Abstract

In the southern fringe of the Central African Lake Chad basin, which is subject to shrinking of surface water, is located the Mayo Tsanaga river basin where unplanned exploitation of groundwater by 500000 inhabitants constitute the following emerging water-related threats: vulnerability to a “silent” fluorosis from lithogenic fluoride, anthropogenic deterioration of the groundwater quality, and climatic and human enhanced depletion of the groundwater quantity. In the phase of these threats, no on- the- catchment scale groundwater data exist yet, which can be employed to initiate sustainable management schemes for the dwindling resources. Moreover, the limitation of comprehensive data on the groundwater quality and quantity hampers the achievement of the Millennium Development Goal number 7 with a task of availing enough and good water for all by the year 2010. This investigation was therefore conceived with the main objective to use inorganic solutes and stable environmental isotopes to trace the groundwater characteristics, in order to identify key variables that could be used in planning management schemes for the groundwater.

Shallow groundwater from crystalline and detrital sediment aquifers, together with rainwater, dam water, water from springs and rivers were chemically and isotopically investigated to appraise its evolution, recharge source and mechanisms, flow direction and age. The observed parameters together were further used to evaluate the groundwaters’ susceptibility to contamination and the basin’s stage of salinization.

The groundwater which was found to be dominantly of Ca-Na- HCO_3 type is a chemically evolved equivalent of surface waters and rain water with Ca-Mg-Cl-SO_4 chemistry. Electric conductivity ranged from 57 – 2581 µs/cm with alternating low and high values along the hydraulic gradient. Water from Piedmont alluvium showed low concentrations in major cations,

which peak in, Mg^{+} within basaltic rocks, Na^{+} within plain alluvium, and Ca^{2+} within the basalt and the sandy Limani-Yagoua ridge. The initial dominant groundwater composition is $CaHCO_3$, which did not evolve within the basaltic and piedmont alluvium aquifers, but evolved to $NaHCO_3$ in the granite and plain alluvium. The main processes controlling the major ions composition include: (1) dissolution of silicates and fluorite; (2) precipitation of fluorite and carbonate; (3) cation exchange of Ca^{2+} in water for Na^{+} in clay; (4) and anthropogenic activities. The dissolution occurred at an estimated rate of 0.014 milli mole/year with annual ionic flux in a decreasing order of $HCO^{3-} > Ca^{2+} > Na^{+} > Mg^{2+} > SiO_2 > NO_3^{-} > SO4^{2-} > K^{+}$.

With respect to natural contaminant, the groundwater was investigated for the first time, with the purpose of identifying the provenance of fluoride, and estimating an optimal dose of fluoride in the study area. Based on the fluoride content of groundwater, fluorine and major oxides abundances in rocks from the study area, mean annual atmospheric temperature, and on-site diagnosis of fluorosis in children, the following results and conclusions are obtained: Fluoride concentration in groundwater ranges from 0.19-15.2 mg/l. Samples with fluoride content of less than 1.5 mg/l show Ca-HCO_3 signatures, while those with fluoride greater than 1.5 mg/l show a tendency towards Na-HCO_3 type. Fluor-apatite and micas in the granites were identified as the main provenance of fluoride in the groundwater through water-rock interaction in an alkaline medium. The upper limit of fluoride in drinking water of the study area is estimated at 0.7mg/l, due to higher consumption rate (~3-4 l/day) of water especially during drier period, as compared to the WHO prescription of 2 l/day.

Anthropogenic contamination by NO_3^{-} was most prominent in water of shallow wells during the rainy period (ranging from 3-130 mg/L) due to flushing. The low concentrations (0.1-4.4 mg/L) observed in surface (rain, dams, and ephemeral springs and river) water may be due to a short interaction time with the anthropogenic municipal waste and fertilized soils. On the other hand the low concentrations (0.08-11 mg/L) in water from deeper boreholes depict either the effect of dilution and/or denitrification.

In low lying region (328-400 m asl), the groundwater was recharged by preferential infiltration of monsoon rain with little or no evaporation, while at higher elevations (400-850 masl) the groundwater was recharged during or after evaporation of rain and surface water. The mean rate of recharge was estimated at 74 mm/year.

Altitude effect of rain and springs show a similar variation of -0.4 ‰ for $\delta^{18}O$ / 100 m, but the springs which were recharged at about 450 m, 680 m and 770 m asl in selected sub catchments, and groundwater showed evaporative enrichment of $\delta^{18}O$ relative to rainwater by 0.8 ‰, and 3 ‰, respectively. The evaporative enrichments correspond to about 4 % and 15 % of water loss during rainwater recharge to ephemeral springs, and groundwater, respectively. After recharge, the groundwater flows south eastwards with a residence time range of 2-58 years, which increases with an increasing Na^+ and F^-, and attenuating NO_3^- and Cl^- concentrations. Spatial maps of Stiff diagrams, Na^+ concentrations, and a tritium-based iso-age map of the groundwater show that the groundwater flow regime is local in the hummocky western relief of the basin. Whereas a regional flow regime dominates from the west to the plain in the east. Although mixing of the various water bodies occur, the ageing direction of the groundwater is mainly towards the basins` margin, while the younging direction is towards the central-north highlands. Evidently, the younger groundwaters are susceptible to anthropogenic contamination and older groundwaters are sinks of lithologenic fluoride. The basins` salinization is still at an early and initial stage. Seventy percent of the groundwater shows poor drinking quality and 90% is suitable for irrigation. Annually, the groundwater aquifer receives 0.7×10^{12} L of water in a phase of annual water demand of 0.002×10^{12} L. This indicates that in the phase of annual evaporation exceeding annual precipitation, the groundwater renewability exceeds demand for human use by 50 folds at minimum. Evaluation of aquifer vulnerability index with the use of DRASTIC (a modeling tool) indicates that the sedimentary aquifers are more vulnerable to surface-derived contamination than the crystalline (granitic) aquifers. If all the stakeholders of water resources in the study area, set up a committed collaboration to manage the groundwater resources, the results obtained in this study can be used to improve management strategies, and spin-offs such as improved human wellbeing could be realized.