CrossMark

A review of the ecohydrology of the Sakumo wetland in Ghana

Cynthia Nonterah (ID) **· Yongxin Xu · Shiloh Osae ·
Thomas T. Akiti · Samuel B. Dampare**

Abstract The Sakumo wetland is an internationally recognized Ramsar site located in a largely urban area and provides essential ecological and social services to wetland community dwellers. Despite its importance, the wetland has over the years been subjected to human interference resulting in considerable risks of deteriorating water quality, biodiversity loss, and drying up of most parts of the wetland. The conversion of land for residential and agricultural uses has significantly altered the hydrological characteristics of the land surface and modified pathways and flow of water into the wetland. Other drivers identified included drainage (mainly as runoff from agricultural farms), anthropogenic pressure (waste discharge) due to infrastructure development associated with urbanization, chemical contamination as a result of industrial and household pollution, and unsustainable fishing practices (overfishing). The purpose of the study was to review some of the physical and chemical properties of the Sakumo wetland on the changing wetland resources with emphasis on water quality. Rapid urbanization, industrialization, and overexploitation of wetland resources were identified as key causative factors affecting the wetland functions. Their effects on the wetland among others include increased nutrient and toxic chemical load which has resulted in reduced wetland surface water quality and decrease in species diversity. pH of the wetland waters was generally alkaline which is characteristic of water bodies influenced by seawater under oxygenated conditions. The increasing trends of electrical conductivity, phosphates, ammonia, nitrate, and nitrite, though small, point to deteriorating water quality in the wetland. The lagoon water was observed to be heavily polluted with nutrients particularly phosphate. The sequence of nutrient in the wetland was found to be in the order of PO_4-P > NH_3-N > NO_3-N > NO_2-N. These, if not checked, will result in further deterioration of the wetland function. In order to protect the wetland structure and function, it is recommended that a determination for both surface water and groundwater (quality and quantity) components of the ecological reserve (aquatic ecosystem) as well as the basic human need should be undertaken. In addition, a complete hydrological study of the wetland must be done. This will enable a well-balanced water allocation scheme to all users while still ensuring long-term survival and sustainability of the wetland.

C. Nonterah (✉) · T. T. Akiti · S. B. Dampare
Graduate School of Nuclear and Allied Sciences, University of
Ghana, Atomic Campus, Legon, Ghana
e-mail: adwoalaar@gmail.com

C. Nonterah · Y. Xu
Department of Earth Sciences, University of the Western Cape, P'
Bag X 17, Bellville 7535, South Africa

C. Nonterah · S. Osae
National Nuclear Research Institute, Ghana Atomic Energy
Commission, P.O. Box LG 80, Legon, Ghana

🖄 Springer

Introduction

The Sakumo wetland is an internationally recognized Ramsar site located in a largely urban area with a growing population. The wetland provides essential ecological and social economic services to the wetland communities. However, over the years, the wetland has land use changes that have been influenced by largely due to human interference. This is due to the conversion of land for residential and agricultural purposes. The conversion of land to agricultural and residential uses has the tendency to significantly alter the hydrological characteristics of the land surface and also modify pathways and rates of water flow to the wetland. The wetland is threatened by pollution from domestic and industrial solid/liquid waste, overexploitation, and urbanization due to burgeoning human population. Urbanization in the wetland is a major cause of impairment of water quality (Anku 2006). This has resulted in short- and long-term impacts including a decrease long-term deep and shallow groundwater recharge, lowering of the water table which may, in turn, dry up the wetland, and produce intermittent dry streams during periods of low flows. These human impacts have negatively impacted on the wetland drainage processes that have affected the quality and quantity of wetland water which, in turn, affects the ecological health and functions of the wetland.

Despite the significance of the wetland as a unique habitat in Ghana, very few published studies have focused on quantifying water inflow and abstraction from the wetland. Most studies have examined the value of the wetland from the perspective of fish (Pauly 1976; Koranteng 1995) or birds (Ntiamoa-Baidu 1991; Gbogbo and Attuquayefio 2010). Many water quality/pollution studies (Koranteng 1995; Yawson 2003; Edor 2008; Asmah et al. 2008; Nartey et al. 2011) have focused on the physicochemical dynamics, nutrient and pollutant fluxes, and heavy metal contamination. These studies however did not consider the whole wetland catchment but focused on the lagoon. The coverage of pollution and water quality studies on the lagoon alone is inadequate for a complete understanding of the extent of changes within the wetland. Also, few water pollution studies have employed simple hydrochemical tools and stable isotopes of O-18 and D in assessing the quality of the wetland water. Laar et al. (2011) used stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$) to infer source of waters into the wetland and the effect of

mixing of seawater and wetland water. These methods often seem to be unable to characterize and differentiate the origins of the pollutants as well as recommend appropriate water quality standards needed to meet the requirements of all users. However, the use of combination of the stable isotopes of water and the radioactive isotope, tritium (^{3}H), has been known to provide better understanding of wetland hydrological dynamics. This is yet to be explored in the Sakumo wetland.

With regard to water-related problems, resource-directed measures (RDM) can be developed to assess the environmental flow requirements of the wetland. The objective of RDM is to ensure the protection of water resources, in the sense of protecting ecosystem functioning and maintaining a desired state of health (integrity or condition). This objective can be met through various processes, including the setting of the ecological reserve (the quantity and quality of water reserved to support ecosystem function). Although relatively new especially in developing countries like Ghana, RDM studies have been conducted for estuaries, rivers, forest, and grassland ecosystem (Colvin et al. 2002; Xu et al. 2002; Yang et al. 2009). A successful classification scheme of the Sakumo wetland will provide a balance between protection of the wetland water resources and socioeconomic development in order to maximize the welfare of the communities within the wetland catchment. The findings will also be applicable to many other wetlands along the coast of Ghana with similar morphological and land use characteristics, many of which are subject to increasing pressure from urbanization.

Questions like: is the wetland a groundwater dependent ecosystem (GDE) or is it rain-fed; is the wetland losing or gaining water; what are the flow rates suitable for ensuring an ecologically balance state of the wetland remain unresolved. The understanding of surface water and groundwater (quality and quantity) components of the ecological reserve (aquatic ecosystem) as well as the basic human need in the wetland will be a prerequisite for mapping out an allocation scheme to all users (e.g., fishing, agriculture, biodiversity, and tourism) while still ensuring the long-term survival and sustainability of the wetland.

Study area

Ghana is located in West Africa on the Guinea coast. At latitudes of 4–12° N, the climate of Ghana is tropical

and strongly influenced by the West African Monsoon. Ghana's climate is influenced by three air masses namely the South-West Monsoon, the North-East Trade Winds (Tropical Continental Air Mass), and the Equatorial Easterly Winds. The warm but moist South-West Monsoon which originates from the Atlantic Ocean and the warm, dry, and dusty Tropical Continental Air Mass (Harmattan) from the Sahara Desert approach the tropics from opposite sides of the equator and flow toward each other into a low-pressure belt known as the intertropical convergence zone (ITCZ) (Fig. 1). The pattern of rainfall is closely related to the movement of the ITCZ (Dickson and Benneh 1995). The Greater Accra Region is divided into eight districts namely the Accra Metropolitan Area (AMA), Tema Municipal Area (TMA), Ga East District, Ga West District, Dangme East District, Dangme West District, Adenta Municipal, Ashaiman Municipal, Ga South District, and Ledzekuku-Krowor Municipal. The Sakumo wetland is located within the TMA area.

The lagoon is connected to the sea by a nonfunctional (now permanently open) sluice. The wetland is periodically inundated especially during the rainy season. However, large portions of the lagoon dry up during the dry season, resulting in hyper-saline conditions. However, wetland water quality studies have been limited to surface water from the wetland which covers only the lagoon reaches (southern zone—closest to the sea, the northern zone—the farthest from the sea, and the middle zone—lying between the two) as shown in Fig. 3.

Climate

The Sakumo wetland lies within the coastal savannah vegetation zone with low annual rainfall averaging 800 mm distributed over less than 80 days. The rainfall pattern of the area is bimodal with the major season falling between the months of April and mid-July and a minor rainy season around the month of October (Fig. 2). The mean monthly temperature ranges from 24.7 °C in August (the coolest) to 28 °C in March (the hottest) with an annual average of 26.8 °C (Dickson and Benneh 1995). The nearness of the wetland to the equator makes daylight hours practically uniform during the year. Relative humidity is generally high, varying from 65 % in the mid-afternoons to 95 % at night. Predominant wind direction is from WSW to NNE with speeds ranging between 8 and 16 km/h. The vegetation cover of the metropolis is primarily shrub and grassland with isolated trees that are only denser toward the northern fringes area.

Geology and hydrogeology setting

The coastal zone of Ghana is underlain by a gentle, mature topography that slopes toward the shore (Muff and Efa 2006). The country is underlain partly by what is known as the basement complex which comprises a wide variety of precambrian igneous and metamorphic rocks. These crystalline rocks cover about 54 % of the country (Junner and Bates 1945). The geology of the Accra coastal environment is made up of various types

Fig. 1 A picture of the structure of the monsoon and land ITCZ over Ghana, Africa
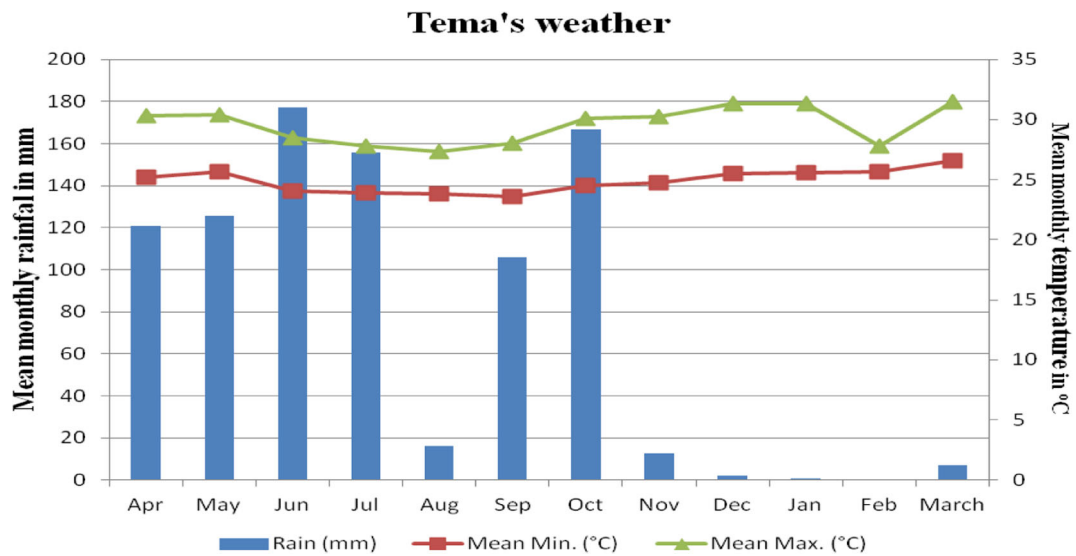
Tema's weather

Fig. 2 Monthly mean rainfall and temperatures at the Tema meteorological station (1995–2012). Source: Ghana Meteorological Agency

of rock. They include unconsolidated sediments, sandstones, quartz, and lagoonal sediment. The western part is predominantly unconsolidated soil, while the eastern part is more of quartz and little portions of lagoonal sediment. The central part is mainly sandstone and a little portion of quartz (Muff and Efa 2006). The geology of the Sakumo catchment which is located in the southeast coastal plains of Accra is mainly underlain by Dahomeyan (Precambrian) rocks (Fig. 3). The Dahomeyan formation is one of the oldest formations, and it consists mainly of metamorphic rocks such as crystalline gneiss and migmatite, with minor quartz and biotite schists. The gneiss is generally massive and has few fractures.

The two main varieties are the silicic and mafic gneisses, which weather into slightly permeable and nearly impermeable calcareous clays, respectively. The generally impervious nature of the weathered zone and massive crystalline structure of the rocks limit the yields that can be obtained from hand dug wells or boreholes. Borehole depths range between 20 and 30 m, with a success rate of 40 % and yield average 0.3–0.8 m/l (Muff and Efa 2006). The source of groundwater for use is mostly from the shallow aquifer. In most parts of the Greater Accra Region, the occurrence of groundwater is mainly due to the existence of linear features as a result of fracturing, faulting, and weathering as the main rocks are impermeable (Banoeng-Yakubo et al. 2010). Depth of groundwater table lies between 5 and 15 m. Recharge is generally low due to low permeability of

overburden clayey layer (Muff and Efa 2006). Soils found in the study area are categorized into four main groups namely drift materials resulting from deposits by windblown erosion; alluvial and marine mottled clays of comparatively recent origin derived from underlying shales; residual clays and gravels derived from weathered quartzites, gneiss and schist rocks; and lateritic sandy clay soils derived from weathered accraian sandstone bedrock formations.

Hydrology

Three principal subdrainage basins have been identified in the catchment area. The major ones are the Mamahuma-Onukpawahe (at the western side) and the Dzorwulu-Gbagbla-Ankonu (situated at the northern end) subbasins. The eastern and southern subbasins constitute the minor ones (Fig. 3). The catchment area has limited groundwater potentials because of the low rainfall and impermeability of the underlying rocks (Muff and Efa 2006). The main feeder streams, the Dzorwulu and Mamahuma, have been rechanneled for irrigation. The Dzorwulu stream has a dam on it, and this is situated north of Ashiaman town near Santeo. The Mamahuma stream also has a dam on its upper catchment. This normally resulted in very little flow of freshwater into the lagoon during the dry season. There are no staff gauges on Sakumo wetland and therefore no records of water levels. The lagoon reaches its lowest in the dry season, and seawater flows into the lagoon
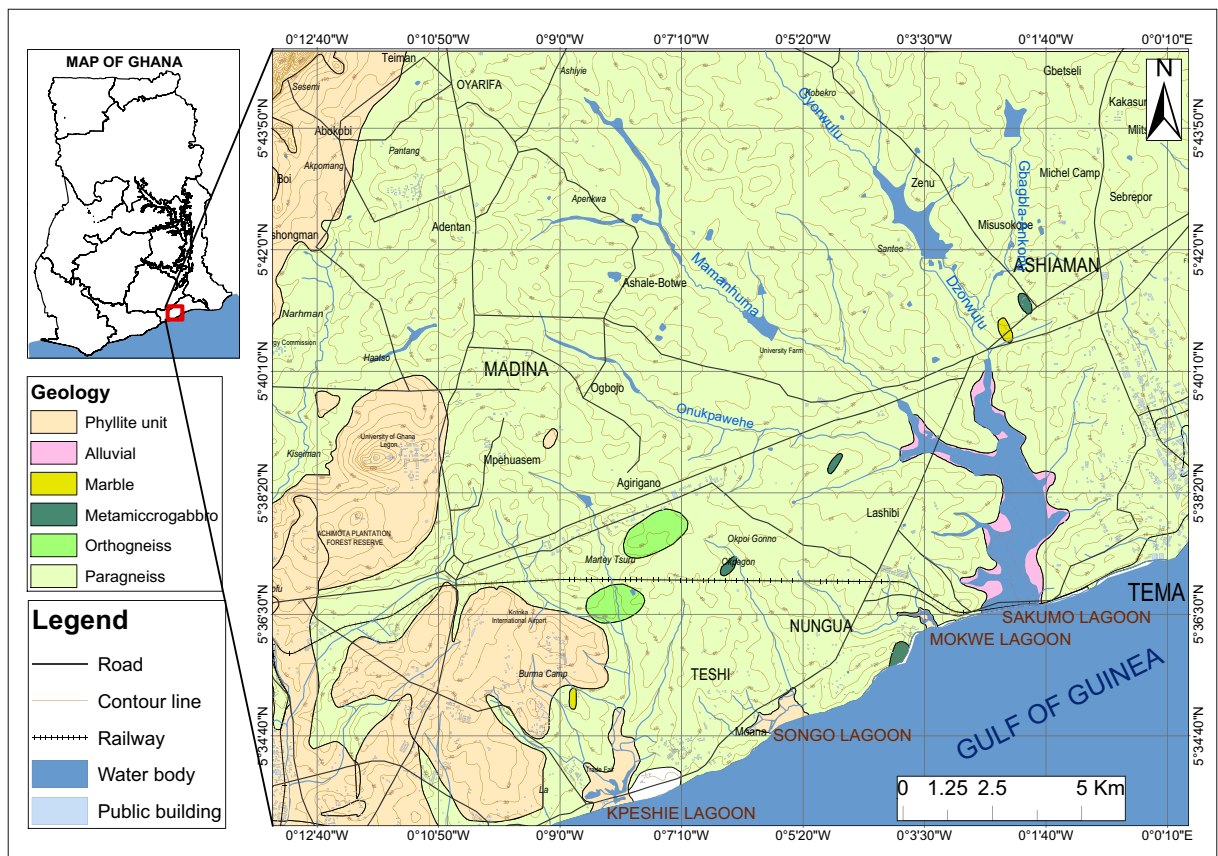
Fig. 3 Geology distribution of the Sakumo wetland, Ghana

during high tides. For this reason, the lagoon water is hyper-saline during the dry season. The lagoon covers an area of 1 km^2 in the dry season, but the entire flood plain may be inundated in the wet/rainy season increasing the surface area to about 10 km^2.

Land use and urbanization

Urbanization is a major cause of loss of coastal wetlands as it turns to exert significant influences on the structure and function of wetlands by modifying the hydrological and sedimentation regimes. In Ghana, settlements with 5000 or more inhabitants are considered urban (GSS 2002). The Sakumo wetland falls between two rapidly growing cities (Accra and Tema) and has one of the highest urban growth rates within the coastal zones in Ghana. Nearly, 60 % of industries in Ghana can be found along the coast of Accra and Tema (GCLME 2007). From 1984 to 2000, the percentage of persons

living in urban areas in Ghana has risen from 32 to 44 %. In 1984, the population within the catchment was 114,619. In 1997, the population rose to 250,000; in 2010, the population rose to 402,637 (GSS 2002, 2012). Most of the population of the catchment lives in suburban areas along the coast. Small urban areas have also developed to the north and lie mostly within rural land cleared for agriculture. The wetland is primarily agriculture. Rice, cassava, and vegetable farming is undertaken in the northern sections of the wetland and also along the banks of the rivers which are the main source of freshwater input into the wetland. Farmers rely on the rivers to irrigate their farms. The wetland catchment is also noted for cattle grazing. Besides population increment, a shift from farming or crop cultivation to real estate development has influenced land cover changes in the catchment. These human activities if not checked could undermine the wise use of the wetland.

Data acquisition

As a starting point, there was a review of the available literature on the Sakumo wetland. Secondary data were collected, analyzed, and reviewed. These included relevant academic articles, books, newspapers, magazines, and reports of previous studies. Major priority issues considered in selecting publications to be used for the review were issues of water quality, due to land-based human activities and also on fishery resources depletion and loss of marine biodiversity. Limitations of the review lack of quantitative and qualitative assessment of the major land-based sources. For instance, where data on pollution concentration are available, data on volumes of discharges are lacking making it difficult to calculate the actual pollution load. Also, where information on types of contaminants is available, no information on transport pathways exists. It is also clear that many of the key sources of pollution are very closely linked (e.g., sewage and nutrients). Knowledge on interaction and synergies between different land-based pollutants in the coastal environments is insufficient. There is an urgent need for a precise qualitative and quantitative assessment of the significant sources of land-based pollution in the study area.

Wetland water quality and nutrient concentration

Due to increased urbanization, water quality regimes of the wetland have become more intensified with storm water runoff from agriculture and urban lands bringing excess water, nutrients, and other contaminants to wetlands. These discharges have been revealed to carry large influxes of nutrients, suspended and dissolved organic matter, contaminants, and other toxic materials into the wetland resulting in poor water quality status of the wetland. Amuzu (1997) noted that, in the early 1990s, coastal wetlands with little stress from human activities (including the Sakumo wetland) maintained good water quality (Table 1).

This has been attributed to the disappearance of some fish species and migratory birds from the wetland. High dissolved oxygen (DO) concentrations in the wetland water have been attributed to photosynthetic activity, associated with the high biomass of cyanobacteria and the intrusion of the seawater at high tide (Biney 1990). Asmah et al. (2008) reported an increase in DO levels that is from 98 % in 1997 to about 140 % in 2002 which they attributed to human activities. Koranteng 1995;

Table 1 Some selected physiochemical characteristics of coastal wetlands in Accra (units in mg/l except pH [no units])

Lagoons	pH	DO	BOD	PO_4^{3-}-P	NH_3-N	NO_3-N
Korle	7.1	4.4	98.9	0.86	3.80	0.30
Kpeshie	8.0	7.3	8.1	0.11	0.29	0.48
Mokwe	7.9	6.4	3.2	0.09	0.20	0.30
Sakumo II	8.2	8.0	12.5	0.08	0.15	0.18
Chemu II	8.1	0.5	71.2	0.59	1.30	0.36
Goa	8.1	6.1	6.4	0.04	0.11	0.96
Laloi	7.6	6.6	5.5	0.06	0.20	0.41
WHO 1996	6-9	–	<0.3	<0.3	–	<10

Source: Environmental Management Associates (1991)

Yawson 2003; Nixon et al. 2007; Asmah et al. 2008) between the late 1990s and 2000s (Table 2) reported slightly to moderately alkaline pH of the lagoon water. Ansa-Asare et al. (2008) reported high NO_3-N and PO_4^{3-}-P at the riverine end of the wetland and also toward the end of the raining season (Nartey et al. 2011). This is contrary to studies done by Koranteng 1995 and Asmah et al. 2008 which reported high nutrient concentrations during the dry season. This was attributed to the processes of evaporation and concentration of solutes during the dry season. Koranteng (1995) reported mean total phosphorus concentrations of 0.644 mg/l, while Asmah et al. (2008) reported a mean of 1.71 mg/l in 2002. Nartey (2011) reported total phosphorus concentrations of 3.62 mg/l which exceeds the EPA maximum guideline value of 2.0 mg/l. The sequence of order of the nutrient in the wetland was PO_4-P > NH_3-N > NO_3-N > NO_2-N. The distribution of trace metals (such as Fe and Mn) in the lagoon have been attributed to urbanization and high exploitation of cultivable lands (Ansa-Asare et al. 2008; Laar et al. 2011). High levels of manganese in the lagoon for instance have been attributed to wastewater discharges and leachates from agricultural farm lands.

Correlation analysis and Piper diagram

The major ion chemistry and compositional relations among ionic species of a sampled water can reveal the origin of solutes and processes that generates an observed water composition. Data for the correlation analysis was extracted from (Laar et al. 2011). From the matrix plot, strong (r=0.8 to 1.0), moderate (r=0.6 to 0.8), and low (r=0.5 to 0.6) correlation between selected

Table 2 Statistical summary of physicochemical results of surface and subsurface water (n=86) in the Sakumo wetland (units in mg/l except temp [°C] and SEC [μS/cm], pH [no units])

	Min.	Max.	Mean	Median	Stand. dev.	WHO (2004)	Seawater value
PH	6.6	8.8	7.88	7.92	0.59	6.5–8.5	NS
Conductivity	9170	43,800	18,819.09	17,060	10392.6		5000
Total dissolved solids	5044	24,090	10,347	9383	5711.26	1000	32,000
Alkalinity as $CaCO_3$	175	742	298.64	265	152.54	400	NS
Carbonate as CO_3	27.6	96.4	53.2	35.6	37.63		NS
Bicarbonate, HCO_3	236	901	389.64	3223	116.67		142
Chloride as Cl	2680	14,095	6244.18	6055	3548.59	250	19,000
Sodium as Na	1381	5714	3043.73	2561	1395.52	200	10,500
Potassium as K	14.1	28.1	21.13	19.4	5.3	12	390
Calcium as Ca	123	1066	364.82	233	112.2	75	410
Magnesium as Mg	183	1732	504.36	363	253.97	100	1350
Iron as Fe	0.24	8.99	2.06	0.782	1.7	0.3	NS
Manganese as Mn	0.256	2.82	0.95	0.4	0.094	0.1	NS
Ammonium as N	0	5	2.41	2.46	0.96		NS
Nitrite as N	0	0.208	0.07	0.034	0.004		NS
Nitrate as N	0	0.32	0.11	0.059	0.009	10	NS
Orthophosphate as P	0.09	2.53	0.62	0.352	0.389	0.3	NS
Sulfate as SO_4	50.8	893	302.35	289	127.33	200	270

variables was found out. To know this objective, r values and correlation probability values were calculated. To nullify the effect of missing data, pairwise missing data deletion technique has been adopted. From Table 3, the surface water samples disclosed a good correlation between electrical conductivity (EC) and Cl (r=0.98) which further indicated that variation in EC concentration is controlled by Cl^- concentration. Another fairly good correlation also observed between Na and EC (r=0.93) and Mg and Cl^- (r=0.95), Mn and Fe (r=0.90), Mn and NO_2-N (r=0.85) confirm a common primary source which is both domestic effluent/ sewage and/or fertilizer application. The level of significance is taken at 1 and 5 %, respectively. However, a perfect positive correlation coefficient was observed between EC and total dissolved solids (TDS) (r=1), whereas high positive correlation was observed between Na^+ and EC (r>0.90), Na^+ and Cl^- (r>0.90) virtually in all the different water sources. In the shallow groundwater (Table 4), high positive correlation coefficient was observed between Na^+ and EC (r=0.91), Na and Cl^- (r= 0.97), Na and K^+ (r=0.93), Mg and Na^+ (r=0.92), Mg and Cl^- (r=0.95), Mg and HCO_3^- (r=0.95), NO_3^- and NO_2^- (r=0.99), PO_4^{3-} and NO_2^- (r=0.94), PO_4^{3-} and NO_3^- (r=0.95), and SO_4^{2-} and TDS (r=0.95). The high

correlation implies that subsurface water chemistry was mainly controlled by these ions.

The piper diagram (Fig. 4) was prepared in accordance with modifications by Black (1966). Ansa-Asare et al. 2008; Asmah et al. 2008 the Piper diagram was used to evaluate differences in major ion chemistry in both the surface water and groundwater samples. The Piper diagram shows that the water generally contains low concentrations of calcium and magnesium compared to sodium and potassium while chloride is the dominant anion. Most of the samples plot in the sodium and chloride regions of the two triangle plots respectively depicting a Na–Cl type of water. The predominantly Na–Cl water type could be attributed to the near coastal surface salt nature of the water.

Isotope signature on hydrology

Published studies on distribution of stable isotopes of ^{18}O and D in the Sakumo wetland are very limited (Laar et al. 2011) which demonstrated that significant isotopic differences exist between wetland water and the riverine waters (Mamahuma, Onukpawahe, and Dzorwulu). From the stable isotope analysis, $\delta^{18}O$ and δD values range from −17.96 to 6.22‰ and −3.68 to −0.26‰ for

Table 3 Correlation analysis of lagoon (surface) water from the Sakumo wetland

	pH	EC	TDS	Turb	T.Alk	CO$_3^{2-}$	HCO$_3^{-}$	Cl^{-}	F^{-}	Na	K	Ca	Mg	Fe	Mn	NH$_4$-N	NO$_2$-N	NO$_3$-N	PO$_4$-P	SO$_4^{2-}$
pH																				
EC	−0.743*																			
TDS	−0.743*	1.000**																		
Turb	0.295	−0.067	−0.067																	
T.Alk	0.218	−0.069	−0.069	0.952**																
CO$_3^{2-}$	0.275	−0.102	−0.102	0.957**	0.930**															
HCO$_3^{-}$	0.042	0.011	0.011	0.874**	0.970**	0.846**														
Cl^{-}	−0.717*	0.989**	0.989**	−0.004	0.003	−0.034	0.087													
F^{-}	0.199	−0.019	−0.019	0.981**	0.975**	0.959**	0.921**	0.043												
Na	−0.578	0.936**	0.936**	0.119	0.129	0.058	0.207	0.965**	0.147											
K	−0.082	0.5	0.501	0.521	0.452	0.37	0.44	0.569	0.446	0.684*										
Ca	−0.642*	0.486	0.486	−0.152	−0.239	−0.172	−0.178	0.483	−0.105	0.310	0.085									
Mg	−0.702*	0.972**	0.972**	−0.045	−0.011	−0.044	0.059	0.956**	0.015	0.907**	0.459	0.328								
Fe	0.489	−0.398	−0.398	0.411	0.295	0.587	0.131	−0.38	0.351	−0.361	−0.133	−0.347	−0.303							
Mn	0.147	−0.139	−0.139	0.245	0.139	0.469	0.014	−0.124	0.219	−0.195	−0.154	−0.016	−0.061	0.908**						
NH$_4$-N	0.245	0.26	0.26	0.487	0.445	0.561	0.313	0.282	0.461	0.321	0.388	−0.285	0.377	0.521	0.502					
NO$_2$-N	−0.179	0.062	0.063	−0.19	−0.087	−0.277	0.048	0.101	−0.203	0.232	0.247	−0.229	0.048	−0.412	−0.499	−0.516				
NO$_3$-N	0.006	0.117	0.117	−0.36	−0.292	−0.493	−0.212	0.126	−0.385	0.264	0.212	−0.287	0.096	−0.54	−0.672*	−0.41	0.858**			
PO$_4$-P	−0.452	0.044	0.044	−0.293	−0.069	−0.265	0.093	0.05	−0.223	0.018	−0.055	−0.109	0.132	−0.374	−0.281	−0.402	0.618	0.359		
SO$_4^{2-}$	−0.257	0.02	0.02	−0.015	−0.02	−0.083	0.111	0.078	−0.081	0.169	0.298	0.054	−0.081	−0.164	−0.172	−0.436	0.671*	0.35	0.306	1

*Correlation is significant at the 0.05 level (two-tailed)

**Correlation is significant at the 0.01 level (two-tailed)

Table 4 Correlation analysis of groundwater samples from the Sakumo wetland

	pH	EC	TDS	Turb	T.Alk	CO3	HCO3	Cl	Na	K	Ca	Mg	Fe	Mn	NH4-N	NO2-N	NO3-N	PO4-P	SO4^{2-}
pH	1																		
EC	−0.702																		
TDS	−0.407	0.699																	
Turb	**0.996****	−0.678	−0.412																
T.Alk	0.712	−0.838	−0.725	0.741															
CO3	0.792	−0.778	−0.773	0.822	**0.966****														
HCO3	0.219	0.314	0.663	0.179	−0.505	−0.411													
Cl	−0.608	**0.979****	0.728	−0.6	**−0.888***	−0.8	0.48												
Na	−0.41	**0.910***	0.737	−0.41	−0.841	−0.72	0.652	**0.971****											
K	−0.387	0.788	0.812	−0.41	**−0.911***	−0.827	0.794	**0.888***	**0.935***										
Ca	−0.566	0.266	0.664	−0.62	−0.603	−0.771	0.279	0.275	0.2	0.454									
Mg	−0.544	**0.961****	0.547	−0.51	−0.742	−0.617	0.322	**0.957***	**0.923***	0.746	0.008								
Fe	0.595	−0.111	0.458	0.565	−0.032	0.011	0.862	0.038	0.246	0.399	0.128	−0.098							
Mn	−0.003	0.413	0.834	−0.04	−0.627	−0.6	**0.953***	0.548	0.67	0.844	0.536	0.339	0.791						
NH4-N	0.016	0.517	0.077	0.092	−0.018	0.133	0.008	0.469	0.487	0.157	−0.634	0.681	−0.087	−0.105					
NO2-N	−0.197	0.321	−0.275	−0.11	0.189	0.26	−0.557	0.185	0.088	−0.263	−0.634	0.443	−0.603	−0.61	0.821				
NO3-N	−0.238	0.33	−0.295	−0.16	0.161	0.234	−0.58	0.194	0.088	−0.258	−0.619	0.45	−0.649	−0.63	0.796	**0.998****			
PO4-P	−0.499	0.535	−0.05	−0.42	−0.071	−0.042	−0.535	0.381	0.233	−0.086	−0.35	0.581	−0.686	−0.498	0.737	**0.944***	**0.951***		
SO4^{2-}	−0.22	0.459	**0.956***	−0.23	−0.553	−0.638	0.688	0.502	0.54	0.68	0.714	0.286	0.611	0.861	−0.112	−0.465	−0.494	−0.274	

*Correlation is significant at the 0.05 level (two-tailed)

**Correlation is significant at the 0.01 level (two-tailed)

Fig. 4 Piper diagram
summarizing geochemistry of
surface and subsurface
groundwater (piezometer) from
the Sakumo wetland
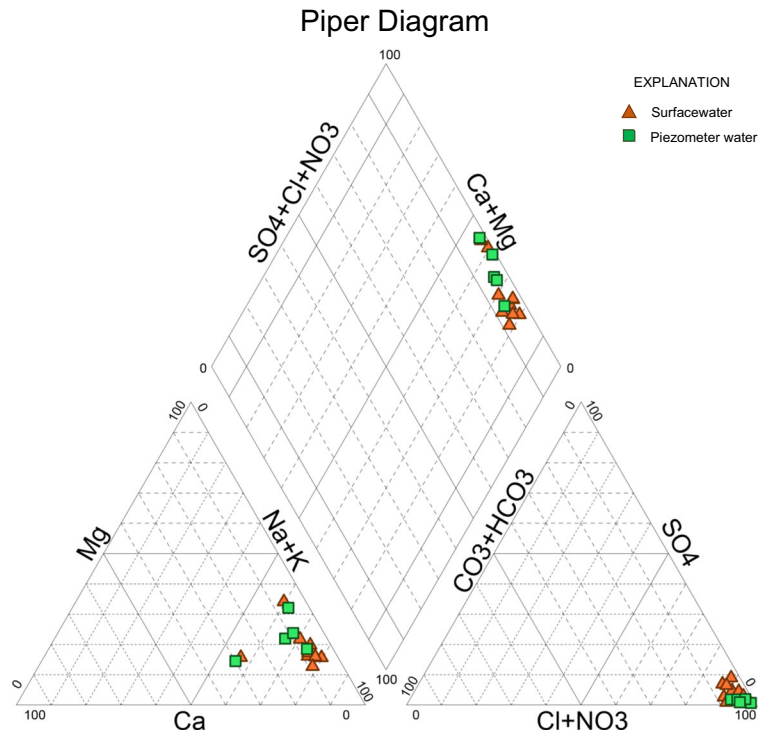
rainwater, 3.42 to 18.30‰ and 0.55 to 3.86‰ for la-
goon water while subsurface water (from the piezome-
ters) ranged from 8.09 to 15.43‰ and 2.01 to 3.45‰,
respectively (Laar et al. 2011). In addition to the existing
data on stable isotopes of water, six piezometers were
installed and the shallow groundwater analyzed for the
stable isotope composition. The stable isotope compo-
sition of the shallow groundwaters was plotted along
with the surface waters (Fig. 5). Perusal of the
plot showed no difference between the $\delta^{18}O$ and
δD concentrations for both surface water and

shallow groundwater. This was attributed to possi-
ble similarity in hydrostratigraphy and climate con-
dition of the catchment.

The effect of evaporation is evident on all the water
types in the area. Isotopic enrichment could be a result
of the interaction between wetland water and seawater
as well as rainfall (Fig. 6) as the waters approached a
seawater value. However, the narrow range in the stable
isotopic composition of the surface water and subsur-
face water is indicative of a fairly homogenized source
of water for the various types of waters.

Fig. 5 Relationship between δD
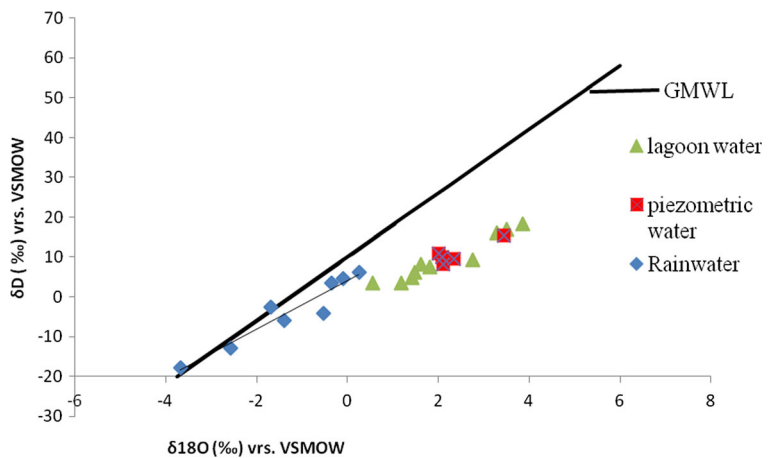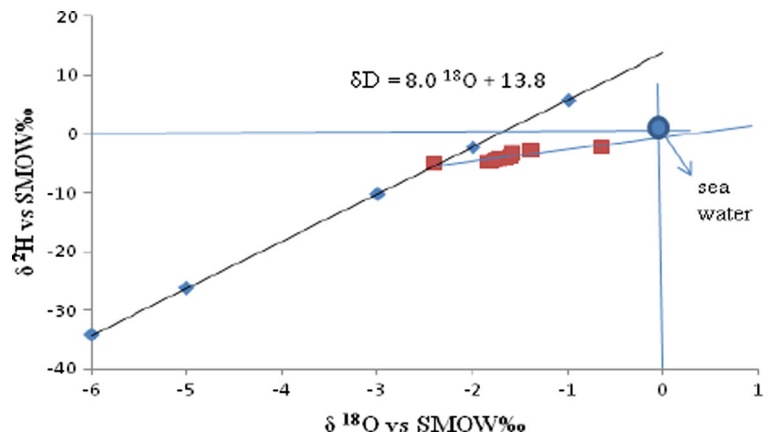vs. VSMOW and $\delta^{18}O$ vs.
VSMOW in the different waters

Fig. 6 A regression line of δD-δ^{18}O of the local meteoric water line (LMWL) with surface water from the Sakumo wetland and theoretical seawater value

Integration of wetland component for ecological water requirement study

Globally, there is an increasing desire to conserve or restore the ecological health and functioning of wetlands for both biodiversity and human use. To achieve this, nations which are signatories to the Ramsar convention are encouraged to develop methods for defining RDM required to achieve desired ecological objectives. A study is proposed to clarify the need for an assessment
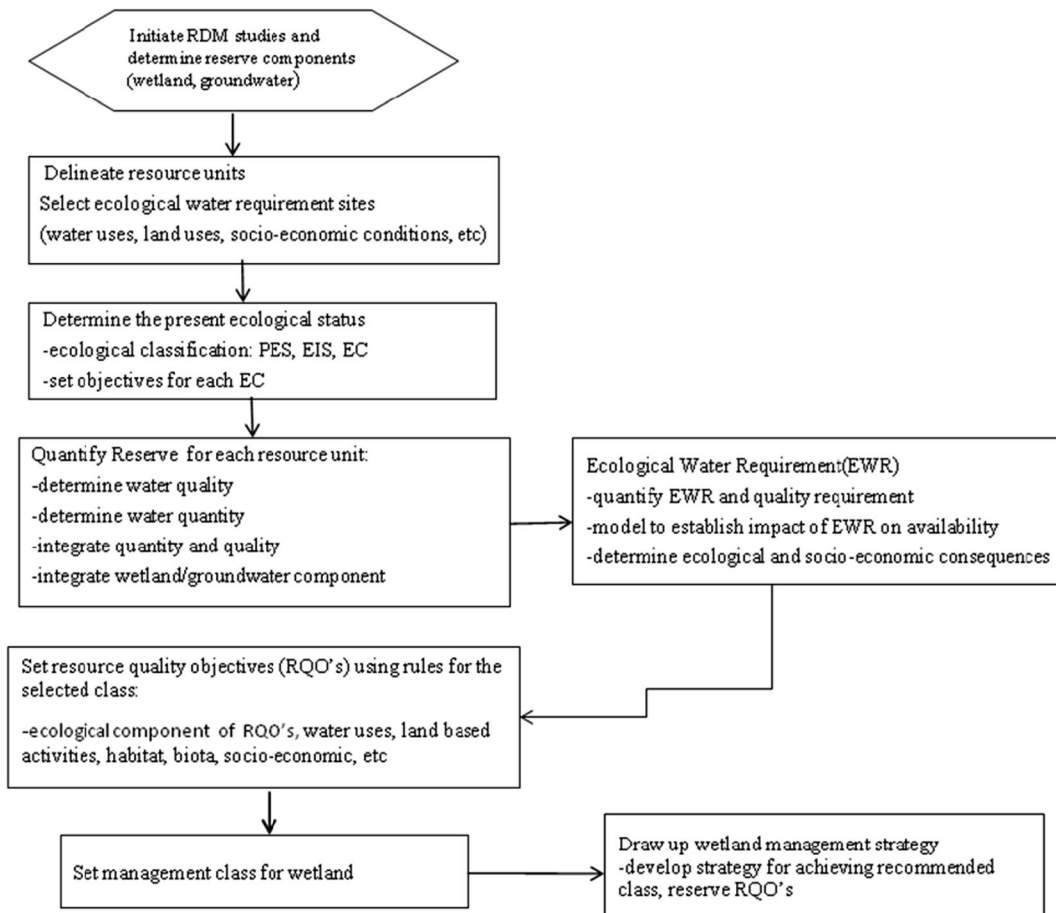

Fig. 7 Procedures for the determination of the ecological water requirement (modified from DWA 2010)

of the wetland component of the ecological water requirement (EWR) component of the Sakumo wetland. A preliminary determination of the surface water (quantity and quality), groundwater component of the wetland as well as the basic human needs will be drawn out. An overall assessment of ecological state of the wetland would be based on the rule-based model developed by the Directorate of Resource Quality Services for Estuaries (DWA 2010) but modified for wetlands. The modified system will use the underlying contemporary hydrological processes and formative geomorphological setting as the basis of classification.

An intermediate determination of the wetland component for the EWR will be undertaken. The purpose is to describe the reference conditions and assess the present ecological state (PES) of the wetland. Reference conditions (RCs) and PES for the wetland components will be evaluated for key ecological drivers (hydrology, geomorphology, and water quality) and response indicators (vegetation and aquatic invertebrates). This will inform the definition of the wetland resource units (quality and quantity) needed to preserve basic human needs and the ecological reserve (aquatic ecosystem). Based on the ecological, social, and economic considerations of the reserve, the wetland will be assigned an ecological

category (EC), ranging from category A (unmodified) to category F (critically modified) which will effectively describe the present state of the wetland. The purpose of the classification system is to recommend an attainable EC, plus alternative categories where appropriate based on an understanding of causes of deviations of the PES from the RC and then set a management class (MC). The purpose of the MC is to maintain the current EC (if it is desirable) or improve management in other to increase to a better/higher EC. A procedure for the determination of the EWR is illustrated in Fig. 7.

The methods to be used in determining the wetland component of the ecological water requirement will include (Table 5):

- An assessment of available geological maps, hydrogeological maps, topographical maps, and aerial photographs
- An assessment of hydrochemical data, aquifer parameters, recharge (ecological role), and wetland vulnerability.
- Population census and population density data will also be reviewed to give an indication of the reliance of wetland catchment communities on groundwater, which will have an impact on the wetland.

Table 5 Summary of data required for baseline assessment

Component	Requirement for baseline study	Description of required data
General	Description of wetland catchment	-Floodplain topography -Land use practices -Water uses -Wastewater discharges
Bathymetry and sediments	Topographical surveys	-Contour maps, location maps, and cross-section plots -Sediment particle size distribution and total organic matter content
Water quality	-Physical water quality -General chemistry major ions -Nutrients	Salinity and temperature profiles -System variables (pH, turbidity, TDS, DO, etc.) -Inorganic nutrients -Toxic substances
Hydrology and hydrodynamics	Catchment size delineation	-Measure river inflow data (gauging stations) at the head of the wetland -Measure rainfall data in the catchment (or in a representative adjacent catchment) -Hydrological parameters (evaporation rates, radiation rates) -Flow losses (e.g., abstraction, impoundment) and gains (e.g., discharges, transfer schemes)
Fish	Species and size composition of fish community	Documented data from the Center for Africa Wetland studies
Birds	Major bird groups and their defining features	Documented data from the Center for Africa Wetland studies

- Land use information such as agricultural activities that rely on or impact on the wetland will also be sourced.
- Once-off cross-sectional survey to determine the geomorphology and hydraulics including surface flow volumes and the delineation of inundation zones, saturation, and vegetation zones to be conducted during the dry season;
- Documented data of key habitats, wetland plants, and aquatic invertebrates, and;
- Assessment of the anthropogenic impacts and trends on both water quality and quantity.

Conclusion

Based on this review, it can be concluded that the key factors affecting the wetland chemistry are domestic waste, agricultural runoff from farms, and seawater encroachment. Source of nutrient to the wetland was also found to be predominantly from fertilizers introduced by subsistence farming activities in the wetland. Stable isotopes of O-18 and deuterium have shown that the main source of water to the wetland is mostly rain and seawater. However, there is a gap on information about catchment behavior in terms of response to rainfall input, runoff, and storage components of the hydrological cycle, and the water balance will provide better understanding of the overall hydrological processes occurring in the wetland. The following are recommended for further studies:

(i) What is the rate of groundwater recharge in the wetland

(ii) What are the flow processes taking place in the wetland

(iii) What is the wetland–groundwater interaction

(iv) What are the flow requirements needed to maintain the basic human needs and the ecological requirements of the wetland (quality and quantity)

References

Amuzu, A.T. (1997). The impact of urbanization and development on surface waters in Ghana. Case studies. Proceedings of Rabat Symposium S4, Rabat, IAHS Publication.

Anku, K. S. (2006). *Managing wetlands in Accra, Ghana*. Nairobi: African Regional Workshop on Cities, Ecosystems and Biodiversity.

Ansa-Asare O. D., Mensah E., Entsua-Mensah M. and Biney C. A. (2008). Impact of human activities on nutrient and tropic status of some selected lagoons in Ghana. West Afr. J. appl. Ecol. 12.

Asmah, R., Dankwa, H., Biney, C. A., & Amankwah, C. C. (2008). Trend analysis relating to pollution in Sakumo lagoon, Ghana. *African Journal of Aquatic Science, 33*(1), 87–93.

Banoeng-Yakubo, B., Yidana, S., Ajayi, J., Loh, Y. & Asiedu, D. (2010). Hydrogeology and groundwater resources of Ghana: a review of the hydrogeological zonation in Ghana. In J. M. McMann (Ed.), Potable Water and Sanitation. Nova Science.

Biney, C. A. (1990). A review of some characteristics of freshwater and coastal ecosystems in Ghana. *Hydrobiologia, 208*, 45–53.

Back, W. (1966). Hydrochemical facies and ground-water flow patterns in northern part of Atlantic Coastal Plain. *U.S. Geological Survey Professional Paper* 498-A, 42.

Colvin, C., Le Maitre, D. & Hughes, S. (2002). Assessment of vegetation ecosystem dependence on groundwater. Draft report WRC Project 1092.

Department of Water Affairs (DWA) (2010). Resource directed measures for protection of water resources: methods for the determination of the ecological water requirements for estuaries. Water Resource Protection and Assessment Policy Implementation Process. Version 3. Pretoria.

Dickson, K. A., & Benneh, G. A. (1995). *A New geography of Ghana*. UK: Longman.

Edor, K. A. (2008). Pollution studies on sakumo ramsar site. Legon: University of Ghana 196pp MPhil. Thesis presented to Faculty of Science

Environmental Management Associates (EMA). (1991). Coastal Management Plan for Accra. A Report for Government of Ghana /UNDP/UNCHS, Accra, Ghana.

Gbogbo, F., & Attuquayefio, D. K. (2010). Issues arising from changes in waterbird population estimates in coastal Ghana. *Bird Population, 10*, 79–87.

GCLME/UNEP/UNEP-GPA/US-NOAA. (2007). Draft protocol to the abidjan convention concerning cooperation in the protection of marine and coastal environment from land-based sources and activities in the west and central african region. 13pp.

Ghana Statistical Services (GSS). (2002). 2000 population and housing census, greater Accra region. Analysis of district data and implications for planning.

Ghana Statistical Services (GSS). (2012). 2010 population and housing census, greater Accra region. Analysis of district data and implications for planning.

Junner, N.R., & Bates, D.A. (1945). Geology Survey Gold Coast Memoir, 7.

Koranteng, K.A. (1995) Ghana coastal wetlands management project. Environmental baseline studies (Sakumo Ramsar Site). Fisheries GW/A.285/SF2/31. pp. 2–22

Laar, C., Akiti, T. T., Brimah, A. K., Fianko, J. R., Osae, S., & Osei, J. (2011). Hydrochemistry and isotopic composition of the Sakumo Ramsar site. *Research Journal of Environmental and Earth Sciences, 3*(2), 147–153.

Muff, R. & Efa, E. (2006) Ghana-Germany technical cooperation project: environmental and engineering geology for urban

planning in the accra-tema area. Explanatory notes for the geological map for urban planning 1:50 000 of greater accra metropolitan area. Accra.

Nartey V.K., Edor, K.A., Doamekpor, L.K. & Bobobee, L.H. (2011) Nutrient load of the Sakumo lagoon at the Sakumo Ramsar site Tema, Ghana. West Africa Journal of Applied Ecology 19.

Nixon, S. W., Buckley, E. A., Granger, S. L., Entsua-Mensah, M., Ansa-Asare, O., White, M. J., McKinney, R. A., & Mensah, E. (2007). Anthropogenic enrichment and nutrient in some tropical lagoons of Ghana, West Africa. *Ecological Applications, 17*(5), 144–164.

Ntiamoa-Baidu, Y. (1991). Seasonal changes in the importance of coastal wetlands in Ghana for wading birds. *Biological Conservation, 57*, 139–158.

Pauly, D. (1976). On the ecology of a small West African lagoon. *Meeresforschung, 24*(1), 46–62.

World Health Organisation. (1996). *Guidelines for drinking water quality.* Second edition. Geneva.

World Health Organisation. (2004). *Guidelines for drinking water quality.* Geneva: WHO.

Xu, Y., Colvin, C., Van Tonder, G.J., Hughes, S., le Maitre, D., Zhang, J., Mafanya, T., & Braune, E. (2002) Towards the resource directed measures: groundwater component (Version 1.1). WRC Report No. 1090-2/1/03. Pretoria: Water Research Commission.

Yang, Z. F., Sun, T., Cui, B. S., Chen, B., & Chen, G. Q. (2009). Environmental flow requirements for integrated water resources allocation in the yellow river basin. *China Communications Nonlinear Science, 14*(5), 2469–2481.

Yawson, S.K. (2003) Gender, environmental management and water quality in the SAkumo catchment. Legon: University of Ghana 210p Mphil. Thesis Presented to Faculty of Science.