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Climate impact on water quality –
Identification of processes responsible
for ION Concentration using stable
ISOTOPES in shallow Coastal Aquifer in
Ghana

Coastal Aquifer in Ghana

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Abstract

Past studies have shown that information on palaeotemperature, past precipitation and recharge regimes can be deduced from the geochemical and isotopic evidence contained in aquifers. Stable isotopes of oxygen and hydrogen were used in the study where specifically the ratio between $^{16}\text{O}/^{18}\text{O}$ and $1\text{H} / 2\text{H}$ were compared to that of standards, (Vienna Standard Mean Ocean Water, VSMOW). Samples comprising 11 surface water samples and 37 shallow wells situated along the coast southeast of the Greater Accra region were collected. Stable isotopic analysis of $\delta^{18}\text{O}$ and δD of the samples were performed using the Delta V plus Isotope Ratio Mass Spectrometer (IRMS). Analyzed $\delta^{18}\text{O}$ values obtained were, minimum -5.64, maximum 2.27, average -2.39‰VSMOW and δD values, minimum -41.58, maximum 9.31, average -14.57‰VSMOW compared with GMWL values, minimum -35.12, maximum 28.16, average -9.14 and Seawater-Meteoric Water Mixing Line (SW-MWL) values obtained were, minimum -26.76, maximum 11.60, average -11.01. Rainfall is considered as major recharge source of the shallow aquifer. Plots of $\delta^{18}\text{O}$ and δD compositions partly fall above and below the Global Meteoric Water Line. This indicates the surface and shallow ground water in the aquifer was open partially to evaporation before or in the recharging process. Shallow groundwater was found to contain more positive $\delta^{18}\text{O}$ values compared to GMWL stable isotopes; this confirms warmer climate and active evaporation in the study area. Overall, precipitation and moisture recycling, and continental effects are considered to be the primary controls on ^{18}O signals in shallow groundwater and surface water.

Keywords: *Geochemical, Environmental Isotope, Coastal Aquifer, Climate, Palaeotemperature*

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Introduction

Across the globe, human development is moving so quickly that governments and businesses struggle to keep up with new technology and increased mobility. But many of the resources that feed and support these rapidly growing processes are limited. A perilous combination of increasing demand, and a climate that is changing as quickly as society is developing, calls for urgent measures (Global Water Partnership, 2021). Climate change is costing the world between 5 percent and 20 percent of GDP each year, according to the World Water Assessment Programme (Water in a Changing World, 2009). An estimated 40 percent of development investments are exposed to climate change hazards, according to analyses by the Organisation for Economic Co-operation and Development (OECD, Bridge over Troubled Waters: Linking Climate Change and Development, 2005). These analyses indicate that, while many development efforts contribute to reducing vulnerability to climate variability and change, climate risks are seldom explicitly factored into development projects and programmes (Global Water Partnership, 2021).

To meet the first targets of SDG 6 – access to safe Water, Sanitation and hygiene (WASH) services for all by 2030 – capital investments must reach €96 billion per year (UN-Water, Water and Climate Change: United Nations World Water Development Report, 2020) – close to three times the current annual capital investment levels in WASH. In addition to initial capital inflows, significant resources are required to operate and maintain water and sanitation infrastructure and sustain universal coverage. These recurring costs will outweigh the capital costs by 1.4 to 1.6 times by 2029 (UN-Water, Water and Climate Change: United Nations World Water Development Report, 2020). The World Bank calculates that, if undertaken optimally at a cost of less than 0.5 percent of GDP, adaptation could remove up to around 70 percent of climate change damages by the end of the century, at a cost that would leave net damages considerably reduced (World Bank, High and Dry, 2016). The Global Commission on Adaptation estimates that investing €1.5 trillion in early warning

systems, resilient infrastructures, improving dryland agriculture and crop production, protection of mangroves, and resilient water resources could create close to €6 trillion in benefits (GCA, Adapt Now, 2019).

Natural factors, such as topographic position, precipitation and the mineral composition of underlying geology, act to produce basic physical and geochemical conditions in groundwater that are reflected in physical properties, such as pH, temperature, specific conductance, and alkalinity, and in chemical concentrations of dissolved oxygen, radon, and major mineral ions (Johnson, G. C. et al, 1993-2002). Occurrences of higher ion concentrations could be attributed to change in the intensity of hydrochemical processes such as evaporation, redox, and mineral precipitation. Sulfate concentrations range typically between less than 10 mg L⁻¹ to more than 50 mg L⁻¹ in aquifers without significant lithogenic sulfur sources (Mayer, B. et al, 2004). Use of fertilizers such as ammonium sulfate or potassium sulfate, industrial point source pollution, and also natural processes such as oxidation of reduced inorganic sulfur compounds (e.g. pyrite) are alternate candidates which may cause increasing sulfate concentrations in aquifers.

In the case of water resources, changing climatic conditions affect both surface/ground water where, warmer, drier conditions promote mineralization of deleterious heavy metals (Murdoch et al., 2000). Nonetheless, the extent of impact imposed by climate change on water resources can be managed by effective adaptation. Maclver (1998) indicates that adaptation is crucial and forms a key component of an integrated and balanced response to climate changeability. Shallow groundwater is most susceptible to climate change because it is directly recharged by surface water and run offs from rainfall directly from the atmosphere. Thus it is the first approach in studies which seeks to identify the effects of climate change on water quality. As it is evidently clear that the climate keeps changing, there is a danger that current infrastructure and other infrastructural designs may not be suitable for this new climate. Substantial modification of designs for existing infrastructure (water treatment plant etc.) and other infrastructural development are therefore required to be able to adapt to the effects caused by the changing climate. The relationship between groundwater and meteoric water was firmly established when it was demonstrated that most waters, had hydrogen and oxygen isotopic compositions that could be related directly to the trend of meteoric water (established by Craig, 1961). This observation confirmed that nearly all groundwater originates from the hydrologic cycle as precipitation.

The shallow aquifers in the study area stretching from Ada East and West districts of the greater Accra region is an example of a groundwater system. The study seeks to determine if there are any changes in the ion concentration in the shallow aquifers in the study area and to identify the processes responsible for the change.

Study Area

The Ada East and Ada West Districts of the Greater Accra Region of Ghana are between Latitudes 06o00'25"N, 00o19'E and 05o 45' 30"N, 00o41' 40"E. The area has wetlands and marshes, sand dunes and islands (Ecological Mapping of the Songor Ramsar Site- Ghana National MAB Committee, 2009). The area receives about 750mm rainfall recorded at Ada Foah Meteorological Station. Temperatures are generally high ranging from 23°C to 33° C. Two types of aquifers occur i.e. the weathered zone aquifers and the fractured zone aquifers (WRR1, 1996).

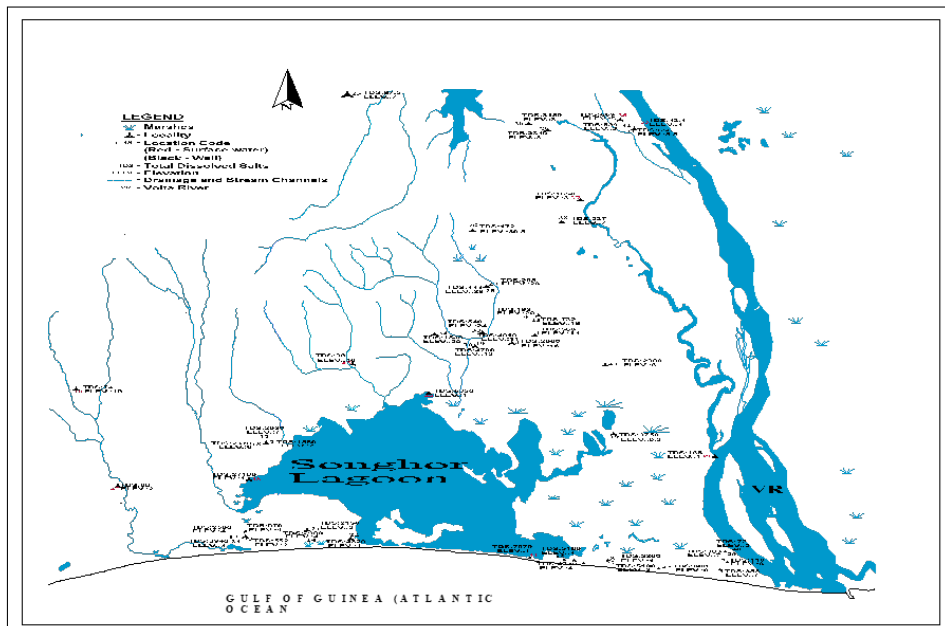


Figure.1. Map of study area indicating drainage, the songhor lagoon, Volta River and sampling points

Methodology

Isotope hydrology is a technique that has been used around the world to determine the source of specific water. the stable isotopes of oxygen and hydrogen and more specifically the ratio between $^{16}\text{O}/^{18}\text{O}$ compared to that of a standard (Standard Mean Ocean Water) and the ratio ^1H to ^2H compared to a standard (Standard Mean Ocean Water, SMOW). By knowing the isotope composition of rainfall, groundwater (Gw) and surface waters (Sw), one can determine the source

of the Gw. Fractionation was avoided when collecting samples by making sure bottles that are used for sample storage are placed away from sunlight and lids tightly sealed. Also, before samples were taken, bottles were rinsed with the source water. The Delta V plus Isotope Ratio Mass Spectrometer (IRMS) was used to analyze the water samples for $^1\text{H}/^2\text{H}$ (D) and ^{16}O and ^{18}O . Stable isotopes ratios are expressed as delta in per mil (‰) relative to VSMOW (Vienna Standard Mean Ocean Water). The isotope precision of measurement based on VSMOW is ± 0.15 ‰ for ^{18}O and ± 1 ‰ for ^2H . In order to postulate the origin of groundwater and related salinity in shallow aquifer system, the stable isotope composition of oxygen (^{18}O per mil, V-SMOW) and hydrochemical data of groundwater samples are statistically evaluated.

Results and Analysis

Results

Table 1 Summary Statistics of ^{18}O isotope values for shallow groundwater (Gw), surface water (Sw), and lagoon samples (Ls) samples in study area collected in April 2013 and June 2013.

Table 1: Summary Statistics of ^{18}O values in Gw, Sw and (Ls) compared to global meteoric water line values.

Id	Parameter	Count	Max	Min	Median	Mean	St. deviation
Gw	$\delta^{18}\text{O}$	37	2.27	-5.64	-2.98	-2.512702703	1.491720946
Sw	$\delta^{18}\text{O}$	8	2.04	-5.34	-1.735	-1.54875	2.3807108
Ls	$\delta^{18}\text{O}$	3	1.03	-2.28	0.03	-0.406666667	1.697655246
Gmwl		48	28.16	-35.12	-12.24	-9.135	13.55768

Shallow groundwater (Gw) and surface water sample (Sw) samples were found to contain positive maximum 2.27 and 2.04 $\delta^{18}\text{O}$ values respectively reflecting warm precipitation from evaporation and meteoric source recharging compared to GMWL stable isotopes (table 1). It is also an indication of interconnection between the shallow groundwater aquifer and surface water in the study area.

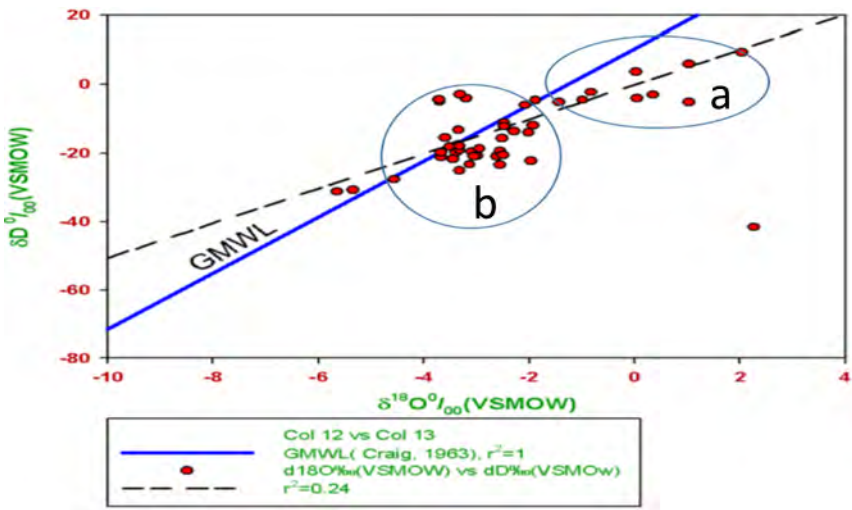


Figure 2. $\delta D - \delta^{18}O$ relation of Gw and Sw and Global Meteoric Water Line (GMWL).

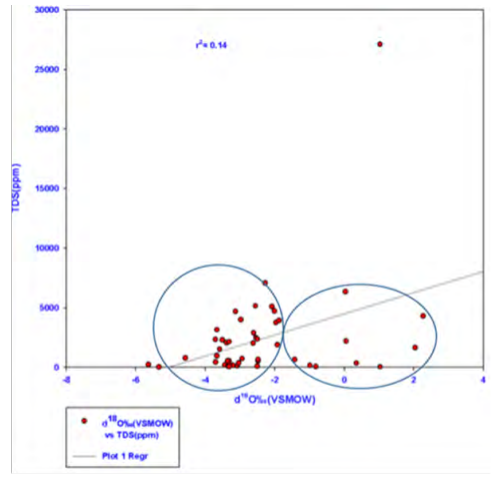
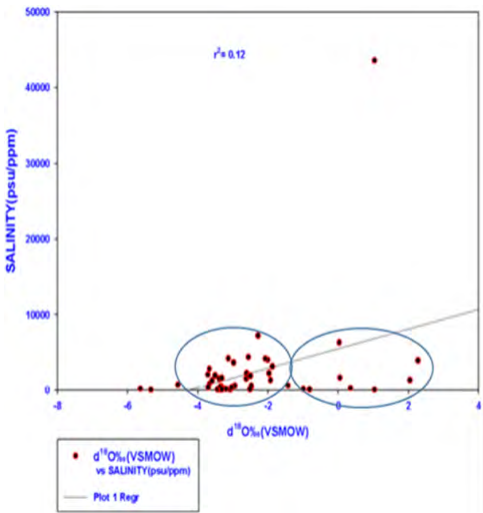


Figure 3. Plot of Salinity and TDS Vs. $\delta^{18}O$ (VSMOW)

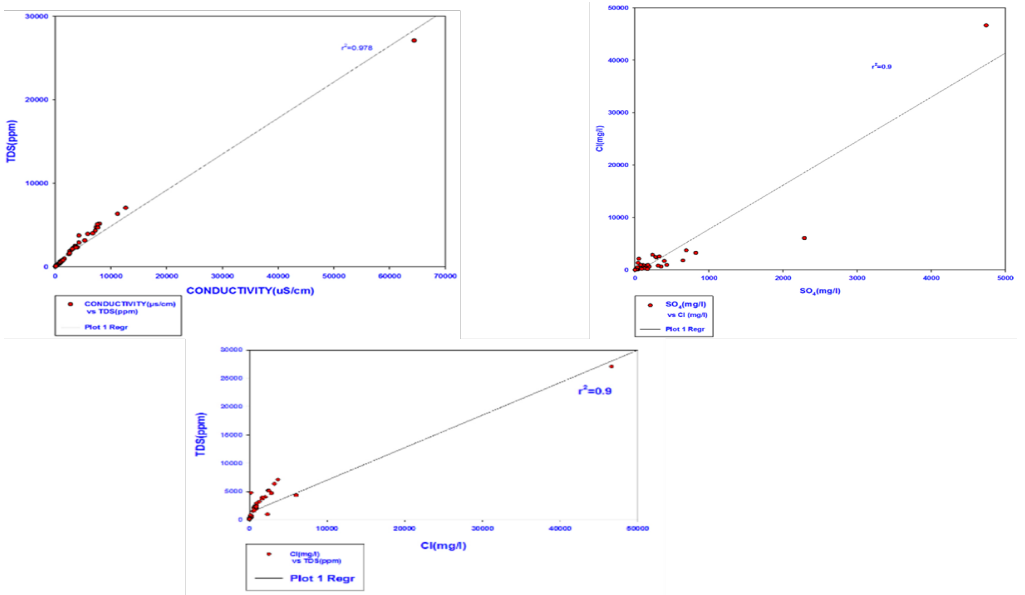


Figure 4. Plots of TDS vs. Conductivity, Cl vs. SO₄ and TDS vs. Cl

Analysis

The background for palaeoclimatic interpretations of changes in the stable isotope composition of water molecules is that vapour pressure of H₂¹⁶O is higher than that of H₂¹⁸O (Craig, 1961). Evaporation from a water body consequently results in vapour poorer in ¹⁸O than the initial water; conversely, the remaining water is enriched in ¹⁸O (Craig, 1961). During condensation, the lower vapour pressure of the H₂¹⁸O ensures that it passes more readily into the liquid state than water vapour made up of the lighter oxygen isotope (Dansgaard, 1961). During transportation of water vapour, isotope fractionation continues with the preferential removal of heavier isotope, leaving water vapour increasingly depleted in H₂¹⁸O. Because condensation is the result of cooling, the greater the fall in temperature, the lower the heavy isotope concentration will be. Isotope concentration in the Gw/Sw can thus be considered as a function of the temperature at which condensation occurs. This is however as observed (table 1) where Shallow Gw, Sw and Ls sample contained more positive δ¹⁸O values compared to GMWL stable isotopes signaling warmer climate and active evaporation in the study area (fig. 2). Water from polar snow will thus be found to be most depleted in H₂¹⁸O. This temperature dependency permits the use of oxygen isotope content of Gw/Sw to provide historic climate record.

It is noticed, from fig.2, precipitation, moisture recycling (evaporation, indicated a), and continental effects (or meteoric recharge indicated b) are the primary controls on δ¹⁸O signals in shallow Gw and Sw. The strong correlations (figs 3&4) exhibited is certain conditions of weathering and dissolution of minerals pertains in study area. These minerals beyond permissible limits may

impact the quality of water.

Impact Of Water Quality on Infrastructure

Higher water temperatures, increased precipitation intensity, and prolonged periods of low flows are expected to intensify many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution. This will, in turn, impact ecosystems, human health, and the reliability and operating costs of water systems. Increasing temperatures are likely to lower water quality in shallow and deeper aquifers.

The permissible limit for chloride and sulphate for concrete works required by the ASTM standards is 500mg/l and the limit value for pH 6. Meaning, chloride and sulphate values above 500mg/l and pH below 6 is a likely threat to concrete infrastructure/foundations. Figures 3&4 shows that most of the investigated Gw samples contain chloride/tds concentration above limits of 500mg/l. Higher concentration of chloride/tds (figs 3&4) above permissible limits exposes any infrastructure in the environment to chemical attack, e.g. concrete foundations etc. This will require special treatment methods to treat the heavily mineralized Gw/Sw for portable use and for farming.

Conclusions

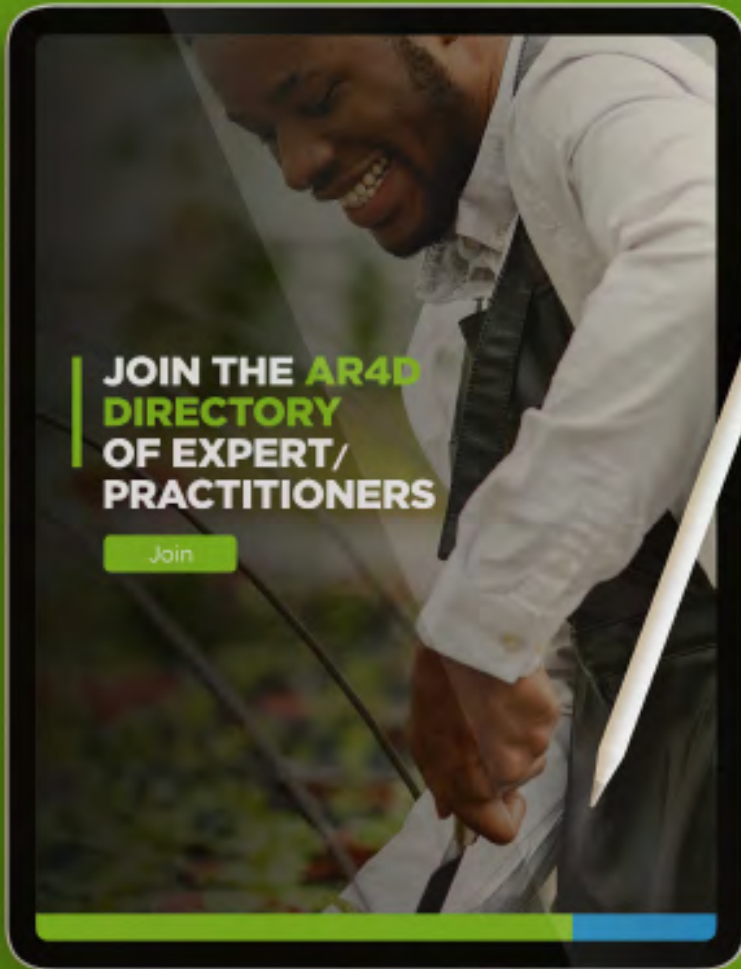
The study unravels groundwater in the areas considered contains chloride/tds and dissolved mineral values above permissible levels. Also results obtained for Gw and Sw show warm precipitation from evaporation and meteoric source recharging. This is also an indication of interconnection between the shallow groundwater aquifer and surface water in the study. The high values obtained for chloride/tds and dissolved mineral will need to be considered when designing, construction and monitoring infrastructure on deteriorating effect of the groundwater geochemistry on infrastructure. Measures should be put in place against chemical attack on infrastructure in the study area for sustainable development.

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