Preface

In the context of regional geodynamics, the Geology of Ethiopia is the result of complex orogenic evolution that involves: terrain accression and collision in Precambrian; peneplanaton, glaciations, and Gondowana breakup in Paleozoic; cyclic marine transgression and regression events leading to accumulation of multilayered sedimentary rocks in Mesozoic; huge continental flood basalt eruption and formation of rift valley in Cenozoic and sedimentation, and deep incision of river valleys and pluvial-interpluvial sediment accumulation in Quaternary. These mega events have left distinct imprints on landscape, hydrology, and groundwater occurence in Ethiopia.

Why this book?

(a) *Evolution in geological knowledge provides new hydrogeological knowledge* How much we know about hydrogeology and groundwater resources potential depend as much on the knowledge of geology. The unique and extensive flood basalts of Ethiopia, the closed basin lakes and associated sediments, and the unique setting of the Great East African Rift attracted several international and national geo-scientific researches in disciplines ranging from global geodynamics, rift evolution, paleo-climate re-construction, and so on. Knowledge in the geosciences of Ethiopia has evolved so much, so that it necessitates a commensurate updating of hydrogeological framework of Ethiopia. Over the last five decade alone over 3,500 scientific papers have been published regarding the geology, geodynamics, tectonics, geomorphology, magmatism, hydrology, hydrogeology, and environment.[1] A rapid look at the scientific literature shows how the knowledge and insight on geology of Ethiopia have

[1] The number of the published scientific literature is estimated from searching for published works on Ethiopia via 'ScienceDirect'. ScienceDirect is one of the largest online collections of published scientific research in the world. The term 'Ethiopia' and 'Geology' has been entered and the search result gives 3,500 articles on the end of 2010. The total number of published works is estimated to double this size if other portals such as Springer Link, Tylor-Francis, Wiley etc., were included.

Table FM.1 Evolution in knowledge on Ethiopian Geology and its implication to hydrogeology

Domain	Old view	Prevailing view
Basement complex	The Precambrian basement of Ethiopia forms a transition zone among the low-grade volcano sedimentary succession and mafic ultramafic complexes of the Arabian Nubian Shield (ANS) and the high grade multiply metamorphosed and deformed schists and gneisses, migmatites, ophiolite fragments, and granulites of Mozambique Belt (MB).Based on field relation, structural style and metamorphic grade of the Precambrian rocks of Ethiopia has been classified into three groups: (1) the Lower complex (Archean cratonic basement), which is composed of the multiply deformed and metamorphosed high grade gneisses, migmatities, and associated granulites; (2) the Middle complex (Paleo to Meso proterozoic platform cover) which consists of psammitic and politic metasediments, and (3) the Upper Complex (Neoproterozoic mobile belt), which constitutes low-grade rocks of island arc-ophiolite association. The lower and middle complex belongs to the MB and the Upper complex to the ANS	The Precambrian basement of Ethiopia forms a transition zone among the low grade volcano sedimentary succession and mafic ultramafic complexes of the Arabian Nubian Shield (ANS) and the high grade multiply metamorphosed and deformed schists and gneisses, migmatites, ophiolite fragments, and granulites of Mozambique Belt (MB).Because of similarity in age between ANS and MB rocks of Ethiopia the classification into Upper Middle and Lower complex is replaced by a 2-fold classification as (1) the reworked pre Pan African Crust and (2) the Pan African juvenile crust.
Mesozoic stratigraphy	The Adigrat Sandstone is a fluvital-deltaic sandstone forming a single unit from its base to top	The Adigrat sandstone is marine-deltaic sandstone with two distinct formations separated by paleosol. The base of the Adigrat sandstone is highly cemented by iron, hard, and indurate, the upper Adigrat formation is porous, reddish, and the upper most layer is highly lateratized and hardened
Rift margin Architecture	Progressive doming, volcanism, and rifting took place at the axial zone of the Rift until present hence including the young volcanics and associated sedimentary rocks are inclined outwards of the Rift axis. This domal structure is believed to be formed contemporaneous with Rifting and flexuring associated with rift formation.	The uplifting of eth Ethiopian Terrain predates the outpouring of the flood basalts and formation of the rift. The dipping of strata at the margin of the rift has complex setting with dipping direction of lithologies varying with time and space.

(continued)

Table FM.1 (continued)

Domain	Old view	Prevailing view
The Volcanic plateau stratigraphy	Traditionally, the Oligocene volcanism of the northwestern Ethiopia has been divided into three formations (Zanettin and Justin-Visentin 1974); the Ashangie and Aiba basaltic units, separated by an angular unconformity and the upper Ignimbritic Alaji unit. This chronostratigraphic subdivision, although only based on a few sections from the eastern and southern part of north western Ethiopian plateau, was assumed to be valid for the entire plateau.	The Oligocene volcanism represents a continuous lava sequence from the base to the top of the plateau rather than the pilling of three or more successive and stratigraphicaly distinct units. Most of the Ethiopian flood basalts erupts 30 Myr ago during a short 1 Myr period to form a vast volcanic plateau. Immediately after this peak activity, a number of large shield volcanoes developed on the surface of the volcanic plateau, after which subsequent volcanism was largely confined to regions of rifting.
Geomorphology, karstification, planation surfaces, drainage history, paleo hydrology	In Ethiopian hydrogeology, the linkages between groundwater occurrences and geologic processes such as geomorphology, karstification, planation surfaces, regolith development, and stripping and drainage history are little known. These are the principal factors that affect groundwater occurrences, usability and vulnerability to climate change, and human forcings. Significant knowledge has been created over the last decade on these processes through geological research. In existing hydrogeological maps of Ethiopia and classification of aquifers were basically based on lithology, recharge conditions, and lateral extent of lithologies with little due emphasis on other controls such as karstification degree, geomorphology, landscape, hydrography, tectonics, diagenetic history, or rocks, environmental functions of groundwater, recharge mechanism and so on. For example, a clear linkage exists between the geomorphology of the Ethiopian flood basalts and their permeability structure. The basal units (traditionally called Ashangie basalts) form gentler topography while the top part (traditionally called the Aiba basalts) is cliff forming. Field evidence shows that none of the parameters such as flow thickness, types of volcanic structures, modal mineralogy, percentage of phenocrysts, and the degree of alteration could be able to explain the geomorphic variations. However, the geomorphic variations are related to presence of zone of soft, nonoutcropping material such as flow top breccias and highly fractured horizons. The geomorphic characteristics of the flood basalts are indicative of the difference in permeability. A high concentration of clay rich paleosols in units at the top of the Ashangie formation may account for reduced resistance of these units and gentler slope. A process called sapping a term that describes the formation of plateaus and escarpments through preferential erosion of nonresistant and nonpermeable horizons by outflow of groundwater that infiltrates the overlying resistant and permeable rocks. Geomorphic evidence shows the Aiba basalts are more permeable than the Ashangie.	

evolved and widened. Table FM.1 provides some of the evolution in knowledge of geology. This evolution provides an opportunity to update the knowledge on groundwater resources of Ethiopia. *The book aims to provide updated and detailed scientific context to the hydrogeology of Ethiopia*.

(b) *Evolution in paradigm of hydrogeology* Groundwater resources assessment which started in the 1960 and continued to recent time evolved under the *paradigm of steady state*. Ground water occurrence mapping and potential assessment sufficed for the purpose. Currently, the prevailing paradigm is that of quantifying aquifer response to changes in climate and human-induced forcing (pumping, land use changes) and maximizing the resources use sustainably. 'Water-centered development' is explicitly seen as the entry point for growth and poverty eradication in Ethiopia. Increasingly, water resource development is integrated with economic development and land use planning. Groundwater is of paramount importance for Ethiopia to supplement the available surface water resources in providing drinking water to its population and for socio economic development (agriculture, livestock, industry, tourism). The usability of groundwater resource in addition to its intrinsic properties such as water quality and vulnerabilities can be affected by the suitability of the system which intends to use it. For example, in Afro Alpine agro-climatic zone the usability of the available groundwater is limited by availability of soil, topography, climate, and so on. Therefore, groundwater resources availability alone cannot lead to its intensive use unless the availability is linked to other external factors such as land use planning, agro-ecology/climate, and accessibility by existing technology. In this book, attempt has been made to increase the scope of groundwater resources assessment beyond the mere description of aquifers to viewing the role of groundwater in other cross cutting issues such as climate change adaptation, poverty reduction, investment opportunities, urban planning, groundwater dependent ecosystem, and so on.

(c) *Groundwater as strategic resource* Over the last decade groundwater development has become a new phenomenon. It has become source of domestic water for growing urban population. It has become of paramount importance in rural areas. There are several reasons why groundwater is of paramount importance in rural areas: Groundwater is generally cheaper to develop relative to alternatives; aquifers are able to offer natural protection from contamination; and groundwater offer reliability of supply and a buffer against drought. For irrigation the benefits of controllability are also significant, allowing efficient and flexible in field application on demand. This is a key reason why yields from groundwater irrigated areas are typically much higher than under surface water schemes. Groundwater is the only practical means of meeting rural community in arid and semi-arid regions of Ethiopia, and note that groundwater also supplies many urban centers including the capital city Addis Ababa. In this regard, future development of settlements and urban centers in Ethiopia are highly dependent on the potential of nearby aquifers to meet ever increasing demand from population growth and industries. In rural poverty reduction, groundwater is an important credit. There is an increasing shift of paradigm: hydrogeological mapping for specific project site (e.g. water supply of a village, a city) loaded with science jargons (transmissivity, storativity, extent of aquifer, water quality, recharge rate, etc) to a new paradigm: groundwater use for development and economic growth, groundwater as strategic resource, groundwater in poverty reduction, and groundwater has environmental function. This necessitates the need of value chaining hydrogeological knowledge, i.e., provision of policy, practice, and management relevant information on groundwater resources. Such policy relevant information include maps such as: drought proof maps, recharge mechanism maps, aquifer vulnerability maps, water poverty indicators for regions, water availability maps, and so on. This book aims to provide such management relevant information on groundwater resources of Ethiopia.

(d) *Groundwater as environmental water* Groundwater is ecologically important. The importance of groundwater to ecosystems is often overlooked, even by freshwater biologists, and ecologists. Groundwater sustains rivers, wetlands and lakes, as well as subterranean ecosystems within karst or alluvial aquifers. While there are other terrestrial ecosystems in more hospitable environments where groundwater plays no central role, groundwater is, in fact, fundamental to many of the world's major ecosystems. Water flows between groundwater and surface waters. Most rivers, lakes, and wetlands are fed by, and (at other places or times) feed groundwater, to varying degrees. Groundwater feeds soil moisture through percolation, and many terrestrial vegetation communities depend directly on either groundwater or the percolated soil moisture above the aquifer for at least part of each year. Hyporheic zones (the mixing zone of stream water and groundwater) and riparian zones are examples of ecotones largely or totally dependent on groundwater. This book provided comprehensive account on groundwater dependent ecosystems including their origin, groundwater surface water relation, and specific roles of groundwater.

Seifu Kebede

Springer

http://www.springer.com/978-3-642-30390-6

Groundwater in Ethiopia
Features, Numbers and Opportunities
Kebede, S.
2013, XIV, 283 p. 116 illus., 96 illus. in color., Hardcover
ISBN: 978-3-642-30390-6