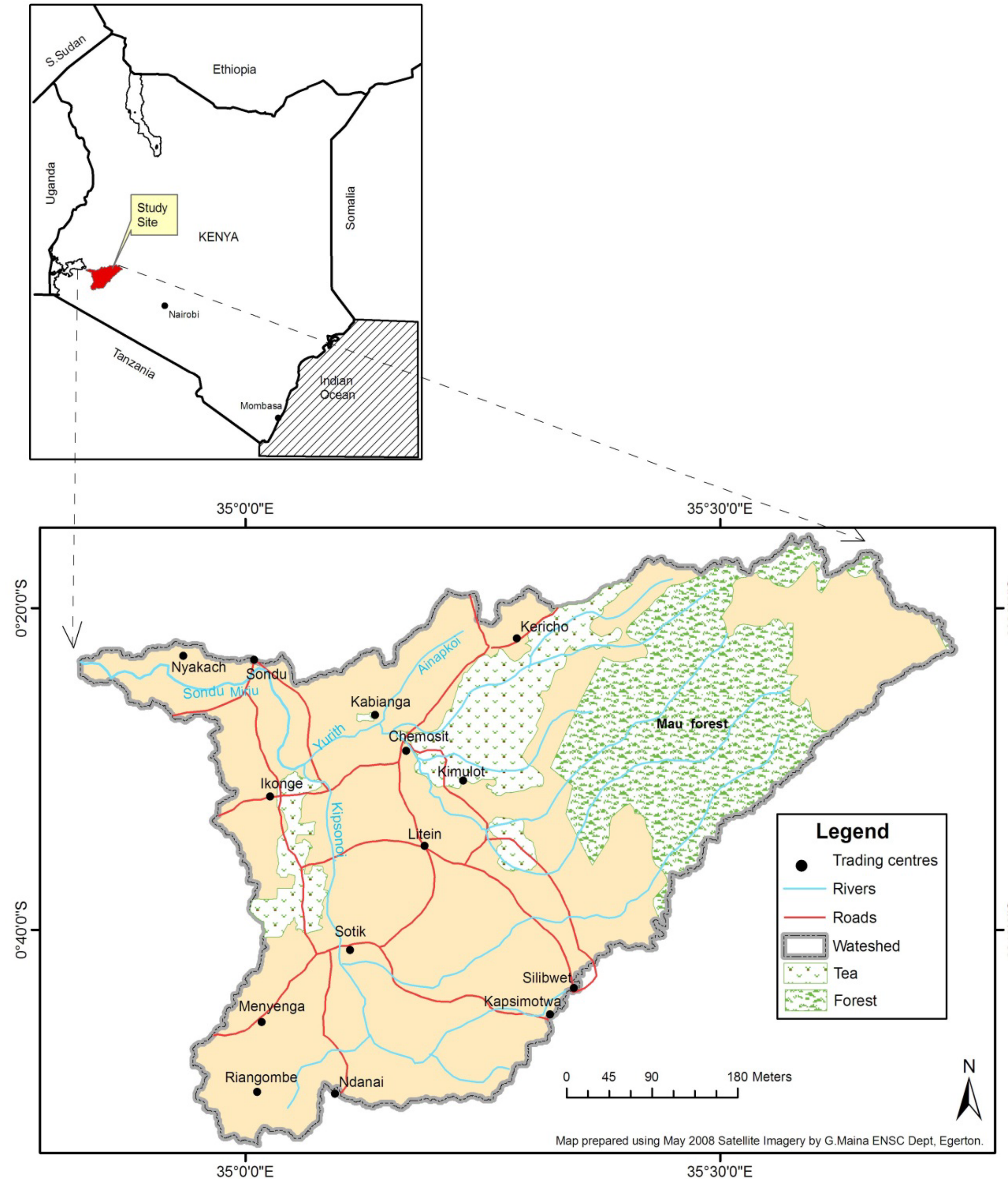

Fig. 1: Sondu-Miriu basin showing River Sondu-Miriu network and study sites (Kabianga and Sondu)

mm/h) into the tanks. In the 10 L tank, contents were then stirred gently and weighed to determine runoff amount (V_R), for each rainfall event as follows:

$$V_R = W_{TB} - W_{TA} \tag{1}$$

where,
W_{TB} = The weight of tank plus runoff
W_{TA} = The weight of empty tank

In the 100-L tanks, a calibrated dip-stick indicator was used to measure the height (h) of runoff collected which was then converted to volume ($\pi r^2 h$). From each tank, a 500-mL sample was collected in plastic sample bottles for determination of Total Solids (TS), Total Suspended Solids (TSS) and Organic Matter (OM) content. Rainfall and temperature data were recorded from the Kenya Meteorological Department station at Kericho. Physicochemical water parameters in RSM were measured *in situ* as previously described. Three replicate water samples were also collected from sampling points in the river in 500 mL acid-washed plastic bottles a few centimetres below the water surface in the middle of the river channel (where possible), stored and transported in a cool box for laboratory analysis at Egerton University.

Laboratory analysis: APHA (2005) standard water quality analytical procedures were followed in the analyses. Samples were filtered through pre-dried and pre-weighed what man GF/C glassmicro-fibre filters (0.6-0.7 µm-pore-sizeand 47 mm-diameter) for determination of TSS and OM. The masses of filter papers, reagents and samples were measured by a digital balance (SCALTEC-SPB31). To estimate TSS, a known volume of water sample was filtered using pre-weighed and dried filters which were then dried again at 95°C to a constant weight for about 24 h. The weight of suspended solids was estimated using the relationship (APHA, 2005):

$$\text{TSS (mg/L)} = \frac{W_c - W_f}{V} \times 10^6 \quad (2)$$

where,

TSS = Total suspended solids
W_f = weight of pre-combusted filter, g
W_c = Constant weight of filter+residue, g
V = Volume of water sample, mL

To gravimetrically determine the OM content in the samples, oven-dried and weighed TSS residue in the filters were ignited to a constant weight in a muffle furnace at 500-550°C for 1-2 h after which the Ash-Free Dry Weight (AFDW) was measured. The organic content was expressed as (APHA, 2005):

$$\text{OM (mg/L)} = \text{TSS} - \text{AFDW} \quad (3)$$

where,

OM = Organic matter content
TSS = Total suspended solids, mg/L
AFDW = Ash-free dry weight, mg/L

TS was estimated by evaporating duplicates of a well-mixed 50 mL sample in a weighed dish and drying to a constant weight in an oven at 103-105°C. The increase in weight over that of the empty dish represented the total solids calculated as:

$$\text{TS (mg/L)} = \frac{[(A-B) x\ 10^3]}{V_s} \quad (4)$$

where,

A = Weight of dried residue+dish, mg
B = Weight of dish, mg
V_s = Sample volume

Data analysis: Data analysis was performed using GenStat® (version 14.2) at 5% level of significance. Prior to statistical analyses, the data was tested for normality using the Shapiro-Wilk test for normality. Kruskal-Wallis One Way ANOVA on data for both sites for variations among land uses for the three hydrological periods was not statistically significant. Therefore data for each site was pooled and analyzed for temporal parity or disparity for each site using K-W One Way ANOVA. Periods with significant variations ($p<0.05$) were further separated using a *post-hoc* Dunn's test for unequal group sizes to delineate significantly different observations. Significant one-way ANOVA for parameters with normal distribution and equal variances were separated using a *post-hoc* Tukey's test at $\alpha = 0.05$.

Related factor complexes were characterized with Principal Components Analysis (PCA) on standardized data and further subjected to Factor Analysis (FA). The extracted components with an Eigen value above 1 were retained to explain associations among indicator parameters. A varimax rotation with Kaiser normalization was conducted to a final solution. In FA, factors assorted by each PC were analyzed individually and collectively to determine the temporal trends in their variations. Significant associations were confirmed at 5% significance level ($p<0.05$) using Spearman rank correlation test.

RESULTS AND DISCUSSION

Physicochemical parameters: At Kabianga, pH, EC, TDS and temperature were generally low during the long-rains (April-May 2011) and high in dry season (January-March 2011) (Table 1). The pH varied from acidic (5.5) in weedy fallow plots to alkaline (8.5) in the natural vegetation. EC ranged from 3.1 to 260 µS/cm in the weedy fallow plots while TDS was highest in the natural vegetation (397 mg/L) and lowest (2 mg/L) in cropped plots. Temperature generally exhibited approximately 10°C range from 18.5°C (natural vegetation) to 28.5°C (weedy fallow plots). In contrast dissolved oxygen was below 0.1 mg/L in November-December 2010 and January-March 2011 in weedy fallow plots. The highest DO concentration (7.3 mg/L) was in the cropped plots in two seasons; January-March and April-May 2011.

Similar to Kabianga, pH, EC and TDS displayed low values in April-May 2011 but high levels in January-March 2011 season in Sondu (Table 2). The pH ranged from 5.0 (cropped) to 7.9 (weedy fallow). EC and TDS both recorded wider ranges (2.2-244 µS/cm and 1.4-146.8 mg/L), respectively from the weedy fallow plots across the sampling duration. The minimum temperature (23.3°C) in Sondu was in November-December 2010 while 36.7°C was the highest in cropped plots. Dissolved oxygen

Table 1: Temporal variability of physicochemical parameters in different agricultural land uses at Kabianga across three hydroperiods

Land use	Period		pH	EC (µS/cm)	Temp (°C)	DO (mg/L)	TDS (mg/L)
Nat Veg	Nov-Dec 2010	Median	7.1	30.0	22.6	6.4	19.2
		Min-max	6.6-7.5	10.4-51.6	20.6-23.3	5.5-6.8	6.63-33.1
	Jan-Mar 2011	Median	7.3	140.7	23.5	6.1	98.8
		Min-max	6.0-8.5	95.9-238.0	20.6-26.2	0.1-7.2	47.2-397.0
	Apr-May 2011	Median	6.1	5.4	20.8	6.0	3.4
		Min-max	5.9-6.5	3.2-13.0	18.5-24.7	5.0-6.9	2.1-8.3
W-fallow	Nov-Dec 2010	Median	6.8	17.8	22.6	5.8	11.4
		Min-max	6.2-8.3	10.6-101.7	20.5-24.2	0.1-7.1	6.8-65.1
	Jan-Mar 2011	Median	7.0	114.3	22.9	5.7	55.6
		Min-max	6.1-7.8	84.6-260.0	21.6-28.5	0.1-6.9	11.2-160.9
	Apr-May 2011	Median	6.3	6.6	21.7	5.7	4.3
		Min-max	5.5-6.8	3.1-20.8	19.2-26.6	4.7-7.0	2.0-13.5
Cropped	Nov-Dec 2010	Median	7.0	25.2	22.9	6.5	16.2
		Min-max	6.7-8.3	9.9-55.6	20.9-25.3	0.2-7.0	6.4-35.6
	Jan-Mar 2011	Median	7.8	91.5	23.7	6.6	53.0
		Min-max	6.0-8.2	12.1-197.3	20.2-26.2	5.9-7.3	7.5-131.2
	Apr-May 2011	Median	6.3	4.8	22.9	6.6	3.2
		Min-max	5.7-6.9	3.4-7.5	18.7-25.8	5.8-7.3	2.2-4.9

Table 2: Variations in physicochemical measurements in agricultural land uses in Sondu between November 2010 and May 2011

Land use	Period		pH	EC (µS/cm)	Temp (°C)	DO (mg/L)	TDS (mg/L)
Nat Veg	Nov-Dec 2010	Median	7.0	23.8	26.3	5.5	15.2
		Min-max	6.7-7.1	19.9-41.4	24.6-28.6	2.0-7.0	12.8-26.4
	Jan-Mar 2011	Median	6.4	88.9	32.1	5.2	53.5
		Min-max	6.1-6.6	68.5-109.3	31.2-33.0	5.0-5.4	41.6-65.4
	Apr-May 2011	Median	6.5	3.2	27.5	5.4	2.1
		Min-max	5.7-7.3	2.3-15.7	24.3-29.3	2.7-5.9	1.5-10.2
W-fallow	Nov-Dec 2010	Median	6.9	24.9	26.4	6.2	15.9
		Min-max	6.4-7.1	15.3-120.8	25.0-29.0	1.3-6.3	9.8-77.3
	Jan-Mar 2011	Median	7.4	229.0	29.3	2.7	81.4
		Min-max	7.0-7.9	60.6-244.0	27.1-30.8	0.2-4.0	38.0-146.8
	Apr-May 2011	Median	5.9	4.4	26.9	5.5	2.9
		Min-max	5.4-7.5	2.2-18.8	23.5-30.3	0.3-6.4	1.4-12.1
Cropped	Nov-Dec 2010	Median	6.9	26.9	25.9	5.6	17.1
		Min-max	6.5-7.1	21.6-38.6	23.3-29.0	4.4-7.8	13.4-24.7
	Jan-Mar 2011	Median	6.9	128.4	33.2	2.2	70.5
		Min-max	6.8-7.5	7.5-156.4	28.1-36.7	0.8-5.4	4.6-85.2
	Apr-May 2011	Median	6.8	6.9	27.9	5.3	4.5
		Min-max	5.0-7.1	5.1-34.5	24.5-29.5	1.1-6.3	3.2-22.4

Table 3: Physical and chemical parameters at Kabianga and Sondu sampling stations in River Sondu-Miriu

Station	Period		pH	EC (µS/cm)	Temp (°C)	DO (mg/L)	TDS (mg/L)
Kabianga	Nov-Dec 2010	Median	6.6	18.2	18.4	6.3	11.6
(R. Ainapkoi)		Min-max	6.5-6.6	11.2-18.6	18.0-19.5	5.9-6.4	11.2-11.9
	Jan-Mar 2011	Median	6.9	40.3	18.3	6.5	27.9
		Min-max	6.7-7.7	27.8-51.7	15.5-19.1	6.2-6.8	15.9-38.2
	Apr-May 2011	Median	6.3	5.7	19.7	6.6	3.7
		Min-max	6.1-6.6	5.5-5.9	17.5-22.7	6.3-6.8	3.5-3.9
Sondu	Nov-Dec 2010	Median	6.7	31.5	21.0	7.4	20.1
(R. Sondu-Miriu)		Min-max	6.5-7.3	28.4-35.6	20.4-21.6	7.35-7.43	18.2-22.8
	Jan-Mar 2011	Median	7.5	45.4	23.1	8.2	29.0
		Min-max	7.3-7.6	44.1-45.9	22.8-24.2	8.10-8.24	28.8-29.5
	Apr-May 2011	Median	7.2	7.3	23.2	7.5	4.8
		Min-max	6.8-7.7	5.6-9.6	22.5-24.4	6.9-7.9	3.6-6.2

concentrations displayed contrasting results compared to Kabianga.

River Sondu-Miriu: The pH at Kabianga and Sondu stations (Table 3) ranged from 6.1-7.7 and 6.5-7.7, respectively. The pH values were below 7.0 at Kabianga but slightly above neutral in January-March and April-May in Sondu. Conductivity and TDS exhibited a similar trend (EC 5.5-51.7 µS/cm; TDS 3.5-38.2 mg/L) with lowest and maximum levels in April-May and January-March respectively at Kabianga. In Sondu EC ranged from 5.6-45.9 µS/cm and TDS was between 3.6-29.5 mg/L for similar seasons. Temperature was highest in April-May at both stations although Kabianga displayed a wider range (15.5-22.7°C) compared to Sondu (20.4-24.4°C). The lowest temperature at Kabianga and Sondu was observed in January-March and November-December respectively. Dissolved oxygen ranged from 5.9-6.8 mg/L and 6.9-8.2 mg/L with maximum concentrations in January-

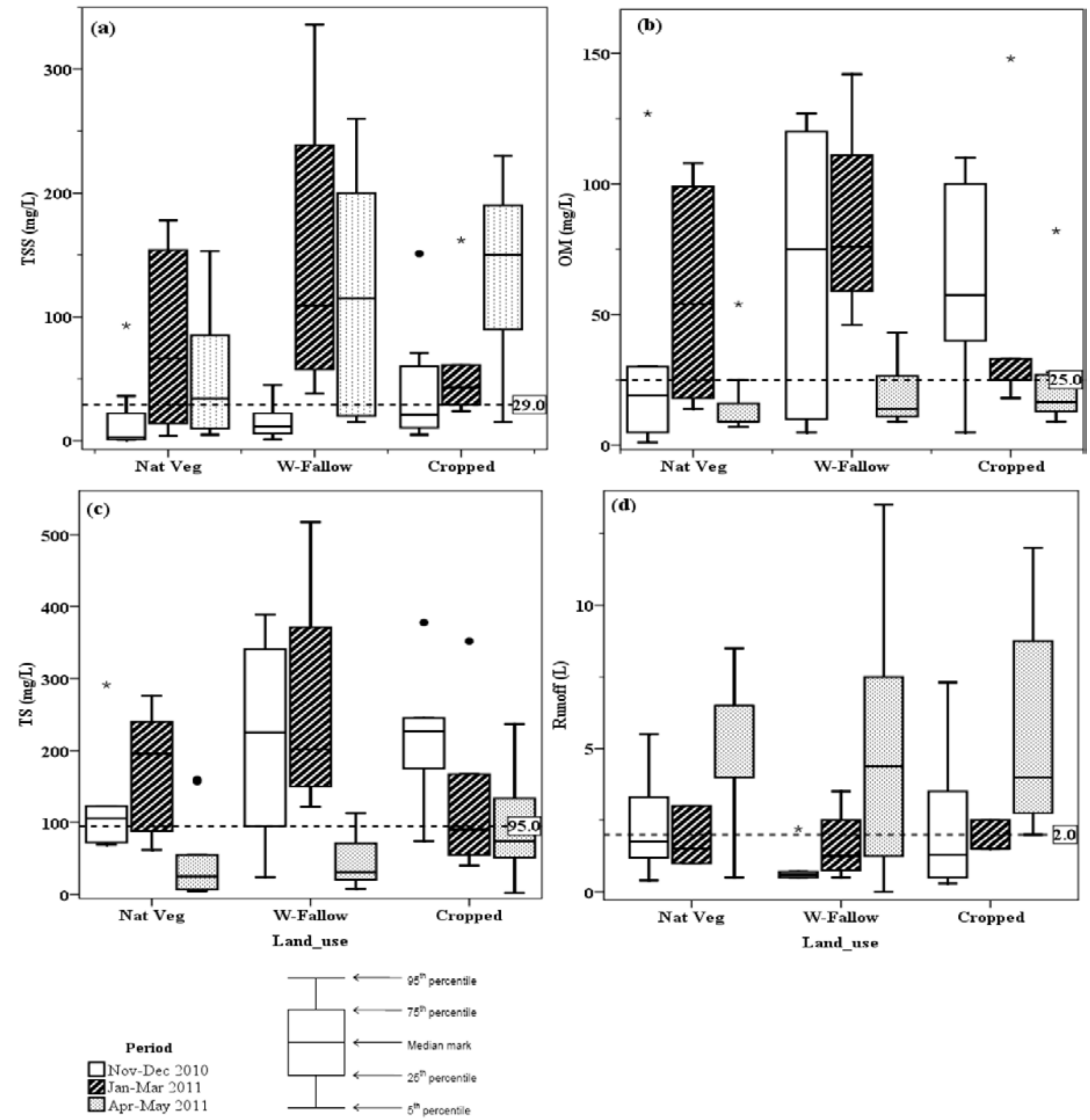

Fig. 2: Temporal variation of TSS (a), OM (b), TS (c) and surface runoff (d) from agricultural land uses at Kabianga during the three sampling periods
Boxes are drawn from the 25^{th} to 75^{th} percentile and the horizontal line within each box is the median; Vertical lines extending above and below the box represent data within the 5^{th} and 95^{th} percentiles; Data lying outside this range (outliers) is represented by solid circles (●) while extreme outliers are represented by asterisks (*)

March and April-May in Kabianga and Sondu respectively. Median DO levels at Kabianga were generally below 7.0 mg/L but higher in Sondu.

Solids, organic matter and surface runoff: Figure 2 shows TSS, TS, OM and runoff volumes from surface runoff in different agricultural land uses in Kabianga. TSS, OM and TS displayed wider ranges from 0.5-336, 1-148 and 2-517 mg/L, respectively while runoff collected ranged from 0-13.5 L in the weedy fallow plots in April-May 2011 season. A comparison of median levels revealed lower values of TSS, OM and TS in natural vegetation in the short and long rainy seasons at Kabianga. In contrast, runoff was lower in the natural vegetation but generally higher in April-May 2011 period. Statistical comparisons of pooled data revealed significantly lower concentrations of TSS (12.5 mg/L) and TS (15 mg/L) but higher runoff volume (6.5 L) in April-May 2011 ($p<0.05$) against the rest of the hydrological periods. Organic content (15 mg/L) was significantly lower in April-May 2011 compared to January-March, 2011 season.

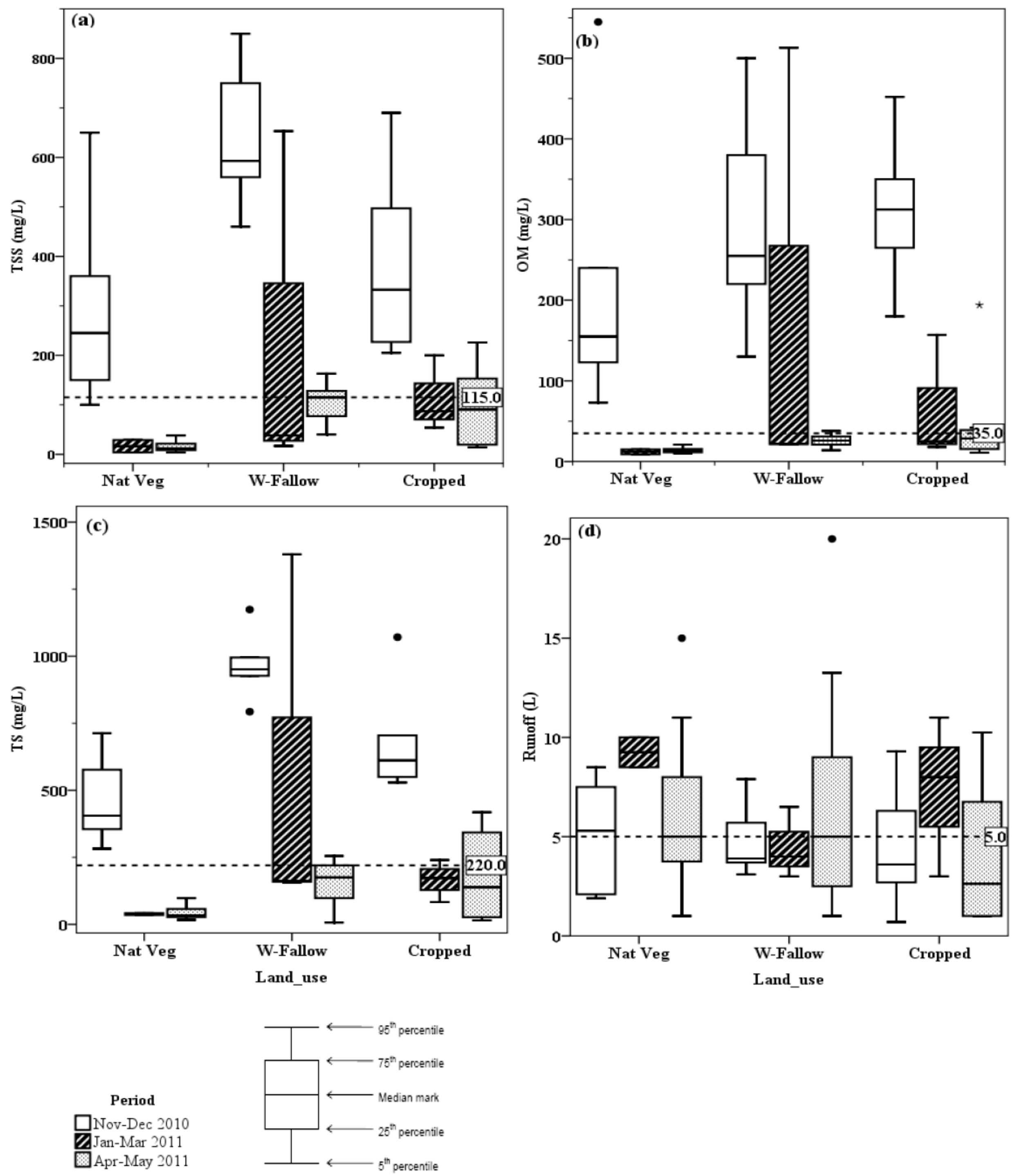

Fig. 3: Temporal variability of TSS (a), OM (b), TS (c) and surface runoff (d) in Sondu between November 2010 and May 2011 Boxes are drawn from the 25th to 75th percentile and the horizontal line within each box is the median; Vertical lines extending above and below the box represent data within the 5th and 95th percentiles; Data lying outside this range (outliers) is represented by solid circles (●) while extreme outliers are represented by asterisks (*)

In Sondu (Fig. 3), wider ranges were observed for TSS (4-850 mg/L), OM (9-545 mg/L) and TS (7-1174 mg/L) compared to Kabianga. Similar to Kabianga, TSS, OM and TS generally displayed lower concentrations in the natural vegetation although maximum levels for these solids occurred in November-December, 2010 in Sondu. Noticeably, median runoff volume was higher in January-March 2011 in the natural vegetation but lowest in cropped systems during April-May, 2011. Median

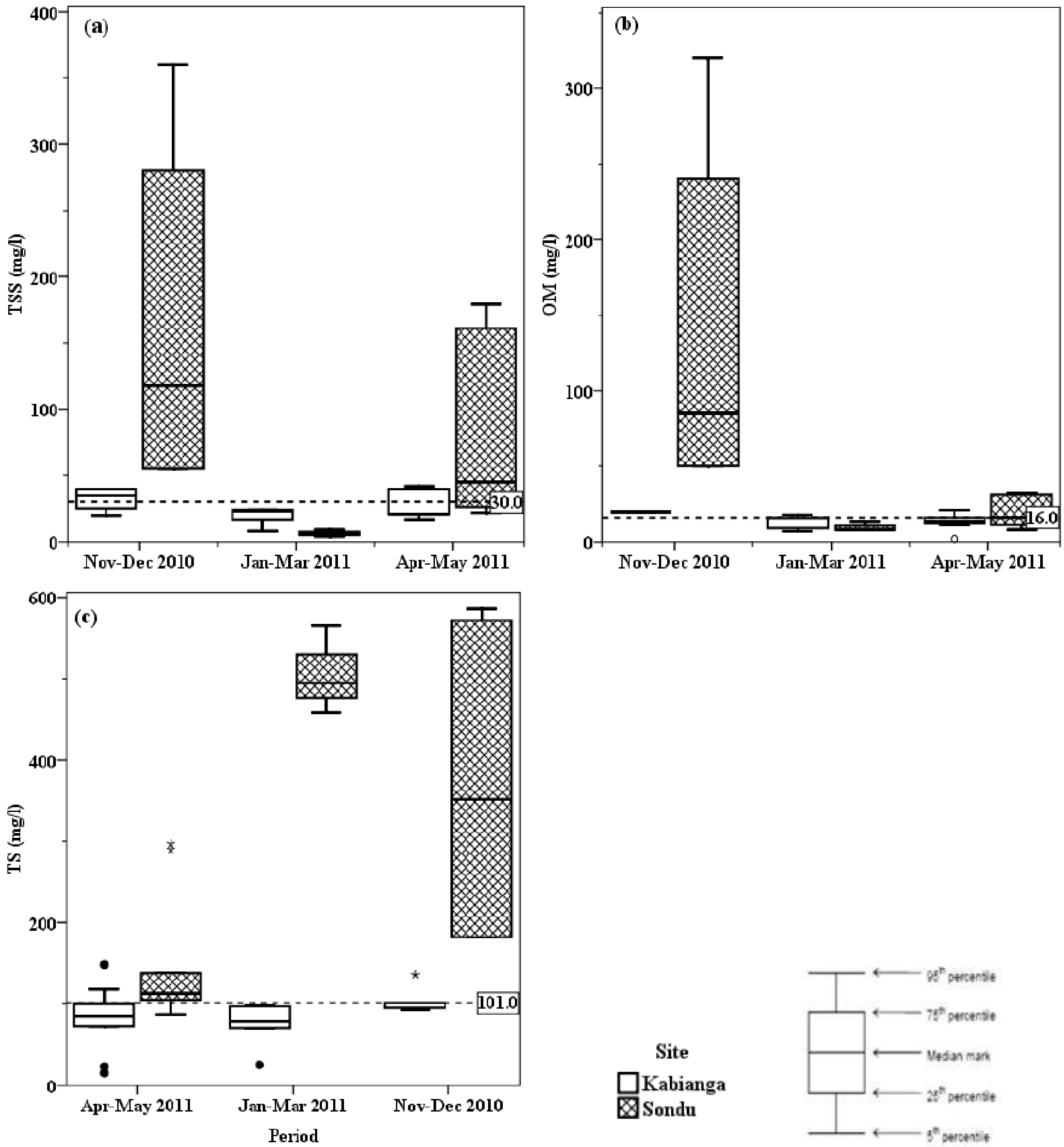

Fig. 4: Total suspended solids (a), organic matter (b) and total solids (c) at Kabianga and Sondu sampling stations along RSM Boxes are drawn from the 25th to 75th percentile and the horizontal line within each box is the median; Vertical lines extending above and below the box represent data within the 5th and 95th percentiles; Data lying outside this range (outliers) is represented by solid circles (●) while extreme outliers are represented by asterisks (*)

concentrations for pooled data of TSS (360 mg/L), OM (255 mg/L) and TS (651 mg/L) were significantly higher in November-December 2011 ($p<0.05$) compared to the other periods.

River Sondu-Miriu: The lowest TSS concentration (8 mg/L) was observed in January-March while minimum values for OM (2 mg/L) and TS (15 mg/L), respectively occurred in April-May 2011 (Fig. 4). Maximum contents for the three solids (TSS 42 mg/L, OM 21 mg/L and TS 148 mg/L) were recorded in April-May 2011 long rains season. However, no statistically significant variations were evident in these parameters across the three sampling periods at the Kabianga station. In Sondu, TSS, OM and TS ranged from 4-360 mg/L, 8-320 mg/L and 87-586 mg/L, respectively with

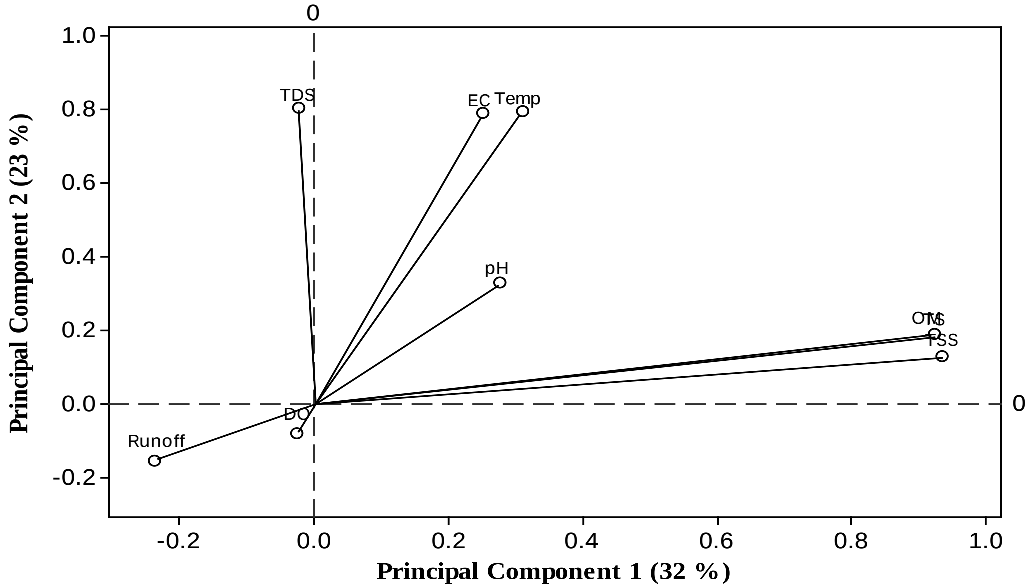

Fig. 5: Principal component analysis of physicochemical parameters, solids surface runoff for the first two PCs in agricultural land uses at Kabianga

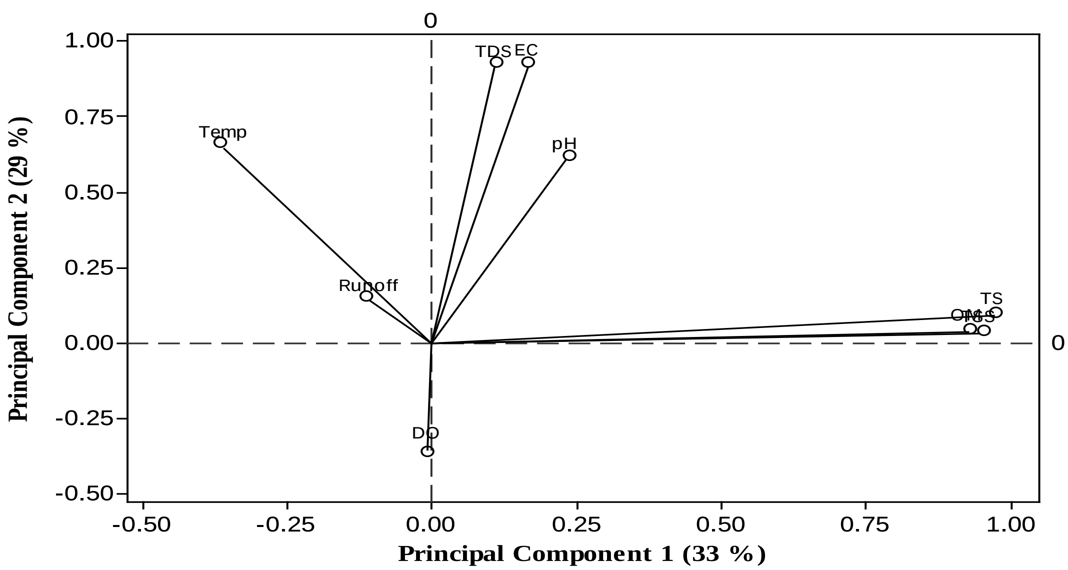

Fig. 6: Principal components analysis of physical and chemical parameters for the first two PCs in agricultural land uses in Sondu

the maximum concentrations occurring in November-December 2010. Significantly lower TSS concentrations in Sondu were noted in January-March 2011 (6.5 mg/L) against November-December 2010 while TS was significantly lower in April-May 2011 (112.5 mg/L) compared to the rest of the seasons. However, OM level was significantly higher in November-December 2010 (85 mg/L) in contrast to the other hydroperiods.

Principal Components Analysis (PCA) and Factor Analysis (FA): Analyses of Principal Components (PCs) for land uses in Kabianga was complemented by factor analysis of the first two PCs. PC1 explained 31.7% of total variance in water quality and had strong positive loadings on TSS, TS and OM (Fig. 5). This factor group is highly and positively contributed by the variables related to surface runoff and erosion and refers to the seasonality factor group. The high and positive contribution of TSS (0.94), TS (0.88) and OM (0.72) indicates loading from land use activities particularly during wet periods; also corroborated by the significant correlations between runoff and the three

Table 4: Spearman's rank correlation matrix of pooled solids and surface runoff data for agricultural land uses at Kabianga during the three sampling periods

Parameter	pH	EC	TDS	Temp	DO	TSS	TS	OM
EC	0.65**							
TDS	0.64**	0.98**						
Temp	0.27*	0.22	0.25					
DO	-0.26*	-0.12	-0.11	0.04				
TSS	0.39**	0.49**	0.50**	0.33*	0.25			
TS	0.49**	0.53**	0.52**	0.35**	0.09	0.76**		
OM	0.43**	0.54**	0.54**	0.36**	0.13	0.88**	0.72**	
Runoff	-0.36**	-0.53**	-0.56**	-0.25	-0.09	-0.47**	-0.42**	-0.41**

*****: Significant correlations at $p<0.05$; ******: Significant correlations at $p<0.01$; n = 57

Table 5: Spearman's rank correlation of pooled data for agricultural land uses in Sondu between November 2010 and May 2011

Parameter	pH	EC	TDS	Temp	DO	TSS	TS	OM
EC	0.47**							
TDS	0.47**	1.00**						
Temp	0.17	0.20	0.20					
DO	-0.07	-0.26	-0.25	-0.37**				
TSS	0.20	0.37**	0.37**	-0.32*	0.09			
TS	0.23	0.46**	0.46**	-0.31*	0.07	0.94**		
OM	0.33*	0.43**	0.42**	-0.36*	0.13	0.92**	0.910**	
Runoff	-0.25	0.14	0.13	-0.19	-0.14	-0.05	-0.019	-0.068

*: Significant correlations at $p<0.05$; **: Significant correlations at $p<0.01$; n = 49

Table 6: Spearman's rank correlation matrix for pooled data for physicochemical parameters and sediments at Kabianga station in RSM

Parameter	pH	EC	TDS	Temp	DO	TSS	TS
EC	0.77**						
TDS	0.80**	0.99**					
Temp	-0.25	-0.48*	-0.440*				
DO	-0.32	-0.44*	-0.470*	-0.17			
TSS	-0.14	-0.29	-0.310	0.29	0.12		
TS	-0.04	-0.19	-0.170	-0.15	0.05	0.34	
OM	-0.04	0.05	0.047	-0.22	-0.10	0.49	0.51*

*: Significant correlations at $p<0.05$; **: Significant correlations at $p<0.01$; n = 21

variables in Table 4 (TSS, r = -0.47; TS, r = -0.42; OM, r = -0.41; $p<0.01$). PC2 had strong positive loadings of EC, TDS and temperature. This component explained 22.9% of total variance depicting the influence of hydrology on ionic pollution of surface runoff. While EC and TDS were moderately but highly significantly correlated (r = 0.64, $p<0.01$), there was no significant correlation between these variables and temperature in PC2. EC and TDS however correlated moderately negatively but highly significantly with surface runoff volume (EC, r = -0.53; TDS, r = -0.56, $p<0.01$). Surface runoff also correlated significantly ($p<0.01$) with certain water quality parameters (pH, EC and TDS) and solids (TSS, TS and OM).

In Sondu (Fig. 6), PC1 accounted for 32.5% variance of overall surface runoff quality and could be linked to changes in hydrological periods which influence the nature and quantity of material transported via surface runoff. This was characterized by strong positive factor loadings of TSS (0.94), TS (0.97) and OM (0.93) attributed to temporal changes in surface runoff loads from the catchment. The three indicators show very strong and highly significant relationships (r = 0.91-0.94, $p<0.01$) despite a non-significant correlation with surface runoff. PC2 could be linked to ionic pollution indicators pH, EC and TDS with moderate to high factor loadings (0.61, 0.92 and 0.92, respectively) and represented 29.1% of the total variance. In Table 5, EC directly and significantly related to level of TDS (r = 1.0, $p<0.01$) which also moderately correlated but significantly influenced the acid-base balance, pH (r = 0.47, $p<0.01$). All the indicators in PC2, except pH, significantly correlated with indicators in PC1.

River water quality: Principal components analysis for RSM at Kabianga station revealed that the first three PCs explained 39-73% of the total variance. PC1 (Fig. 7) suggested ionic pollution contributed by dissolved substances given the high negative factor loadings on pH (-0.95), EC (-0.96) and TDS (-0.97) which displayed highly significant positive correlations (r = 0.77-0.99, $p<0.01$) (Table 6). PC2 was described by TSS and TS and could be associated with sediment load introduced into stream via surface runoff especially the wet seasons (Fig. 7). Despite high factor loadings of both parameters in PC2, there was no significant correlation. In Sondu, stream water quality was explained by three retained PCs which accounted for 92.9% of total variation. PC1 principally associated with changes in ionic pollutants, OM and DO levels and explained 39.90% of total variation (Fig. 8). However, only EC and TDS were significantly correlated (r = 0.99, $p<0.01$) as well and DO and OM (r = -0.75,

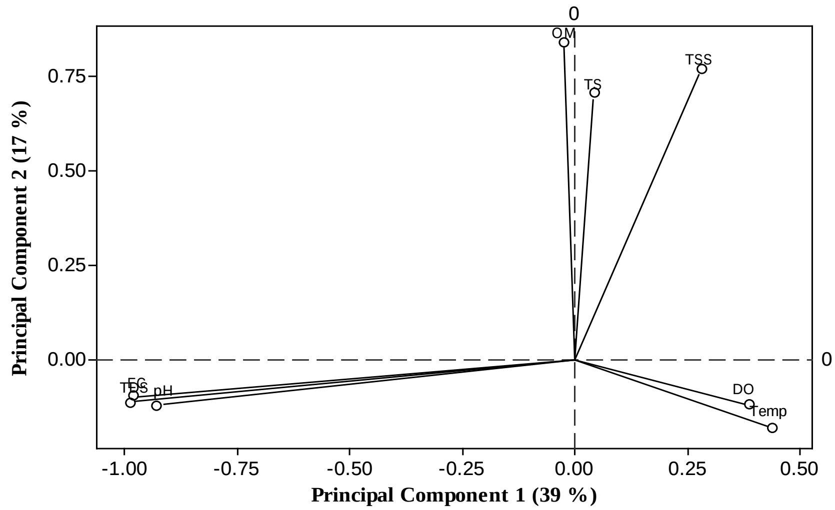

Fig. 7: Principal components analysis of physical and chemical parameters in River Ainapkoi tributary of River Sondu-Miriu at Kabianga sampling station

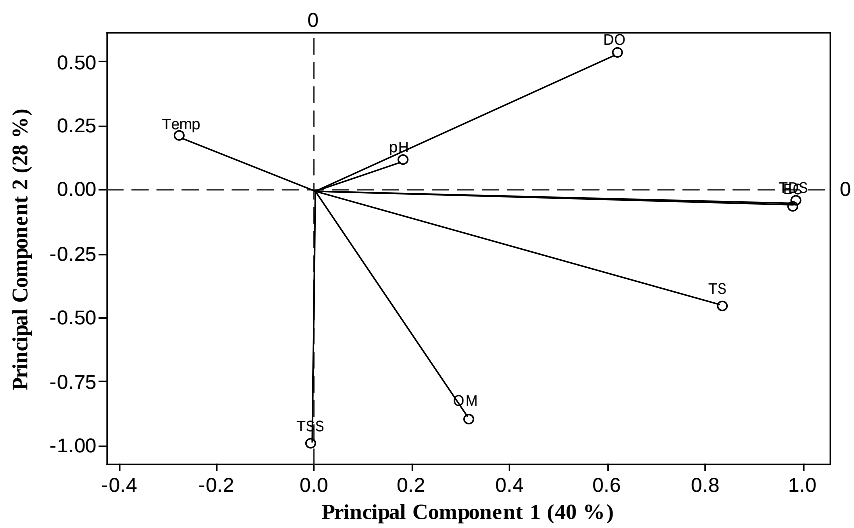

Fig. 8: Principal components analysis of physical and chemical parameters in River Sondu-Miriu at Sondu station

Table 7: Spearman correlation matrix for pooled data of physicochemical, solids and organic matter at Sondu station in River Sondu-Miriu

Parameter	pH	EC	TDS	Temp	DO	TSS	TS
EC	0.17						
TDS	0.16	0.99**					
Temp	0.50*	-0.15	-0.18				
DO	0.72**	0.34	0.35	0.40			
TSS	-0.48*	-0.14	-0.14	-0.60**	-0.85**		
TS	0.13	0.65**	0.64**	-0.48*	0.06	0.27	
OM	-0.61**	0.07	0.06	-0.77**	-0.75**	0.90**	0.45

*: Significant correlations at $p<0.05$; **: Significant correlations at $p<0.01$; n = 18

$p<0.01$) in PC1 (Table 7). PC2 was characterized by sediment factor loads, TSS (-0.98) and TS (-0.88) but with no significant correlation despite explaining 28.40% of total variance. This component could be linked to hydrological changes relating to seasonal variations frequently marked by changes in discharges volumes.

The variations in most of the surface water quality parameters coincided with temporal hydroperiodical changes in Sondu-Miriu basin. The impact of anthropogenic activities on the basin is demonstrated by the variations in water quality from different agricultural land uses as well stream water across sampling periods. The physicochemical parameters indicated elevated levels of pollutants and low water quality in cropped and weedy fallow systems especially during the dry season. Anthropogenic activities have been observed to override natural sources of surface water pollution in agricultural catchments (UNEP, 2006; Shrestha and Kazama, 2007; Najafpour *et al*., 2008; Bu *et al*., 2010). Additionally, the complex dynamics of surface runoff, interflows, erosion rates and subsurface flows are influenced by site specific land use/land covers systems (Saenyi, 2002; Kandrika and Venkatatram, 2005). Factor analysis of the physicochemical parameters and solids significantly loading on the principal components clearly indicated the influence of seasonality at Kabianga and the significance of anthropogenic impacts on surface water quality in Sondu. In the tropics and sub-tropics, high intensity rainfall generates significant surface runoff which easily erode loose soil, debris and contaminants into the respective sinks (Dabrowski *et al*., 2002) including surface water bodies (Saenyi, 2002; Antikainen *et al*., 2008). The changes in EC and TDS are related to ionic pollutants (Zhang *et al*., 2011) since conductivity levels reflect the status of dissolved inorganic constituents in water such as metal ions, nitrates, phosphates and chloride soriginating from surface runoff (UNESCO-WHO-UNEP, 1996; Jonnalagadda and Mhere, 2001). Temporal differences in EC and TDS also suggested the influence of seasonality.

Although not evident in this study, historically; agricultural land use activities have predominantly been the main source of human-enhanced sediments in water bodies (Baker and Richards, 2003). Swallow (2006) noted that conversion of forest to grass and cropland over the last century in LVB has been a major factor contributing to declines in soil fertility, soil physical condition and increased soil erosion. Compared to forest and bushland, areas dominated by grass and crops are 16 times more likely to be affected by severe erosion (Swallow, 2006). The conversion of land under natural vegetation cover to cropland or bare land can increase soil erosion and the associated sedimentation in streams, particularly when soil is exposed.

Sediments are an integral and inseparable part of aquatic environments and are important in the physicochemical and ecological dynamics of any aquatic ecosystem. Sediments are important in the transport and retention of ions, organic and particulate compounds, such as phosphorus (Kitaka *et al*., 2002; Adeogun *et al*., 2011). Therefore, there is a high potential of such pollutants to be retained in sediments, especially ions than their release in the water column (UNESCO-WHO-UNEP, 1996). In this study, sediments correlated significantly with EC, TDS and temporal trends in river Sondu-Miriu suggesting the influence of seasonality and antecedent conditions. During dry weather, which precedes long wet seasons, land preparation and sparse vegetation together with the huge build-up of loose soil and debris on land creates potential surface runoff loads. These materials and other contaminants are easily eroded into streams as surface runoff with the onset of rains (SUMAWA, 2005; Yillia *et al*., 2009). However, diffuse sources of suspended sediments, pathogens, nutrients and pesticides in agricultural land uses are often difficult to measure (Baker and Richards, 2003). Nevertheless, TSS, OM and TS trends observed in RSM concurred with that observed in similar river studies (SUMAWA, 2005; Khadka and Khanal, 2008; Mtethiwa *et al*., 2008; Yillia *et al*., 2009). Seasonal variations in precipitation intensity and amount and surface runoff strongly alter river discharges and consequently the concentrations of sediments and pollutants in stream water (Sing *et al*., 2004). In addition, other natural factors such as geology, soil type, topography and vegetation cover affect water quality in aquatic systems. In-stream activities of humans and livestock have been previously identified as important contributors to diffuse pollution in streams (Mathooko, 2001; SUMAWA, 2005; Yillia *et al*., 2007). Fluctuations in river discharge can and have also been affected by human activities; for instance, due to abstraction, urbanization or impounding; discharges from industry, agriculture or sewerage among others. Many of these anthropogenic influences are part of the larger process of catchment land use or land cover change that can affect water quality in both rivers and lakes (Baker and Richards, 2003).

CONCLUSION

Temporal variations in sediments and surface runoff water quality both in different agricultural land uses and river Sondu-Miriu were observed. Temporal variations in surface runoff volumes, water quality and sediment load correlated significantly to seasonality (hydroperiods). Hydrological changes impacted highly in agricultural land uses which exposed soil to erosion by reducing land cover, increased surface runoff accompanied by higher sediment and nutrient loads. This adversely affected the water quality of recipient surface waters in the basin including River Sondu-Miriu.

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