別紙様式８

研 究 主 論 文 抄 録

論文題目　Hydrological Study on Groundwater in the Banana Plain and Mount Cameroon area – Cameroon Volcanic Line (CVL)–
カメルーン火山帯（ＣＶＬ）のバナナ平原とカメルーン山の地下水に関する水文学的研究

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主論文要旨

Cameroon is endowed with large amounts of water resources. It is the country with the second highest volume of available water in Africa (after the Demographic Republic of Congo) estimated at 322 billion m^3. Groundwater constitutes 21.5% (57 billion m^3) of this resource and plays a very important role in the socio-economic life of the country. Common uses of groundwater include drinking, domestic, industrial and agricultural. Understanding the quality of groundwater is therefore fundamental for the sustainable use of this resource.

The Cameroon Volcanic Line (CVL) is one of the major geological structures of the African plate and continent and is known as the second most important geological curiosity in Africa after the East-African-Rift system. The CVL is the principal watershed of Cameroon but unfortunately little has been done to understand the quality of groundwater along the CVL.

The Banana Plain and Mount Cameroon area of the Cameroon Volcanic Line with their rich and diversified natural resources, rich andosols and large quantities of water are attractive zones for the influx of both migrants and indigenous populations. Enhanced anthropogenic pressure has increased the demand for groundwater for plantation and subsistence farming, urbanization and domestic water uses.

This thesis focuses on the use of hydrochemistry, multivariate statistics and environmental tracers (^{18}O, ^{2}H, ^{3}H and CFCs) to establish the origin, geochemical evolution, usability and groundwater flow system of groundwater resources of the Banana Plain and Mount Cameroon area.

In the present study, 67 groundwater samples were collected from boreholes, open wells and springs in the Banana Plain. Eighty- four samples (67 spring samples, 6 borehole samples, 10 rain samples and 1 stream sample) were collected in the Mount Cameroon area. The samples were analyzed for major ions,

environmental isotopes and CFCs. After all sample analyses were completed, Principal Component Analysis (PCA) and Factor analysis (FA) were performed on the data set to obtain factors hydrochemical processes that give rise to the observed water quality of groundwater in the study areas.

In the Banana Plain, main water types are $Ca\text{-}HCO_3$, $Ca\text{-}Mg\text{-}HCO_3$, $Ca\text{-}Na\text{-}HCO_3$ and $Ca\text{-}Na\text{-}NO_3\text{-}Cl\text{-}HCO_3$. The following hydrogeochemical processes were identified as the main processes that influence the chemical composition of the groundwater: incongruent silicate dissolution, cation exchange and anthropogenic activities. CO_2 driven weathering of silicate minerals followed by cation exchange control largely the concentrations of major ions in the groundwater of this area. Nitrate, chloride and sulphate concentrations strongly express the impact of anthropogenic activities (agriculture and domestic activities) on the groundwater quality. Sixty-four percent of the waters have nitrate concentrations higher than the drinking water limit. Also limiting groundwater use for potable and domestic purposes are contents of Ca^{2+}, Mg^{2+} and HCO_3^- and total hardness (TH) that exceed World Health Organization (WHO) standards. Irrigational suitability of groundwater in the Banana Plain was also evaluated and results show that all the samples are fit for irrigation.

Environmental isotopes (^{18}O, ^{2}H and ^{3}H) revealed that groundwater in the study area exist in two aquifers (a shallow and a deep aquifer) which are of meteoric origin. The shallow aquifer groundwater have very short residence times (modern waters) while the groundwater in the deeper parts of the aquifer system are sub-modern (older waters). The groundwater system is well-mixed as evidenced by the narrow range of values of the environmental isotopes. Deviation from the rainwater signature indicates the combined effect of local processes such as direct percolation through preferential channels, evaporation and anthropogenic contribution to the groundwater system.

In the Mount Cameroon area, main water types are $Ca\text{-}Mg\text{-}HCO_3$ and $Na\text{-}HCO_3$. Three processes are controlling the groundwater quality. (1) CO_2 –driven silicate weathering (2) reverse cation exchange (3) tropical oceanic monsoon chloride/sulphate rich rainwater seems to affect the groundwater chemistry at low altitude areas. In general the spring waters are suitable for drinking and domestic uses. TH values indicate a general softness of the waters which is linked to the development of cardiovascular diseases. Based on Na%, RSC, SAR and USSL classification, the spring waters are considered suitable for irrigation. Though there is wide spread use of chemical fertilizers and intense urban settlements at the lower flanks of the volcano, anthropogenic activities for now seem to have little impact on the groundwater quality.

$\delta^{18}O$ and $\delta^{2}H$ composition of rainwater and groundwater in the Mount Cameroon area fit the LMWL of WMO meteorological station in Douala. Present day rainwater stable isotope data indicates large climatic

variability within the last 39 years around the mountain. For springs sampled during the dry and rainy seasons, the dry season samples have higher recharge elevations than rainy season samples. Seasonal variation exists in the tritium values with the rainy season samples systemically being higher than those of the dry season samples. This implies that the input of new water from the rains causes the groundwater system to rejuvenate. CFC apparent ages for rainy season samples are systemically younger than those of dry season samples. There is seasonal variation in groundwater flow characteristics in the Mount Cameroon area and also in the different flanks of the volcano. The groundwater flow system is conceptualized in 2 models; a Bypass/piston flow model for the flow system during the rainy season and a binary mixing/piston flow model characterizes the flow system during the dry season.

After laboratory analysis for their chemical composition, the chemical data set generated was subjected to Principal Component Analysis (PCA) and Factor Analysis (FA) to determine the significant sources of variation n the hydrochemistry. PCA results indicate that five factors explained 77.45% of the variance in the data set of the Banana Plain. In the Mount Cameroon area, six factors account for 80.78% of the total variance. FA identifies two factors responsible for the groundwater chemistry in the Banana Plain and nitrate contamination of its groundwater. They are an "anthropogenic factor" which plays a major role and a "geogenic factor" whose contribution is minimal. In the Mount Cameroon area, a two-factor model too is suggested with a "geogenic factor", which plays a major role in the hydrochemistry and a "salinity factor "which is a minor contributor. The risk of nitrate-nitrogen contamination of groundwater resources in the two selected areas especially in the Banana Plain is already significant.

The findings of this thesis are important in that they contribute in the identification of groundwater quality evolution and flow dynamics in these two important agro-industrial areas thereby contributing to the sustainable management of their groundwater resources. Of particular interest is the vulnerability of the shallow aquifers to nitrate contamination from anthropogenic activities (intense urban settlements and agro-industrial activities). In the Mount Cameroon area, the conceptualization of the flow system and the occurrence of different recharge elevations achieved in this study will play a role in finding proper sites for future groundwater development and catchment area protection.