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Basin characterization and determination of hydraulic connectivity of mega basins using integrated methods: (The case of Baro-Akobo and mega watershed beyond)

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A B S T R A C T

Despite being the longest river and the fourth in drainage area, Nile River has the lowest discharge per unit areas among the top ten rivers of the world. Understanding the hydrologic significance of the regional litho-stratigraphy and structures help to better understand the hydrodynamics. This work is aimed at characterizing the Baro-Akobo-Sobbat sub-basin of Nile and determine *trans*-basin flows. Integrated method is used to characterize the basin and determine the Baro-Akobo-Sobbat sub-basin's relationship with African Mesozoic Rifts. Oil and water well drilling logs; aeromagnetic, gravity and vertical electrical sounding data; and various study reports are used to establish regional lithostratigraphic correlations and determine *trans*-regional hydrogeological connectivity. A total of 633 samples collected from wells, springs, rivers, lakes, swamps and rain water are analysed for their chemical, stable isotopes, tritium and radon properties. The Baro-Akobo river basin is commonly presumed to have good groundwater potential, particularly in its lowland plain. However, it has poor exploitable groundwater potential and recharge rate due to the extensive clay cover, limited retention capacity and the loss of the bulk of the groundwaters through regional geological structures to the deep seated continental sediments; presumably reaching the hydraulically connected African Mesozoic Rifts; mainly Melut and Muglad. The deep underground northward flows, along Nile River is, presumably, retarded by Central African Shear Zone in the Sudan.

1. Introduction

1.1. Background

The Nile, with a length of 6695 *km*, is the world's longest river and occupies the fourth largest drainage basin. However, it has the lowest discharge per unit area of all major rivers of the world (Seligman, 2008). The reasons for such a low discharge are not well established. Understanding how the regional litho-stratigraphy and mega structures in the Nile Basin regions influences groundwater hydrology to fully explain the hydrology of the Nile Basin. The hydrodynamics of the Baro-Akobo-Sobbat (BAS) sub-basin, a major tributary of the Nile, also contributes to this understanding.

The BAS sub-basin is considered as one of the most promising regions for oil in the Eastern Nile Sub-basin (Sileet et al., 2013). The Baro-Akobo sub-basin, the subject of this research, is a major source of surface and subsurface flows; and it constitutes about 7% of the total surface area of Ethiopia. The BAS has the third highest runoff estimated to be 11.8×10^9 m^3 and specific discharge of 22.6 10^9 m^3 (Kebede, 2013; Misky, 2012; National Wetlands Working Group, 1997; SELKHOZPROM EXPORT, 1990a, b; TAMS and ULG, 1997).

Over the past few decades, the Baro-Akobo Basin experienced various hydrological and anthropogenic dynamic changes. Population increase and climate variability have brought visible changes to the ecosystem of the basin (TAMS and ULG, 1997). The Baro River, which used to be navigable connecting the then south Sudan with Ethiopia, during the four months of the rainy season, is no longer navigable beyond the border area due to diminished flow (SELKHOZPROM EXPORT, 1990b).

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Few attempts have been made to study and interpret the regional tectonostratigraphy of the basin for hydrogeological purposes. Despite its critical hydro-political and hydrological importance, the Baro-Akobo basin is poorly documented and has been the subject of very few hydrological studies, e.g., Levin et al. (2009); Gani et al. (2008); Wallin et al. (2005) and Sutcliffe and Parks (1999). Levin et al. (2009) used isotopic composition of waters from Ethiopia and Kenya to shed light on moisture sources for Eastern Africa. Wallin et al. (2005) also used isotope methods for management of shared aquifers in Northern Africa. Among the works on stratigraphic and structural evolution of Mesozoic African Rifts, the works by Gani et al. (2008), well explained the stratigraphic and structural evolution of the Blue Nile Basin, and adjacent basins in the Sudan. The comprehensive work by Sutcliffe and Parks (1999) provide in-depth analysis of the hydrology of the Nile at sub-watershed level, including the Sobat basin.

The objective of this study is to characterise the Baro-Akobo sub-basin by determining the nature of *trans*-basin flow in relation to the Nile flow system. Integrated methods comprising: remote sensing, geophysical, geological, hydrogeological, hydrochemistry, and environmental isotope techniques have been applied to establish the relationship between the Baro-Akobo and African Mesozoic Rifts (AMR), and explain the basin's surface and groundwater flow dynamics.

1.2. The study area

1.2.1. Location

The Baro-Akobo River Basin is located between N5°30′ to N10°50′ and E 33°00′ to E36°18′ in Western Ethiopia; bordered by the wetlands of southern Sudan in the West; by the Blue Nile river basin in the north and by the Omo-Ghibe river basins in the South and South East (Fig. 1). The western part of the Baro-Akobo basin is considered to be part of the Machar Marches and the Groundwater Basin of Sudan, Ethiopia, and Kenya (Mirghani, 2012).

1.2.2. Climate and hydrology

The wide difference in elevation, ranging from 395 to 3240 *m above sea level (m.a.s.l.),* in the Baro-Akobo basin has caused variations in climatic conditions. For example, the mean temperature varies from 22°*C* to 40°*C* in the highlands and the lowlands, respectively, whereas the rainfall ranges from <1000 *mm* in the western lowlands to >2500 *mm* in the eastern highlands (ARDCO-GEOSERV, 1993). The estimated mean annual rainfall for the whole basin is ~1450 *mm*.

The Baro-Akobo river basin has the highest specific discharge among all the river basins of Ethiopia. The main rivers of the basin start from the highlands in the eastern part and flow westward to form Sobat River and join the White Nile in South Sudan. The mean annual runoff in the basin is estimated to be 23$bm^3/year$, as gauged at Gambela town station. One of the peculiar features of this basin is the extensive wetlands, which are part of the Machar Marshes (Fig. 1). These wetlands are fed by a combination of local precipitation, by the torrents originating from the western Ethiopian plateau, and by flooding formed by the rivers flowing into the wetlands.

1.2.3. Geology and hydrogeology

The main geological outcrop in the Baro-Akobo basin is the basement rock that covers 41% of its area and is found at shallow depths even in most of the areas covered by Tertiary Volcanics and sediments. Except in areas of thick regolith and fractures, the basement rocks are considered to be poor aquifers. Tertiary and Quaternary Volcanics cover 38% of the basin and are mainly found in the recharge zone; of which. The majority are Tertiary Volcanic rocks that are fractured and weathered and forming moderate aquifers. The remaining Quaternary volcanic cover forms a poor aquifer except in places where it exhibits scoracious. The lowland areas predominantly covered by Neogene and Quaternary sediments, constitute ~21% of the basin and form the Gambela Plain (Fig. 2), which is an extension of the oil-rich South Sudan's prolific

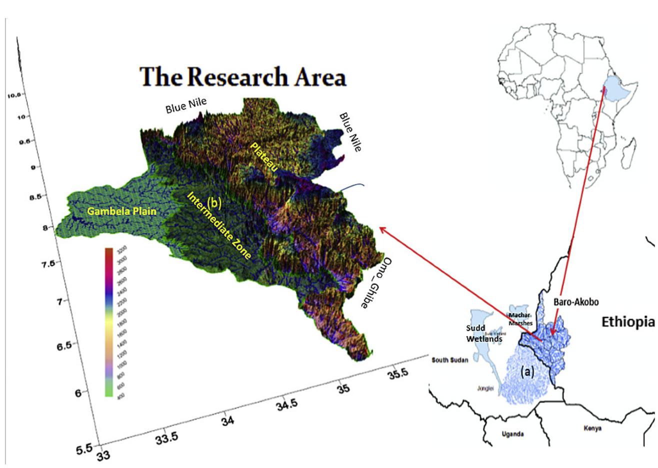

Fig. 1. Location map of the study area showing: (a) the Sudd Wetlands, Machar Marshes and its connection with Jongolie region in South Sudan; and (b) the three prominent hydrogeomorphic zones (the Plateau, the Intermediate Zone and the Gambela Plain).

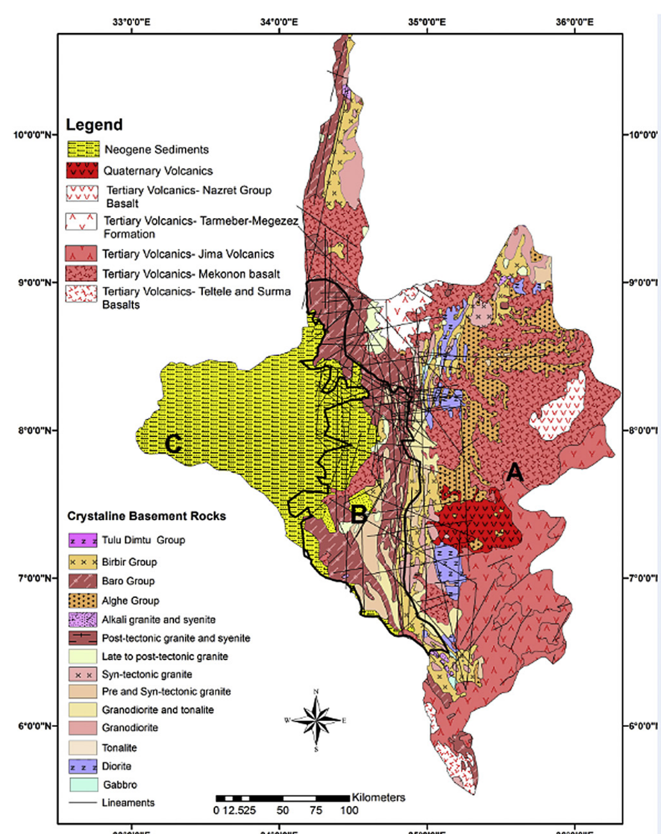

Fig. 2. Geological Setting of the study area modified from (Alemayehu et al., 2003; Tefera et al., 1996) and the three prominent hydrogeomorphic zones (A = the Plateau; B= Intermediate Zone; and C = the Gambela Plain).