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Modeling groundwater recharge through rainfall in the Far-North region of Cameroon

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ABSTRACT

The Far-North region of Cameroon is threatened by extreme water shortage. Over the years groundwater has increasingly been used as the main source of domestic water supply. In spite of the increased, groundwater exploitation has been done without adequate planning. One of the key parameters of a sustainable groundwater management is the regional groundwater recharge rate, which defines the upper limit for which groundwater abstraction should not exceed. This paper summarizes the results of transferring the water balance model GROWA to the Far-North region of Cameroon. The main aim was to assess the spatial distributed groundwater recharge rate through rainfall. Due to the lack of adequate regional data bases, international data sources, e.g. the World soil map in scale of 1: 3,000,000 were used to derive the input parameters needed to run GROWA model. The simulated GROWA results show a satisfying agreement with existing groundwater recharge rate assessments for most areas of the study region. Against this background, it was concluded that GROWA model results represent reliable reference values for groundwater recharge through rainfall even though the input parameters were derived from small-scale generalized international maps. This approach provides a relevant initial step for a more detailed groundwater recharge estimate. A more accurate estimation for groundwater recharge should be carried out once the input data for the study area are available in higher spatial resolution including runoff records for a plausibility check of the modeled water quantities for groundwater recharge.

1. Introduction

Groundwater is an important resource for food production, drinking water supply, drought mitigation, and economic development especially for rural communities around the world. According to Adelana and MacDonald (2008), about 100 million of the rural populations in sub-Saharan Africa are serviced by groundwater for domestic supplies and livestock rearing. The main reason why groundwater is increasingly gaining prominence as a water source is because of the high natural storage capacity; the water quality is often good; the infrastructure is more affordable to poor communities (Adelana and MacDonald, 2008) and their usage is less restricted by seasonal and inter-annual flow variation (Döll and Fiedler, 2008). Hydrogeological condition and the aquifer system characteristics have a direct bearing on groundwater management (Zektser and Everett, 2004).

Large portion of Far-North region (Cameroon) constitutes the Lake Chad basin. Even though existing hydrogeological maps provide information, knowledge about water use, main recharge areas and the general flow patterns are poorly known in the Lake Chad basin (Ngounou et al., 2008). The variation in river discharges and the lack of surface water (especially during the dry season) has made groundwater an important source for water supply in the region. The significant increase in population in the region has led to the extensive construction of dams, groundwater pumping and land cover/land use changes (Geerken et al., 2012). Furthermore, groundwater exploitation in rural communities has increased and this has been done without adequate planning (Ngounou et al., 2008).

The Lake Chad Basin Commission (LCBC) was established to collect data (such as climate, hydrology and hydrogeology) from member states for the purpose of carrying out regular assessment and to publish a hydrological yearbook. Although more data from previous work are available, groundwater recharge assessment has not received enough attention in the scale of the whole basin (Ngounou et al., 2008).

Previous studies (Njitchoua & Ngatcha (1997), Edmunds et al. (1998), Goes (1999), Djoret and Travi (2001), Leduc et al. (2000), Ngounou et al. (2001), Edmunds et al. (2002), Goni (2002), Gaultier (2004), Goni (2006), Leblanc et al. (2007), Ngounou et al. (2007a), Ngounou et al. (2007b), Boronina and Ramillien (2008), Babama'aji

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(2013)) have made important contribution on improving groundwater recharge investigation in the Lake Chad basin. Rainfall and surface water are the main sources of groundwater recharge in the region. Water table level becomes systematically deeper as one move away from the recharge axes constituted by the hydrographic network (Ngounou et al., 2005). Depth to groundwater table ranges between 0 m and greater than (>) 45 m (United States Department of Agriculture, Soil Conservation Service and Fonds d'Aide et de Cooperation France, 1978) (see Fig. 6).

Land use also changes the permeability and storage characteristics of the subsurface (Ngounou et al., 2008) and this favors the percolation of water from floodplains into the aquifer (Ngounou et al., 2001; Ngounou and Mudry, 2004). Groundwater levels are higher during the wet season than during the dry season (Ngounou et al., 2008). As a consequence of the decrease in groundwater levels, over 60% of wells and boreholes run dry in the region (Ngounou et al., 2005). Furthermore, increasing the length of groundwater recharge because of prolonged dry season can cause a drop in the water table. This process facilitates the drying up of wells in the region and this constitutes the main source of water supply for most rural communities in the north part of Cameroon (Molua and Lambi, 2006).

In addition to the natural causes of groundwater depletion, other reasons might be because of the construction of boreholes and wells in areas with low groundwater yield or a situation where by the abstraction rate of wells is greater than groundwater recharge rate. Groundwater flow is very slow, meaning that the consequences of overexploitation might only become apparent after years or decades (Ngounou et al., 2008). According to EU Water Framework Directive, a "good quantitative status" of groundwater is achieved when the mean long-term groundwater extraction does not exceed the mean long-term groundwater recharge. In spite of the widespread and increased use of groundwater in the region, the knowledge base concerning groundwater (Ngounou et al., 2008) and the spatial distribution rate of groundwater recharge are still deficient.

Groundwater resources can be used sustainably if their spatial extent and their variation through time are properly understood. According to Ngounou et al. (2008), there is still a critical need to improve the hydrodynamics data sets and organize them on maps through mathematical models for the Lake Chad basin. Most studies about groundwater recharge modeling in the Far-North region of Cameroon have been done within the context of Lake Chad basin. There is no large-scale study on groundwater recharge rate for the Far-North region of Cameroon. Additionally, opinions regarding the degree of a reasonable fit for all models used in the Lake Chad basin have been varied. For example, Massing and Zhonghua (2010) stated that models used in Eberschweiler (1993), Leblanc (2002), Boronina et al. (2005) were conceptual models because traditional hydrogeological parameters were sparse, not homogeneously distributed in space, and highly variable in time. This made it difficult for the results to be upscale over the whole aquifer. Genthon et al. (2015) emphasized on the poor spatial resolution and data coverage in some previous studies e.g. Leblanc (2002), Gaultier (2004), Zairi (2008), Boronina and Ramillien (2008) and Candela et al. (2014). Table 1 summarizes selected studies of the groundwater recharge rate within the Far-North region of Cameroon. On like the previous studies mention, no disapproval or drawbacks have been put forward against the results stated in Table 1.

Empirical models are often used to model the long-term groundwater recharge rates in large catchment areas. The best choice for a particular situation depends upon the spatial and temporal scales being considered and the intended application of the recharge estimate (Scanlon et al., 2002). Therefore, other objectives of the paper were as follows: (1) to test the general transferability of GROWA model to the site conditions of the Far-North region in Cameroon, (2) to test the reliability of the model results in case where world data bases are use due to the lack of detailed regional databases, and (3) to demonstrate the added value of groundwater recharge through rainfall based on GROWA model for the overall purpose of implementing sustainable groundwater management strategies.

2. Study area description

Far-North region of Cameroon is located within the coordinates of latitude 10° 34´55´´North and longitude 14°19´39´´East. Fig. 1 shows a map of the region and some physical characteristics. The region has a total surface area of about 34,263 km^2 and shares international boundaries with Chad and Nigeria in the east and west respectively. Maroua is the capital of the region. The region is a semi-arid region with high temperature and evapotranspiration. Temperature ranges between 28 °C and 45 °C. The region has a population of about 3.5 million inhabitants which makes it one of the most populated regions in the country. About 80% of the population depends on agriculture for subsistence, with little or no surplus for marketing.

Water availability and climate variability poses a major problem in agriculture and domestic water supply. Analysis of temperature and precipitation data between 1957 and 2006 concluded that water shortage in the region might be as a result of poor water management and not (directly) climate change (Cheo et al., 2013). The region is characterized by a very distinct long dry season that lasts for about seven months (October-April) and a short rainy season that last for about 5 months (May-September). Rainfall varies greatly and historical records have also shown series of years with rainfall and drought. Annual rainfall ranges between 300 mm to about 1100 mm (WorldClim-Global Climate Data: Credits: Hijmans et al., 2005). Fig. 2 shows the map of the mean annual rainfall in the region. The region is crisscrossed by many non-perennial and perennial rivers.

Soils are dominated by light, porous and sandy soil with low organic matter content ranging between 1% and 3%, but rich in minerals such as quartz and feld spar (Brabant and Gavand, 1985). The major soil types include Vertisols, Fluvisols and Planosols. Permeability levels in the region are generally poor because of the hydraulic properties of the rocks. Fig. 3 shows the geological map of the region. The northern lowlands consist of mostly lacustrine clay and silty clay rocks whereas the south-western areas are covered with hard rocks such as gneiss and biotitic granite. The middle area extending toward the south is covered

Table 1
Selected groundwater recharge studies within the Far-North Region, Cameroon.

Location	Groundwater recharge rate (mm/year)	Period	Method	Map types	Reference
Southern border of Lake Chad Basin	25 to 125	1970–1985	Thornthwaite-Mather	No Map	Ngounou et al. (2007b)
Yaéré plain	9	Not available	Using empirical formulas by Allison et al. (1983)	No Map	Vassolo et al. (2016)
Along the Logone River	25	Not available	Using empirical formulas by Allison et al. (1983)	No Map	Vassolo et al. (2016)
Lake Chad Basin	0 to 324.17 (for 2003)	2003–2010	WetSpass	Recharge Map	Babama'aji (2013)

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