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Enhancing Ethiopia's Resilience to Drought and Hydrological Variability with Inter and Intera-Basin Water Transfer

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Abstract
It is hardly possible to think of sustainable development of society without access to safe and adequate water. Perhaps that is the reason that most of the civilizations have developed on the banks of rivers or other water bodies. However, water availability varies in space and time. At various places, its availability is either too much or too less. Further, in countries where poverty is a chronic problem, access to safe and adequate water and sanitation facilities is low. The severity of water shortage is pronounced in Sub-Saharan regions and mild in other parts of Africa. Ethiopia, a country of ancient culture is located in the north-eastern part of the horn of Africa. The water resources development and management conditions in Ethiopia are no better than any other Sub-Saharan African region, if not worse. Less than half of the population has access to safe and adequate drinking water. Only one-third (approximately) of the population has access to adequate sanitation services. Further, during the last century, Ethiopia has experienced recurring droughts. During such periods, water-related diseases become rampant. Most of the surface water sources dry up and the remaining water bodies get contaminated. Further, the major river basins in Ethiopia are transboundary in nature with wide variation in water availability. Keeping this in mind, the present study advocates the inter-linking of rivers for rational and equitable distribution of water resources in various river basins to the extent possible. A proposal has been prepared on the basis of water availability which can be further examined for its technical and economic viability.

Keywords: Water Scarcity, Interlinking, Water Allocation, Blue Nile Sub Basin, Transboundary Rivers

Introduction and Background of the Problem

Ethiopia is situated in the north-eastern part of the horn of Africa. It is located between 3° to 18° N latitude and 33° to 48° E longitude. The country covers the major portion of the horn of Africa and some part of subtropical and tropical east Africa. The location map of Ethiopia is given in Fig. 1. The countries bordering Ethiopia are Somalia to the east, Kenya to the south, South Sudan to the south-west, and Sudan to the west, Eritrea to the north and Djibouti to the north east. The geographical area of Ethiopia is about 1.13 million km2 out of which about 99.28% is land and 0.72% is water body. The central plateau of Ethiopia with mountainous terrain is divided by Great Rift Valley. The Great Rift Valley which is surrounded by lowlands and runs down the Red sea divides the highlands into southeast and northwest. The rugged terrain topography on either side of the rift valley is steepest especially on the north. This caused a huge diversity in altitude within the country which affects the climate of Ethiopia.

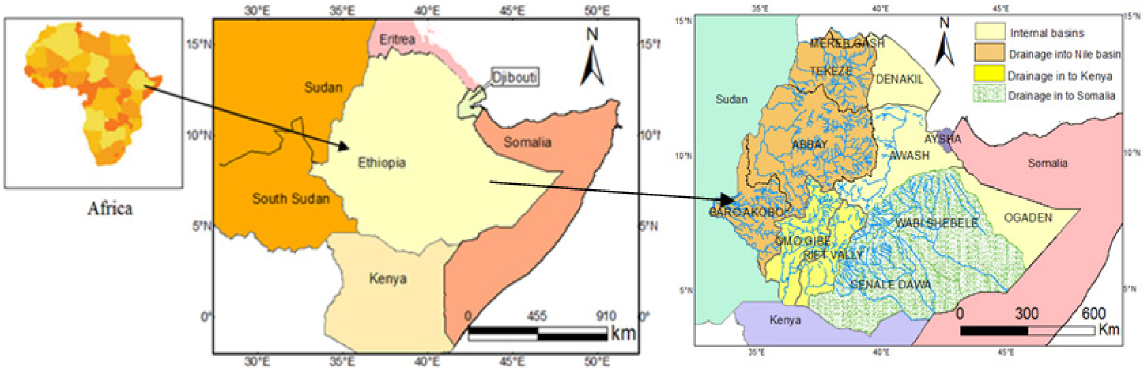


Figure 1: Location map of Ethiopia

The spatial and temporal distribution of Ethiopia's water resources is highly uneven. The water resources are increasingly diminishing both in quantity and quality in different basins due to natural and anthropogenic causes. The per capita water availability in all of the basins is in a decreasing trend and water shortage is severe in some of the basins. Further, most of the Ethiopian river basins are transboundary and the waters of these rivers are not equitably shared and allocated among the riparian countries Adeba (2016) [1]. Evidences show that many transboundary basins in Africa are mismanaged, and equitable allocations of either the fresh waters themselves or the benefits arising from them, are rare. These international rivers can be a source of conflict or a catalyst for cooperation depending on whether there is a treaty regarding their allocation between and use by the riparian countries. Water resources allocation takes place at a number of levels in which all states and stakeholders are represented in any important decision making processes like integrated basin-wide management that affect the common interests of each state. The management of a river basin means, to allocate scarce resources among competing users, both for now and the future which requires cooperation and trust. In basins shared by different riparian states, it is important that effective transboundary water allocation systems are put in place, supported by shared data on the status of the basin. The first level of allocation should be made equitably between riparian states. International agreements are required regarding the sharing, development and management of these rivers. Despite the large number of rivers, and the significant importance of water resources for the basic livelihood of the people sharing the resources, the Nile basin countries have not been successful in establishing treaty of its shared rivers. The agreements and institutions to sustainably manage the resources are weak or totally absent, and where they exist they are not adequate to cope with conflict resolution. Some are lacking effective dispute resolution mechanisms. None of these treaties also included all the river basin states. Instead it revolved only around Sudan and Egypt. Further many of the riparian countries lack institutional capacity at the national or transboundary level for effective implementation and optimal sharing of water resources and the benefits derived from water.

Due to the fact that the Nile riparian countries have a long history of disputes over water allocation, political tensions have often escalated to threat against other member states. Egypt and Sudan are the only signatories to the Nile waters agreement while the other riparian countries remain outside the treaty and do not necessarily feel obliged to either recognize or abide by its provisions. Agreement between Egypt and Sudan in 1959 guarantees the full utilization of the water from the Nile to Egypt and Sudan. The proportion of their share according to this agreement is 55.5BCM for Egypt and 18.5BCM for Sudan. Egypt continues to view its 55.5BCM share, as an inviolable Yohannes (2008)[2]. Egypt's influence in the share of Nile water is due to its political, military, economic and diplomatic hegemony in the region. Egypt has often threatened to use military force against upstream riparian country to stop any development endeavor on the river Nile that might interrupt the natural flow of the river to Egypt. Further, Egypt is often successful in preventing Ethiopia to secure international funds for projects on the Nile River. However, Egypt must consent to other nations' use of the Nile's water. Common pool resources, such as international river basins with multiple riparian states, are hard to manage efficiently and equitably unless there exists adequate institutional capacity. The building of trust, shared knowledge and a shared vision of the basin across boundaries is very important, particularly in highly vulnerable areas that already lie in conflict zones like in the Nile basin.

Due to this and other similar reasons, the competition for water and its growing scarcity stands as the greatest challenge and is a threat to alleviate poverty in rural areas of Ethiopia. While the water resources are diminishing, the population is growing and various economic activities pose further pressures on the country's water resources. As a result, Periodic drought and famines have characterized Ethiopia throughout its history. The story of drought and famine in Ethiopia is an image that characterizes the history of food insecurity in the country. In light of the uninterrupted cycles of drought and famine from year to year, Ethiopia has come to be identified with hunger and starvation, and trapped with dependency on international donations.Webb and Braun (1994)[3] recorded at least 10 severe famines between 1960 and 1994, which hit the northern highlands and the western lowlands of Ethiopia. During the 1970-1975 a series of failure of rainfall resulted in a severe drought and famine which caused an estimated death of 250,000 people mostly in Eritrea (the then part of Ethiopia), Tigray and parts of Amhara (Webb and Braun 1994)[3]. Another six major drought have been recorded from 1994 to 2006. In the 2002–2003 drought cycles alone, the lives of about thirteen million Ethiopians have been threatened by hunger and starvation. The droughts of 1973, 1984/85, 1998 and 2002/2003 were identified as being particularly severe. Even in years of average rainfalls and bumper harvest, up to six million Ethiopians regularly rely on international food aid indicating that the country is food insecure Yohannes, (2008)[2]. Ethiopia's chronic food insecurity stems partly from an overdependence on rain-fed agriculture, which is vulnerable to non-uniform, irregular or interrupted rains, and full-scale droughts Adeba (2016)[1]. The first sector to be heavily affected by water scarcity is agriculture because; rain-fed agriculture is highly vulnerable to variations in the patterns of water availability. This implies that it cannot be relied upon rainfall alone for agricultural production especially in arid and semi-arid basins where rainfall is erratic. This calls for storing water in reservoirs and supplying it to agriculture. This helps enhance agricultural production by supplying water to crops fully or for supplementary irrigation when the rainfall fails and the season is dry. An optimal balance between the carrying capacity of the ecology, optimum population sizes and sustainable development of its water resources is required if Ethiopia is to genuinely eradicate poverty and attain food security.

While the country is regularly hit by drought, the annual average rainfall in Ethiopia is about 850mm per year. However, different regions of Ethiopia are prone to low and erratic rainfall. The mean annual flow of rivers in Ethiopia is about 122BCM. If properly developed and managed the total water resources of the country is sufficient for sustainable economic development. However, the country could not manage its water resources sustainably due to various reasons.

According to the water poverty index that ranked 147 countries in 2002 in terms of their water resources and capacity to access and use those resources, the bottom ten countries included Ethiopia, Eritrea, Rwanda, and Burundi Yohannes, (2008)[2]. However, Ethiopia, contributing 86 percent of the mean annual Nile flow (Blue Nile 59%, Baro Akobo 14% and Tekeze –Atbara 13%), the country is hydrologically the wealthiest in the entire Nile basin countries. Therefore it can be concluded that poverty in the midst of plenty and thirst in the midst of sufficient water defines contemporary Ethiopia Yohannes (2008)[2]. Therefore, it is proposed to transfer water from surplus basins to deficit basins to alleviate the chronic water problems of the country.

Proposed Interlinking of Rivers in Ethiopia

The concept of inter-and intera-basin water transfer is not entirely new. The economic development of many countries in the world is brought about by out-of-region supply of water and this out-of-region may sometimes mean another country Dinar and Wolf (1994) [4]. From 1940 to 1980, the world has witnessed the peak period of the construction of large scale long distance inter-basin water transfer projects. The global inter basin water transfer increased from 22 to 56, from 56 to 257 and from 257 to 364 km3 per year during the period 1900-1940, 1940-1980, 1980-1986 respectively and is estimated to increase to 760-1240km3 by 2020, Shiklomanov (1999)[5]. Global water withdrawal has increased by about six fold during the twentieth century compared to a fourfold increase in population from 1.5 to 6 billion Ghassemi and White (2007) [6]. Since the 1950s most developed countries enthusiastically proposed IBWT schemes as a solution to water supply problems in the areas with perceived shortages. The issues of water stress and scarcity impacts a large number of people all over the world Van Meter et al., (2015)[7] and it results in conflict.

Ethiopian economies rely heavily on agriculture, and are thus easily affected by water scarcity, harsh climatic conditions and poor water infrastructures which call for construction of dams for balancing the ill distribution of water resources. Possible causes of water scarcity in Ethiopia can be due to demand and supply induced and unequal distribution of the water resources. For example in the basins like Awash, water scarcity is supply induced, because, the resources are diminishing as a result of over exploitation by different sectors like agriculture and industry, on the one hand and increase in the population on the other hand. The transboundary nature of the river basins in Ethiopia has also contributed significantly towards water scarcity. The severity of water shortage is more in central and north-eastern part of Ethiopia where the basins are physically water deficit. Over half of Ethiopia's population lives in central and eastern part, where rainfall is low and water is scarce. Table 1 shows river basins of Ethiopia and their water resources. The table also shows deficit and surplus basins based on Falkenmark's (1989) water stress index [8].

Table 1: Water Resources Status Of Various Basins In Ethiopia

S. No	Name Basin	Water resources potential (BCM)	Per capita water availability (m^3/year)		Basin Status Surplus / Deficit	
			Present (2018)	Projected (2050)		
1	Abbay	86.40	3871	2098	Surplus	
2	Baro Akobo	24.24	3580	1930	Surplus	
3	Omo Gibe	17.6	1462	820		Deficit
4	Rift Valley	5.64	532	308		Deficit
5	Genale Dawa	6.00	930	411		Deficit
6	Wabi Shebele	6.80	710	372		Deficit
7	Ogaden	negligible	negligible	negligible		Deficit
8	Awash	4.64	325	176		Deficit
9	Aysha	negligible	negligible	negligible		Deficit
10	Denakil	0.86	292	225		Deficit
11	Mereb	0.83	304	150		Deficit
12	Tekeze	24.7	2829	1534	Surplus	

Referring to table 1, surplus and deficit basins are identified based on per capita water availability in each basin. Three surplus basins of Ethiopia and nine deficit basins are identified. The surplus basins are Abbay, Baro Akobo and Tekeze basins. All, the three surplus basins in Ethiopia from which water transfer is proposed are Transboundary Rivers. However, the proposal of water transfer from the surplus to deficit basin has considered the transboundary nature of the basins and the quantity of water to be transferred is kept minimum. Keeping the above in mind, following proposals are made:

1. Water transfer from Baro Akobo to Awash basin
2. Water transfer from Abbay to Rift Valley basin
3. Water transfer from Tekeze to Denakil basin,

Seven out of twelve river basins of Ethiopia are perennial and trans-boundary. The Abbay (Blue Nile), Tekeze and Baro Akobo are parts of Nile basin which is shared by eleven east African countries. Omo Gibe basin is shared between Kenya and Ethiopia, Genale Dawa and Wabi Shebele basins are shared between Somalia and Ethiopia. Likewise, Mereb basin is shared between Ethiopia, Eritrea and Sudan. Awash, and Rift valley basins are internal and perennial river basins while Ogaden and Aysha basins are dry basins. The Abbay, Baro Akobo and Omo Gibe basins account for more than 70% of the total runoff from an area of only 32% of the total land mass of the country. Fig.2 shows the three proposed river links in Ethiopia for equitable water resources distribution and table two shows the salient features of the proposed links.

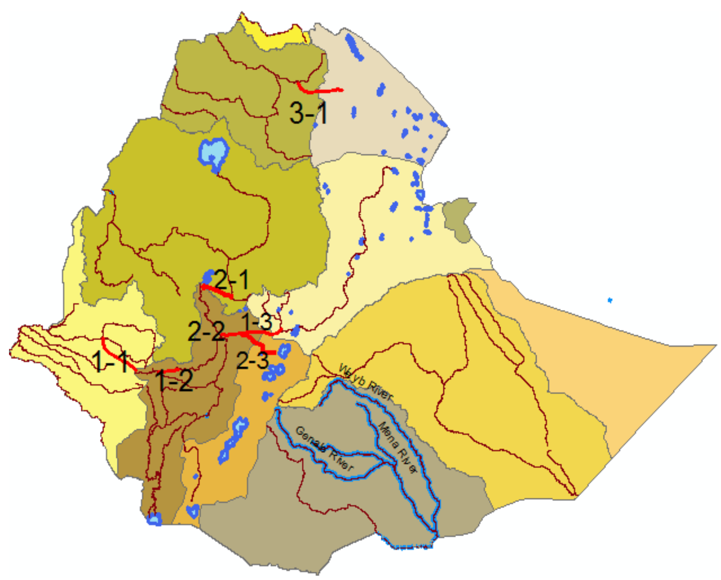


Figure 2: Proposed water transfer routes

Table 2: Salient features of the proposed IBWT routes

Segment	IBWT Link	Diversion point elevation (m)	Coordinate (UTM)		Delivery point elevation (m)	Coordinate (UTM)		Distance (Km)
			Northing	Easting		Northing	Easting	
1-1	Baro Akobo to Awash	1565	54473	916909	1965	136493	840180	111
	Flow in natural waterway	1965	136493	840180	1900	181472	842825	45
1-2	Baro Akobo to Awash	1900	181472	842825	2074	234918	843354	50
	Flow in natural waterway	2074	234918	843354	2000	332285	919554	153
1-3	Baro Akobo to Awash	2000	332285	919554	2264	480452	934371	160
2-1	Abbay to Rift Valley lake	3100	332285	919554	2899	382747	928367	53
	Flow in natural waterway	2899	283859	1033539	2000	332285	919554	159
2-2	Abbay to Rift Valley lake	2000	382747	928367	2700	451539	875450	112
2-3	Abbay to Rift Valley lake	2700	327807	919341	2500	481475	930317	150
3-1	Tekeze to Denakil	1500	514404	1495596	400	665328	1498348	130

Historically, large-scale water development projects have played a major role in poverty alleviation by providing food security, protection from flooding and drought, and expanded opportunities for employment. Building a dam on Transboundary Rivers can open up the way to successful cooperation events. Most research papers on the topic agree that transboundary water management gives higher incentives for states to enter a cooperative mode Kameri-Mbote 2005, Yoffe et al. 2003, Uitto and Duda, (2002) [9, 10,11]. The birth of the Nile Basin Initiative (NBI) in 1999 is a clear indication that cooperation could prevail even in basins where there are very diverse riparian interests. Nile Basin Initiative (NBI) has been established to foster cooperation of Nile basin counties on the management and sharing benefits of Nile water. It is a remarkable achievement towards the cooperative development and management of the common Nile water resources by Nile basin states. It seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security. As a result there is a construction of dam underway in Ethiopia with a storage capacity of 72BCM of water to produce 6000MW of electricity. Whilst this is of a general concern across the region, due to the high levels of water stress, there is high risk in Ethiopia. Already high levels of poverty and under-development in the region put the rural communities particularly at risk.

The Nile Basin

The lake plateau of equatorial East Africa and the Ethiopian plateau are the two primary runoff producing regions in the Nile Basin. Within the Nile basin, there are five major lakes with a surface area of more than 1,000km2 (Victoria, Edward, Albert, Kyoga, and Tana lakes). There are also vast areas of permanent wetlands (the Sudd, Bahr al-Ghazal, and Machar marshes), five major reservoir dams (Aswan High Dam, Rosaries, Khashm El Girba, Sennar, and Jebel Aulia), and four hydroelectric power dams (Tis Isat, Koga, Finchaa, and Owen Falls). The relative contribution to the mean annual Nile flow at Aswan of 84 billion m3 is approximately 4/7 from the Blue Nile, 2/7 from the White Nile (of which 1/7 is from the Baro-Akobo-Sobat and 1/7 from the Tekeze-Atbara river). This indicates that the Ethiopian catchments (Baro Akobo-Sobat, Blue Nile and Tekeze-Atbara river) contribute to about 6/7 of the Nile water resources at Aswan. There are eleven countries sharing the Nile basin. They are Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, South Sudan, Tanzania and Uganda. Table 3 shows the total areas of each country sharing the basin, the area within the Nile basin, and percent of the total basin area of each country.

Table 3: Countries Sharing Nile Basin and Area of Respective Country within the Basin

S. No	Country	country area (km^2)	Area within the Nile basin	% of the total basin area	% of the country in the Nile basin
1	Burundi	27835	13260	0.4	47.6
2	DR Congo	2345410	22143	0.7	0.9
3	Egypt	1001450	326751	10.5	32.6
4	Eritrea	121320	24931	0.8	20.5
5	Ethiopia	1127127	365117	11.7	32.4
6	Kenya	582650	46229	1.5	7.9
7	Rwanda	26340	19876	0.7	75.5
8	Sudan	2505810	1978506	63.6	79
9	Tanzania	945090	84200	2.7	8.9
10	Uganda	236040	231366	7.4	98
Source: Diana Rizzolio Karyabwite, 1999 UNEP/DEWA/GRID –Geneva					

Blue Nile Sub-Basin and the Problem of its Water Allocation

Three major sub basins flow out of Ethiopia into Sudan, constituting the Eastern Nile basin, as distinct from the White Nile flowing from the equatorial east Africa. These sub basins are the Tekeze–Atbara flowing out of northern Ethiopian highlands, the Baro–Akobo–Sobat flowing from southern Ethiopian highlands, and the Blue Nile (Abbay) flowing from central highlands.

The Blue Nile sub basin receives between 1,400 and 1,700 mm of rainfall annually, and covers about 17 percent of the Ethiopia's total land area Yohannes (2008)[2].

The large disparity in the water resource availability of Ethiopian basins is due to rainfall variability in different regions of Ethiopia. This lack of symmetry in the distribution of water has always caused unease between the inter-state relationships of the country. To address the uneven spatial and temporal distribution of water resources, Ethiopia's desire to fully harness and develop its water resources started in the second half of the 1950s. To show its determination to develop its water resources, Ethiopia requested and received external assistance from the United States Bureau of Reclamation (USBR) in the 1960s for a comprehensive feasibility study of the Blue Nile basin. The various schemes identified by USBR during the period would have required the detention and storage of up to 51 BCM of water, representing almost the entire annual flow of the Blue Nile (Yohannes 2008)[2]. However, since most of the schemes identified in the Blue Nile basin were to be non-consumptive, the annual loss of water to downstream users would have amounted to only 6.5 BCM of water, representing a mere 8.5 percent reduction in Nile flow (Yohannes 2008)[2]. However, Ethiopia did not carry out the projects identified by the USBR experts.

Today, Ethiopia needs additional water of Nile River annually to expand irrigation projects to insure food security for its increasing population. On the basis of hydrological contribution to the Nile basin, Ethiopia could have claimed the highest share of the water of the Blue Nile. However, the Ethiopia's share of the waters of the Nile River is practically negligible. Based on the drainage area, Sudan, is sharing 63.6% of the Nile basin. In the proportion of geographical area in the basin, Sudan would have claimed the largest share of the water of the basin. However Sudan's share is also nearly one-third of Egypt's. Egypt's contribution to the basin either in area or hydrologically is less than the two countries, Ethiopia and Sudan. This indicates that Egypt's share of 55.5BCM of the Nile's water is unacceptable at any legal means. Therefore, all things considered, Ethiopia's request to additional water annually from its Blue Nile river is fair and acceptable. According to a set of water rights allocations of existing international water laws, Ethiopia has the right to claim a given share of the Nile water, because it contributes more water than any other riparian country to the Nile basin. In this regard it is required to find a workable formula for sharing of the river water not only for Ethiopia but also for all riparian states on an equitable basis. Egypt should accept and cooperate the fair share and allocation of the water of the Nile River to all riparian countries. Nigatu and Dinar (2013) [12] identified five Water Resources Allocations, (WRAs) of Nile River between Ethiopia, Sudan and Egypt. Accordingly, WRA-I allocates 12.2, 22.0, and 65.8 percent, respectively, to Ethiopia, Sudan, and Egypt. WRA-I is based on the notion of Egypt's long-term use of the water and on the fact that Ethiopia's share should be based on the contribution of Ethiopia to the Nile river water and the irrigable potential in both the countries (Ethiopia and Sudan).

WRAs-II employed an equitable water allocation based on the Article 5.8 of the United Nations Convention on international watercourse of 1997. The article suggests factors and circumstances for equitable allocation of international basins. This method of allocation is based on the notion of equitable access to a common pool resource as reflected in the 1997 Convention. Based on the population principle, Nigatu and Dinar allocated the Nile water to the three riparian countries as follows; 38.4, 14.1, and 47.5 percent (37.8, 13.9 and 46.8 BCM) to Ethiopia, Sudan, and Egypt, respectively. WRA-IV allocates 50.0, 12.5, and 37.5 percent, respectively, to Ethiopia, Sudan, and Egypt. It recognizes Ethiopia as being the source of the Blue Nile, which endows it with half of the long-term flow. Each of the WRAs (WRA-1, WRA-II, and WRA-IV) is justified on the basis of various political, legal, or economic factors of Egypt, Ethiopia and Sudan.

Equity in transboundary water relationships is associated with the notion of 'equitable and reasonable utilisation' – an approach that is central to the 1997 United Nations Convention on international watercourses. Further, it is related to earlier codifications of customary international water law, such as the Helsinki Rules of 1966. This includes, physical factors, social and economic needs of the water course states, and the population dependent on the water course in each riparian state. The article discusses the effects of the use of water courses by one state on the other states, existing and potential uses of the water course, conservation, protection, and development of the water resources and planned or existing water use.

In international watercourses, encompassing both rivers and lakes, the actions of one riparian state in using or protecting the watercourse and its resources necessarily affect the opportunities of other riparians. This leads to collective action that can easily turn into conflicts. These conflicts do not only threaten the security in the respective river basin, but also negatively influence the overall socioeconomic development prospects in the region. Therefore more emphasis should be given to the equitable sharing of water resources and their benefits among riparian states of the Nile basin to reduce the risk of environmental hazards that mutually affect the security of the states. Differences in socio-economic development between riparian countries contribute to differences in the demand for and use of transboundary waters. Furthermore, a country's institutional capacity to manage water is closely linked to the level of socio-economic development. In any account, the present water allocation and use of Nile River should be replaced by a rational, equitable and a common vision to serve all states that occupy the basin through common understanding and cooperation.

Water Scarcity in Ethiopia

The appropriate scale for understanding water scarcity is at the local or regional level, notably within a river basin or sub-basin, rather than at the national or global level. To understand water scarcity, different indices are used to demarcate areas under water stress, and several methods have been developed for this purpose locally, nationally and globally Kummu et al., (2010)[13]. Examples at the global and the national level include the Falkenmark index, a measure of per capita water resources availability Falkenmark et al., (1989)[8], and water vulnerability index, which measures the total annual withdrawals as a percentage of available water resources Raskin et al., (1997)[14]. Further, an availability index based on a normalized ratio of water demand to availability Meigh et al., (1999)[15], and WATER GAP models Alcamo et al., (2003); Sullivan et al., (2003) are used [16,17]. The most widely and frequently used indicator of water scarcity is the Falkenmark Water Stress Indicator (WSI). The index relates the available water resources in a given region per year to the number of inhabitants, regardless of the temporal and spatial distribution of the water resources. The most challenging aspects of sharing water resources whether it is abundant or scarce, is its rational and equitable distribution. In some countries, like Ethiopia, poverty slows down institutional capacity building and development which are crucial for water management. Skilled human resources are essential to generate sound water resources management together with institutional capacity.

Water is relatively abundant in the Abbay, Baro Akobo, and Tekeze basins while it is scarce in basins like Awash, Rift Valley, Denakil, and Wabi Shebelle. In addition some of the eastern and central basins, where about 40 percent of the total population of the country lives are water scarce. Large numbers of people living in poverty in rural and pre urban areas of these regions are already vulnerable to water-related risks, whether floods, droughts, poor water quality, or increasing water scarcity. Therefore, in this situation, it is natural to think in terms of inter basin water transfer from better endowed basins to deficit areas in order to address water shortage in deficit basins and equitably allocate water resources. Physical water stocks of deficit basins can be augmented through inter-basin transfers from relatively water abundant basins by controlling the flow of rivers using different hydraulic structures. The steps to be followed in water transfer includes, identification of the availability of surplus water in the basin and estimation of quantity of water required to be transferred to deficit basin without adversely affecting the communities and the environments of the donor basin. The important point in interbasin water transfer is not in identifying the deficit and surplus basins, but in the quantification of the amount by which basins will have surplus or deficit waters. Further, determining the feasible route of transfer and estimation of total investment and O&M costs of the project are required while proposing inter-basin water transfer.

Based on the proposed Nile river water sharing among the riparian countries by Nigatu and Dinar (2013)[12] it is suggested to transfer a volume of water from Baro Akobo to Awash, Blue Nile to Rift Valley and Tekeze to Denakil basins of Ethiopia. Besides addressing the water shortage of arid and semi-arid regions of the country, redistribution and optimum utilization of water resources by means of inter-basin water transfer is closely associated to the rational and equitable use of the resource. Further, the water to be transferred can generate electricity enroute using favorable topography of routes of transfer. However, developing water resources without degrading ecosystems is a challenging but prudent goal, given that a large proportion of rural population in Ethiopia depends directly on the ecological services of rivers and river corridors. In this study it is proposed that water may be transferred from Baro Akobo to Awash basin, from Abbay to Rift Valley and from Tekeze to Denakil basin. Depending on the topography of both the donating and the receiving basin, water transfer can be carried out by pipe, an open channel or tunnel either by pump or gravity.

Water Transfer from Baro Akobo to Awash Basin

The Baro Akobo basin is located between the Latitudes 5°31' and 10°54'North, and the longitude 33°and 36°17'East and covers an area of about 76,000 km2. The basin drains Gambela and parts of its neighbouring states including Oromia, Benshangul Gumuz and SNNPS. About 31% of this area falls in Oromia; 9.8% in Benshangul Gumuz; 24.6% in Southern Nations Nationalities and People's state (SNNPR) and 34.3% in Gambela state. Table 4 shows the proportion of area of each state in the basin.

Table 4: Proportion of areas of the Baro Akobo basin in different states of Ethiopia

State	Area (km^2)	As percentage of the total area of the basin (%)
Gambela region state	26068	34.3
Oromia regional state	23788	31.3
SNNP regional state	18696	24.6
Benshangul Gumuz State	7448	9.8
Total	**76000**	**100**

The rivers originate in the eastern highland parts of the basin and flows westward to Gambela plain. The population in the basin is estimated at 6.77 million (2015). About 60% of the basin population lives in Oromia; 21% in SNNPR; 11% in Benshangul Gumuz and about 8% in Gambela state. The distribution of population in different states is shown in Table 5.

Table 5: Population distribution in different states of the basin

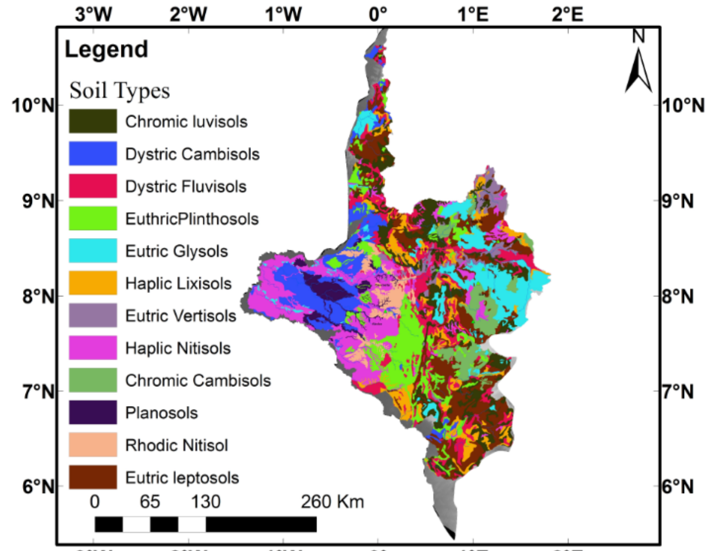
State	Population (Million)	Population (%)
Gambela region state	0.5416	8
Oromia regional state	4,062,000	60
SNNP regional state	1,421,700	21
Benshangul Gumuz State	0.7447	11
Total	**6,770,000**	**100**

Population density is more in central highland plateaus of Ethiopia, in some parts exceeding 122 peoples per km2.The densities in the floodplains and escarpments are very low. The economy of the Baro Akobo basin of Ethiopia is predominantly natural-resource based, relying on land and water resources of the basin. These economic activities include: farming; livestock grazing; fisheries; and wildlife hunting. Therefore, any development intervention in the basin requires a critical assessment of the impacts of strong dependency of the community on the natural resources systems. There are only two hydraulic structures on the Baro Akobo river basin in Ethiopia; the Alwero/Abobo dam constructed to irrigate 10,400 ha of land and the Sore hydropower plant (to generate 5MW of electricity). However, the Alwero dam is not yet fully operational. Characteristics of the major tributaries of Baro-Akobo-Sobat (BAS) sub basin is given in Table 6.

Table 6: Key catchment and river characteristics of main tributaries in BAS basin

Catchment Name	Catchment area (km^2)	Catchment length (km)	Elevation of centroid (m)	River length (km)	River slope	Flow path from centroid (km)	Longest flow path (km)
Baro	43,890	1454	1378	295	0.0021	257	508
Akobo	30,228	1262	491	280	0.0018	255	504
Gilo	20,101	1,183	433	150	0.002	201	429
Pibor	74,130	2,163	485	400	0.002	283	699
Source: Eastern Nile Technical Regional Office (ENTRO)							

The drainage network of the basin is complex with bifurcation and spills at several places in the basin to form seasonal wetlands at different places of which Machar is the largest wetland in the sub-basin. There are two major rivers constituting Baro Akobo basin: the Baro River from the Ethiopian Highlands and the Pibor River from southern Sudan and northern Uganda. The majority of the basin flow is supplied by Baro River. The other tributaries contributing flow to the Baro River include the Akobo, the Alwero the Gilo the Jikau, the Birbir, the Geba and the Sore Rivers. Fig 1 shows the dominant soil group in the basin and the physical property of the soil in the basin is given in Table 7.



Source: Adeba et al., 2015

Figure 1: Soil Map of Baro Akobo Basin

Table 7: Physical Properties of Soil in Baro Akobo Basin

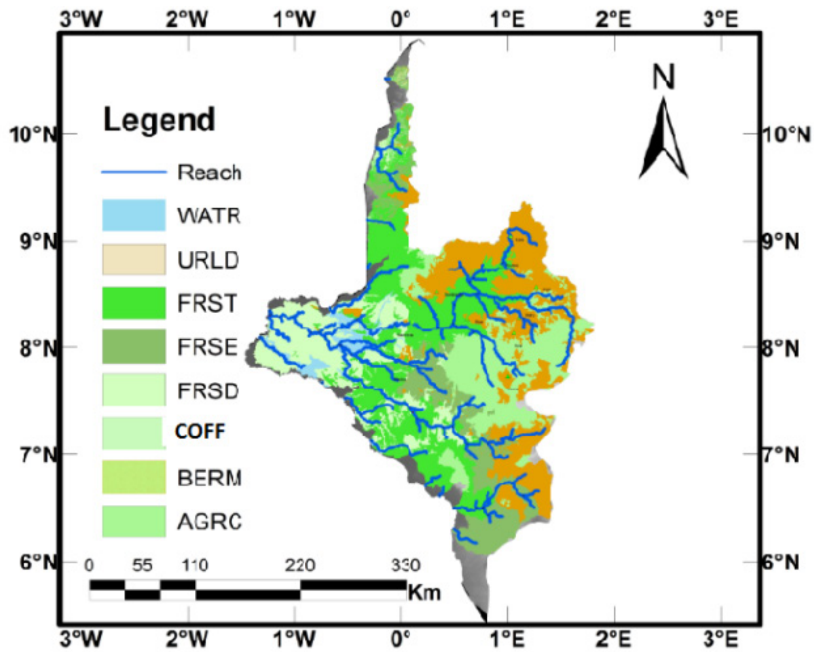
No	Soil Name	Max. Depth (mm)	Hydraulic Conductivity (mm/hr)	Textural Composition			Soil BD (g/cc)	Soil AWC (cm/cm)	Area (Km2)	Watershed Area (%)
				Clay	silt	sand				
1	Chromic L.	1830	1.7	38	6	56	1.5	0.11	3531	5
2	Dystric C.	700	14.88	21	35	44	1.44	0.13	8164	11
3	Dystric F.	1400	15.49	20	40	40	1.43	0.14	10086	13
4	Eutric P.	2000	29	17	70	70	1.5	0.08	2237	3
5	Eutric G.	600	2.16	40	37	37	1.41	0.13	6857	9
6	Haplic L.	1829	15	9	21	21	1.39	0.2	7141	9
7	Eutric V.	1400	0.45	61	25	25	1.31	0.11	2195	3
8	Haplic N.	8000	6.9	29	58	58	1.5	0.1	10710	14
9	Chromic C.	1320	1.56	38	40	40	1.52	0.1	8455	11
10	Planosols	1800	15.76	17	61	61	1.49	0.1	2045	3
11	Rhodic N.	2460	72	8	78	78	1.45	0.07	6083	8
12	Eutric L.	2500	0.01	50	40	40	1.34	0.12	6935	9

The average annual weather data of Gambela station of Baro Akobo basin is given in Table 8.

Table 8: Average annual weather data of Gambela station

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)	6	10	35	72	159	173	225	251	183	105	49	12	1280
RH (%)	47.6	43.3	46.6	51.3	69.8	74.3	77.3	78.7	75.7	71.6	67.8	53.1	63
Water surface evaporation (mm)	181	186	212	189	121	97	80	84	93	102	117	150	1612
Air temp. (°C)	28.2	29.6	30.7	30.2	28.3	26.9	26.1	26.1	26.7	27.1	27.2	27.6	27.9
Wind speed (m/s)	0.7	0.9	1	0.9	0.8	0.6	0.5	0.4	0.5	0.5	0.5	0.6	0.7
Solar radiation in units equivalent to evaporation (mm/day)	7.5	8	8.4	7.8	6.9	6.8	6.8	6.2	6.9	6.7	7	7.3	7.2
Source: Baro Akobo basin master plan study, 1997													

The basin is characterized by 17.81% agricultural land 56.78% forest cover of different type (deciduous mixed and evergreen), 22.20% grassland 3.06% water body and 0.02% low density urban setting. The land use map of the basin is given in Fig.2 and Table 9. Slope classes and the respective watershed areas in the slope range are shown in Table 10.



Source: Adeba et al., 2015

Figure 2: Land use Map of Baro Akobo Basin

Table 9: Land use Category of the Baro Akobo Basin

No	Land use category	Class	Watershed area (Km²)	Watershed area (%)
1	Agricultural land close grown	AGRC	13,357.05	17.64
2	Brome grass	BERM	16,949.81	22.43
3	Forest Deciduous	FRSD	11,841.34	15.58
4	Forest mixed	FRST	21,230.91	27.97
5	Forest evergreen	FRSE	10,027.18	13.19
6	Water body	WATR	2,322.72	3.16
7	Residential low density	URLD	176.99	0.03
	Total		**75906**	**100**

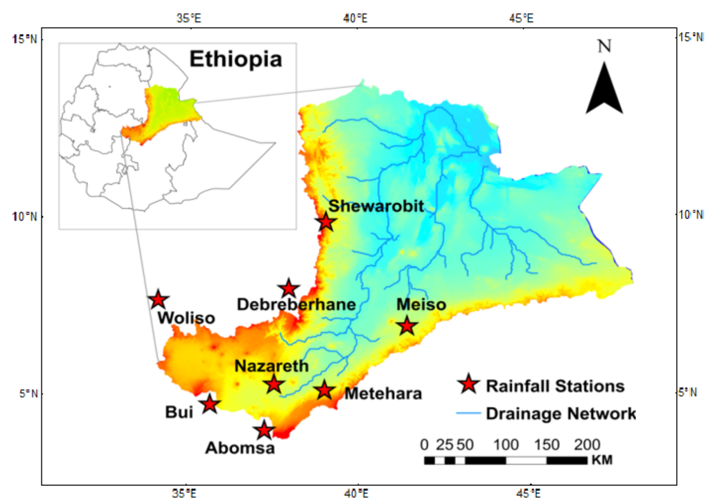
Table 10: Slope Classes of the Basin

No	Slope classes	Watershed area(Km^2)	Watershed area (%)
1	0-15	59,464.76	78.34
2	15-35	13,913.57	18.33
3	>35	2,527.67	3.33
Total		75906	100

The general flow direction of Baro Akobo River is from eastern highlands of about 2000m-3500m above msl characterised with high rainfall to the western lowland plains of elevation less than 500m above msl characterized with relatively low rainfall and low river gradient. Attempts have been made to make quantitative description of the hydrology of the Baro Akobo River considering the spatial and temporal heterogeneity of the basin. The mean annual flow of the basin is estimated at 23.24 BCM. The present and projected per capita water availability of the basin is estimated at 3432m3 and 1862m3 respectively.

Awash basin of Ethiopia is a water scarce basins where the physical water availability is limited and the demand for water cannot be met. The per capita water availability of the basin is estimated at about 325 m3/year Adeba et al., (2015)[18]. Issues involving inadequate supplies to meet demands can result from growing urbanization, need to meet instream flow requirements, and conflicts over private property and public rights regarding water allocations. Physical water resources, which contribute to food security in an economy, can be either rainfall, which is directly used by crops for growth, or water available as runoff in rivers, lakes, and aquifers, Earle (2005)[19]. Use of the former is free, while the latter requires storage and incurs transfer costs. Together, these two types of water, sometimes, referred to as “green” and “blue” respectively form the basis of natural water resource endowment of a country. As the physical water availability is short of demand in Awash basin, so it is desired to transfer a given volume of water from Baro Akobo basin to Awash basin in order to address its water shortage. The concept of transferring water from one basin to another has evolved over centuries as a useful means of meeting water demand Hollers (2010)[20]. Water transfer from a surplus basin to deficit basin is often relied upon when population centers or potential irrigable land or industry are not located near adequate water supplies Kansal et al., (2014)[21].

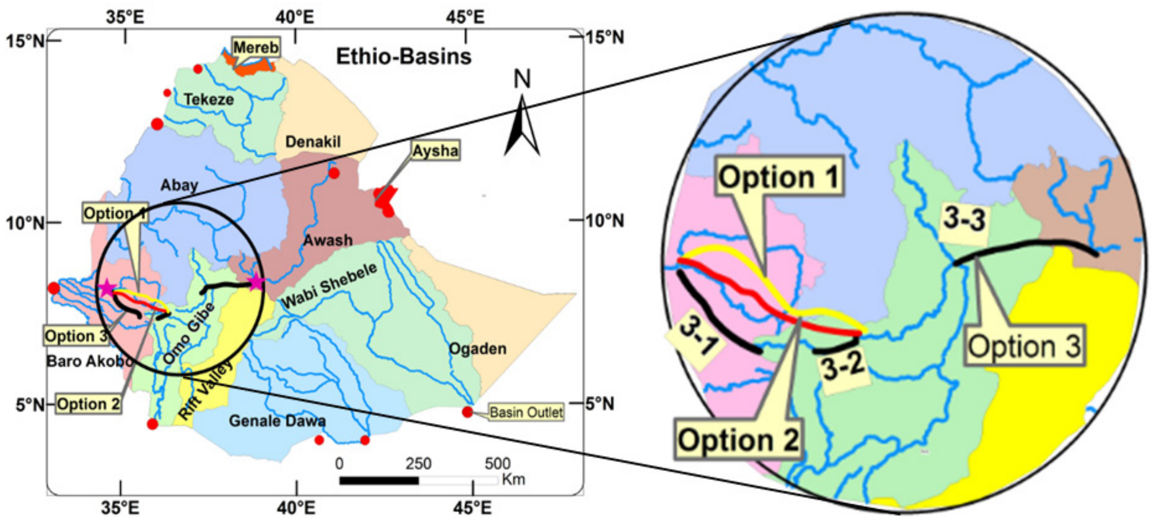
At present, the water scarcity level in the basin is estimated to be about 30 MCM/year which is projected to increase to about 116 MCM/year in the future Adeba et al., (2015)[18]. Adequate supply is not the only water problem being faced by the Awash River basin. Water quality is also a cause of considerable concern in the basin. In order not to affect the future development of the donor basin and the environmental flow requirement of the basin, the volume of water proposed to be transferred to the deficit basin is only about 0.5% of the mean annual flow of the Baro Akobo basin. So the ultimate goal of water transfer from Baro Akobo to Awash basin is to address the spatial inequality in the availability of water in different river basins. The location map of Awash basin is given in Fig.3. The proposed transfer route of water from Baro Akobo to Awash basin and its profile is given in Fig.4 and 5 respectively.



Source: Adeba et al., 201

Figure 3: Location Map of Awash Basin

The diversion and receiving point coordinates and elevations of water transfer proposals from the Baro Akobo to Awash basin for the most feasible option Adeba et al., (2016) [22] is given in table 11.



Source: Adeba et al., 2015

Figure 4: Water transfer from Baro Akobo to Awash basin

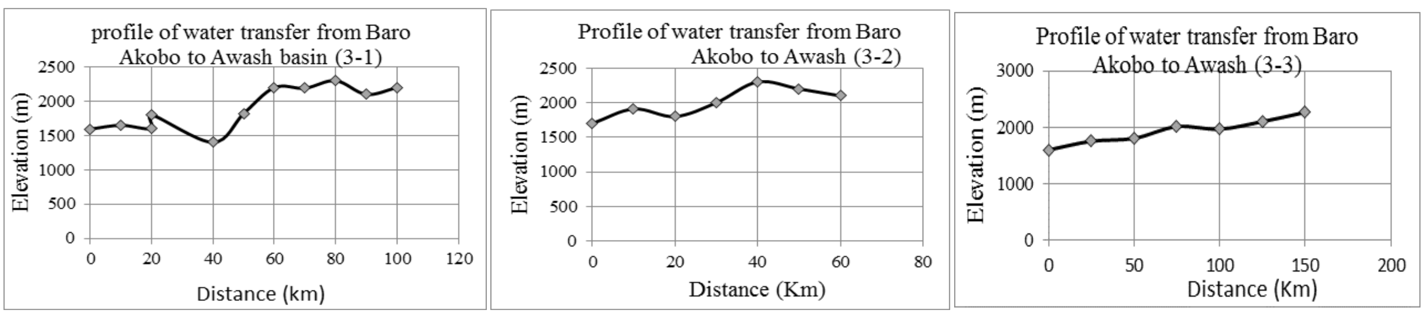
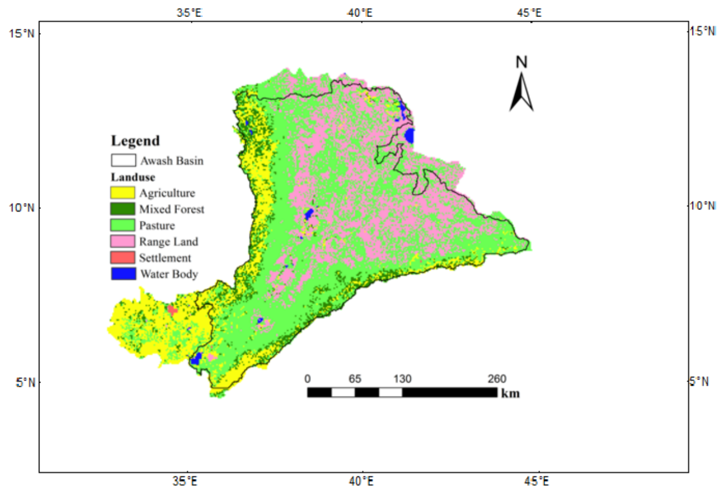


Figure 5: Profile of the Transfer Routes for water transfer from Baro Akobo to Awash basin

Table 11: Diversion and Receiving Point Coordinates and Elevations in the three water transfer proposals

Segment	IBWT Link	Diversion point elevation (m)	Coordinate (UTM)		Delivery point elevation (m)	Coordinate (UTM)		Distance (Km)
			Northing	Easting		Northing	Easting	
3-1	Baro Akobo to Awash	1565	54473	916909	1965	136493	840180	111
	Flow in natural waterway	1965	136493	840180	1900	181472	842825	45
3-2	Baro Akobo to Awash	1900	181472	842825	2074	234918	843354	50
	Flow in natural waterway	2074	234918	843354	2000	332285	919554	153
3.3	Baro Akobo to Awash	2000	332285	919554	2264	480452	934371	160

Figure 6 and 7 show the land use land cover and the soil map of Awash basin respectively while Tables 12 and 13 show land use category and slope classes of the basin and soil physical property of the basin respectively.

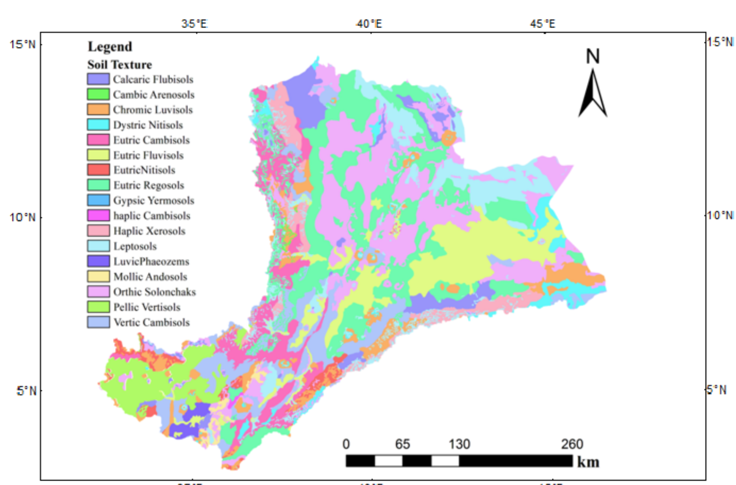


Source: Adeba et al., 2015

Figure 6: Land use Map of Awash Basin

Table 12: Land use Category and Slope Classes of the Basin

Land use				
No	**land use category**	**land use Class**	**Area (km²)**	**Watershed area in (%)**
1	Agricultural land close grown	AGRC	33058.92	51.65
2	Meadow Brome grass	BROM	19087.44	29.82
3	Range brush	RNG B	5190.09	8.11
4	Forest mixed	FRST	4884.35	7.67
5	Water body	WATR	499.2	0.75
6	Residential	URBN	1280	2
Slope classes				
1		0-25	58736.64	91.78
2		25-45	2253.99	3.52
3		≥45	3009.37	4.7



Source: Adeba et al., 2015

Figure 7: Soil Map of Awash Basin

Table 13: Physical Properties of Soil in the Basin

No	Soil Name	Hydraulic conductivity (mm/hr)	Textural composition (%)			Soil BD g/cc	Soil AWC (cm/cm)	Area (km^2)	Water-shed area (%)
			sand	silt	clay				
1	Eutric C.	18	22	44	34	0.18	1.44	2792.9	4.41
2	Leptosols	0	40	10	50	0.12	1.34	304	0.12
3	Orthic S	38	30	45	25	0.11	1.45	3802.9	6
4	Haplic X.	20	44	41	15	0.15	1.43	1184.4	1.87
5	Calcaric F.	15	40	40	20	0.15	1.43	5480.7	8.65
6	Dystric N.	2	38	32	30	0.21	1.39	8280.4	13
7	Eutric R.	110	47	45	8	0.1	1.51	526.6	0.83
8	Vertic C.	6	55	30	15	0.11	1.47	14705	23.2
9	Chromic L	2	32	24	44	0.11	1.5	4.9	0.01
10	Eutric F.	29	70	13	17	0.08	1.5	65.3	0.1
11	Cambic A.	117	78	7	15	0.04	1.42	2660.5	4.2
12	Pellic V.	1	62	12	24	0.24	1.39	4878.6	7.7
13	Gypsic Y.	750	12	16	64	0.07	1.41	45.6	0.07
14	Eutric N.	72	22	14	64	0.08	1.45	381.6	0.6
15	Mollic A.	91	65	26	9	0.15	1.43	13335	20.36
16	Luvic P.	307	34	55	11	0.15	1.31	231.5	0.37
17	Haplic C.	15	34	57	9	0.2	1.39	5320.3	8.39

Often large water development projects bring about access to new infrastructure like roads, markets and clean water supply all of which are important to raise the standard of living of the communities in the basin. Improving rural livelihoods in the deficit basins can be advanced as a result of inter-basin water transfer. Inter-basin water transfer from Baro Akobo to the Awash River basin can also help alleviate poverty in the basin by addressing the recurrent droughts.

Transfer of Water from Abbay to Rift Valley lake Basin

Owing to unequal endowment and the relative locations of water resources in Ethiopian river basins, inter-basin water transfer is required to redistribute available water for balanced economic growth of different regions. The Abbay basin drains much of Amhara National Regional State, portions of Tigray and Oromia, and much of Benshangul-Gumuz regional states. The Abbay river, from which water is proposed to be transferred to the other basin, travels through different physiographic units in Ethiopia and Sudan with geographically distinct catchment zones and complex drainage networks. The topography of the basin is generally rugged and mountainous. Its elevation ranges from about 490m at Ethio-Sudanese border to 4260m above msl on the north-eastern highland part of the basin. The source of the river is the Little Abbay River in the Ethiopian Highlands. The Little Abbay flows into Lake Tana, which discharges into the Blue Nile and runs 900 km down through the highlands into Sudan. The Lake Tana is the largest freshwater lake in Ethiopia having a catchment area of about 3100 km2 and estimated storage volume of 32km3. The outflow from the lake is about 8% of the Abbay river flow. The northeastern and eastern highlands of the Abbay basin contain enormous water and other resources that provide the basis for potential development. The volume of water available for transfer from the basin of its origin to the receiving basin is probably the most important factor determining the feasibility of a diversion Yevjevich (2001)[23]. The major land use/land cover of the basin is given in Fig. 8 and table 14.

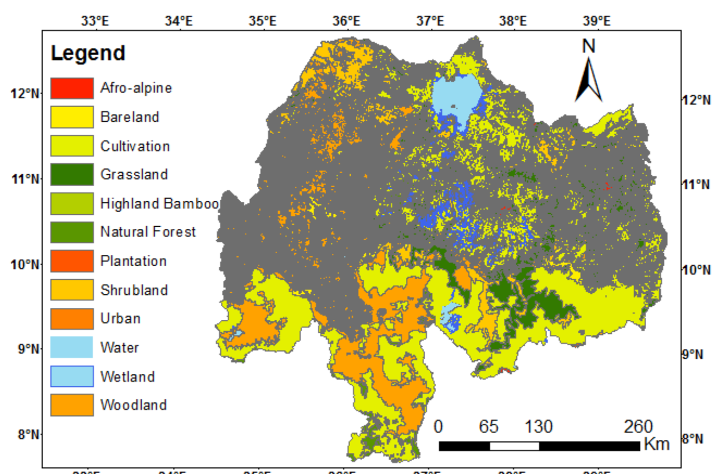


Figure 8: land use land cover of Blue Nile basin

Table 14: Major land use land cover of Blue Nile basin

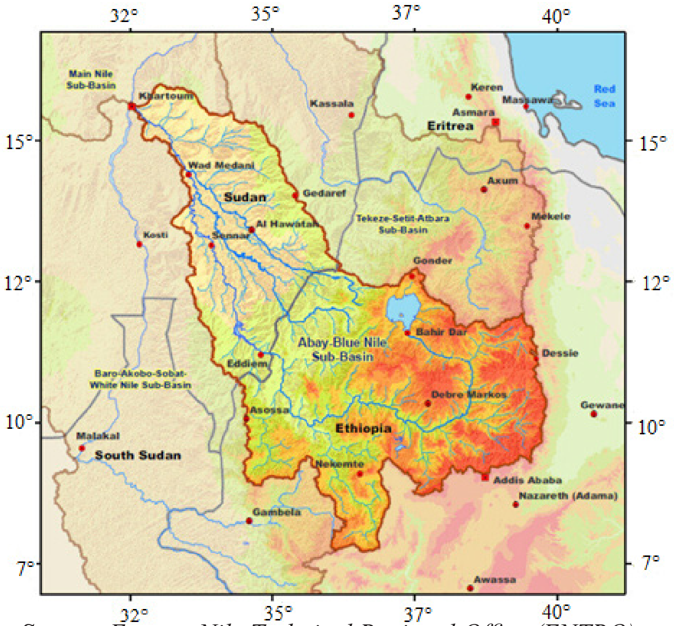
Land cover	Total area km^2	Total (%)
Cultivated	68150	34.1
Tree crops	260	0.1
Plantation	537	0.3
Afro-alpine	1103	0.6
Disturbed forest	2276	1.1
Bamboo	7326	3.7
Woodland, Bush land, Shrub land	60438	30.2
Grassland	46143	23.1
Wetland	2384	1.2
Water body	3415	1.6
Rock	7932	4
Urban areas	108	0.05
Total	199812	100

The course of the Blue Nile (Abbay) flows from highland regions with abundant moisture to lowland plains with semi-arid to arid conditions. There are different soil groups in the basin as shown in Table 15. Nitosols are the dominant soil groups in the basin followed by Vertisols and Lithosols.

Table 15: Major Soil groups of Blue Nile basin

Major Soil Groupings	Area(km^2)	% of Basin Area
Fluvisols	799	0.4
Regosols	799	0.4
Vertisols	28,173	14.1
Arenosols	4,596	2.3
Cambisols	17,783	8.9
Phaeozems	1,399	0.7
Luvisols	24,177	12.1
Acrisols	12,988	6.5
Nitosols	71,333	35.7
Lithosols	26,775	13.4
Rendzinas	9,791	4.9
Marshes	1,199	0.6
Total	199,812	100
Source: Eastern Nile Technical Regional Office (ENTRO)		

At the border between Sudan and Ethiopia the mean annual flow of the basin is estimated at about 54.4BCM while it is about 84BCM at Aswan high dam. As it is discussed earlier Egypt and Sudan shared the total mean annual flow of Nile ignoring all the other riparian countries. The management option of water in this basin led to water dispute among the countries sharing the basin because of this unfair allocation of the resources between Egypt and Sudan. Yet common sense dictates that a bilateral agreement on a sensitive and crucially important international river system is likely unacceptable to the other nine riparian states. Sharing, development and management of water resources of the Nile basin on an equitable basis as well as sharing and exchange of information and data through cooperation have been non-existent. Therefore, all things considered, Ethiopians have a legitimate basis to refuse to acknowledge the existing Nile water allocation system. The equitable allocation of fresh water to particular sectors (agriculture; industry; services) is an important element in the linkage between transboundary water resources and national/regional economies. In the light of the growing degradation of ecosystem services, and diminishing quantity and quality of water resources in the Nile basin, Egypt's insensitivity to the water needs of co-basin states could be a critical source of friction in the basin Yohannes (2008) [2]. The sub basin is given in Fig 9 and the mean monthly rainfall of the three sub basins of the Nile basin, the Blue Nile, Baro Akobo and Tekeze basins are given in Table 16.



Source: Eastern Nile Technical Regional Office (ENTRO)

Figure 9: Blue Nile sub basin of Nile basin

Table 16: Mean monthly Rainfall of the Blue Nile, Baro Akobo and Tekeze basin of the Nile basin

No	Month	Blue Nile	Baro	Tekeze
1	January	18	26	32
2	February	26	43	11
3	March	48	81	14
4	April	59	101	33
5	May	121	190	32
6	June	194	206	59
7	July	307	237	99
8	August	308	231	256
9	September	205	206	91
10	October	81	95	27
11	November	25	60	14
12	December	13	33	10
Source: Eastern Nile Technical Regional Office (ENTRO)				

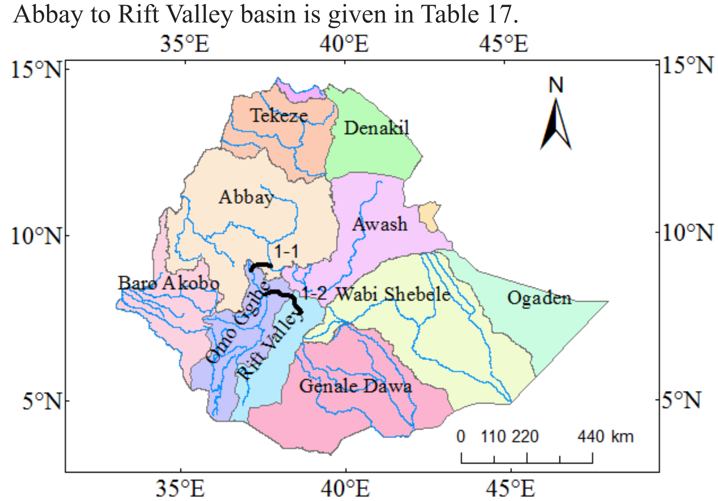
The average annual precipitation over the sub-basin is 1420 mm, making it the highest among all the sub-basins of the Nile. The lowest rainfall is recorded over the eastern part of the sub-basin where the average annual precipitation does not exceed 800 mm. The highest values are over the southern part of the catchment (Didesa tributary) with the values exceeding 1,900mm. The construction and the development of the Grand Ethiopian Renaissance Dam (GERD) on the Abbay river at about 40 km from the border of Ethiopia and Sudan is designed to store more than 74 BCM of water/year. This increases the flow of the Nile river at the border almost one and half times its mean annual flow. There are also additional suitable sites to construct more dams to store more volume of water as the physiographic and hydrological characteristics of Ethiopia make it suitable site for construction of dams without much impact to the environment.

The current and projected population of the Blue Nile basin is estimated at 22.32 and 41.57 million respectively. The present per capita water availability of Abbay basin, considering its mean annual flow of 54.4BCM, proposed volume of water stored behind the Grand Renaissance Dam of 74BCM and 2BCM of groundwater potential of the basin, is about 5930m3 and its projected water availability is estimated at about 3000m3/per year. It is proposed to transfer, about 5BCM of water/year to Rift Valley basin to improve per capita water availability of the basin. The amount of water transfer from Abbay to Rift Valley basin is limited to 5 BCM/year considering water demand by downstream countries of the basin.

The Rift Valley basin is located at the central part of Ethiopia, and the basin is one of the physically water scarce basins. The mean annual flow of the Rift Valley basin is estimated at 5.4BCM. The area of Rift Valley basin is about 52739km2. It is a basin where economic activity and growth of the community living in the basin is heavily constrained by shortage of water. The water scarcity in the basin occurs when water supply and demand are out of balance i.e., when demand outstrips supply due to different economic activities that make use of water. A supply of water is limited due to hydrologic variability in the basin and lack of integrated water management system to buffer seasonal or inters annual variability. Evapotranspiration of the area is about 1600mm. The maximum precipitation is about 1800 mm while the yearly average precipitation is about 600mm. The current and projected population of the basin is 10.08million and 18.85million and its present and projected per capita water availability is estimated at 555 m3/year and 300 m3/year respectively. It is likely that the demand for water in rural areas will continue to grow due to expanding economic activities indicating further decrease in water availability in the basin and necessitating inter-basin water transfer. The water that is to be transferred from Abbay to Rift valley basin can improve the per capita water availability of Rift valley basin from the current 555m3/ per year to about 1000m3/ per year.

The growing demands for water, changing land use/land cover and variability in water resources availability as well as deteriorating water quality in the rift valley basin are becoming major challenges for sustainable water resources management. An interbasin transfer will provide the Rift Valley lake basin with an additional source of water to continue to support its economic growth and an expanding population. So the drought proneness of the Rift Valley basin can be addressed by availing water from the Abbay basin which is a water surplus basin.

The proposed water transfer route and the profile of the route of transfer are shown in Fig 10. The diversion and receiving point coordinates and elevations in the water transfer proposals from Abbay to Rift Valley basin is given in Table 17.



From Abbay basin to Omo Gibe basin
Form Omo Gibe to Rift Valley basin

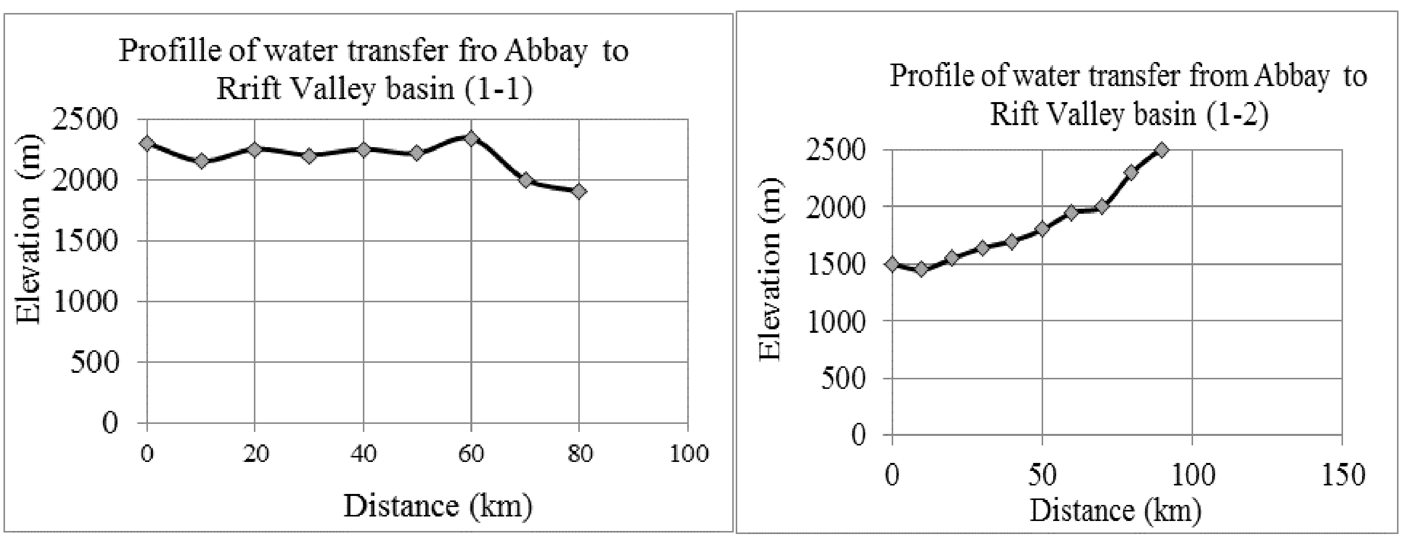


Figure 10: Water transfer route from Abbay to Rift Valley Lake basin and profile of the transfer routes

Table 17: Diversion and Receiving Point Coordinates and Elevations in the water transfer proposals from Abbay to Rift Valley basin

Segment	IBWT Link	Diversion point elevation (m)	Coordinate (UTM)		Delivery point elevation (m)	Coordinate (UTM)		Distance (Km)
			Northing	Easting		Northing	Easting	
1-1	Abbay to Rift Valley lake	3100	332285	919554	2899	382747	928367	53
	Flow in natural waterway	2899	283859	1033539	2000	332285	919554	159
2-2	Abbay to Rift Valley lake	2000	382747	928367	2700	451539	875450	112
2-3	Abbay to Rift Valley lake	2700	327807	919341	2500	481475	930317	150

The Rift Valley basin exhibits different land use land cover as shown in Fig.11 and Table 18.

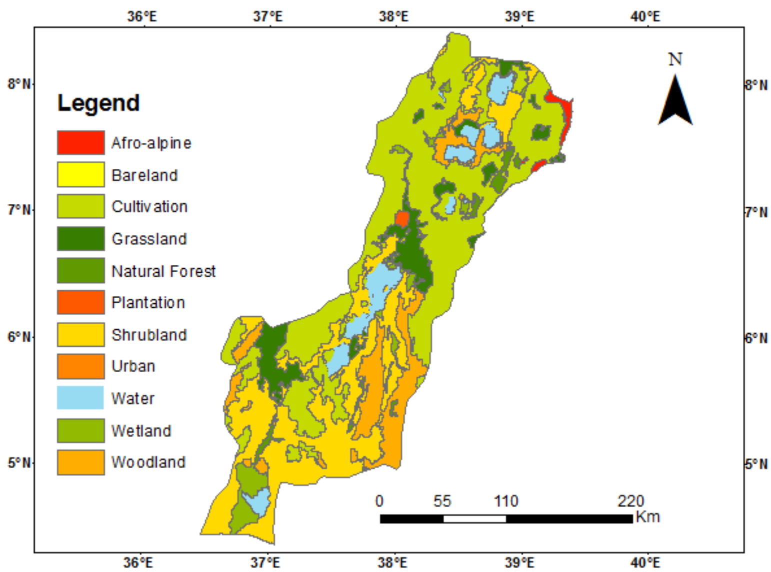


Figure 11: Land use land cover of Rift Valley basin

Table 18: land use land cover of Rift Valley basin

S. No	Land use name	Area (ha)	Area (km^2)	Area cover %
1	Afro-alpine	40534.49	405.34	0.77
2	Bare land	872.00	8.72	0.02
3	Cultivation	2255893.95	22558.94	42.60
4	Grassland	424168.36	4241.68	8.01
5	Natural Forest	85216.00	852.16	1.61
6	Plantation	15248.00	152.48	0.29
7	Shrub land	1413612.50	14136.13	26.70
8	Urban	144.00	1.44	0.003
9	Water	302264.00	3022.64	5.71
10	Wetland	180772.00	1807.72	3.41
11	Woodland	576582.48	5765.82	10.89
	Total area	5295307.78	52953.07	100.00

The water transfer route as can be seen from Fig. 10 is planned in such a way that the water from its basin is first diverted to the Gibe river course. Then from the Gibe river course, the water is carried to the Rift valley basin either by a canal or a tunnel, depending on the suitability of the topography of the route. This type of water transfer is categorized as long distance water transfer, because it takes water across two to three basins. According to (Noone 2006) [24], this type of transfer is a first order division in which water is transported from one basin to another across what is commonly referred to as a continental divide, where neither of the two basins ends into the same ocean.

To upgrade the availability of water to a minimum threshold of 1000m3/person/year it is intended to transfer 5BCM /year of water from the Abbay basin. The donor river basin is characterized by relatively high maximum precipitation and less evapotranspiration relative to the Rift Valley Lake basin.

Water Transfer from Tekeze Basin to Denakil Basin

A better physical understanding of resource dynamics through time and space and monitoring of hydrologic balances are essential to the proper management of water as a scarce resources. Water resources planning and management activities are usually motivated by the realization that there are problems to address and opportunities to attain increased benefits from the use of water and related land resources. Large river management projects that divert water to the dry areas have promoted intensive year-round farming and urban development in the receiving basin. The Tekeze basin drains a large portion of Tigray national regional state. The basin also drains the northern and north-west part of the country. The mean annual precipitation over the basin area is 800mm, the lowest among the Nile sub-basins. The basin receives relatively high value of more than 1,300mm of annual rainfall over the Ethiopian Highlands which decreases to less than 90mm downstream at the junction of the Atbara River with the Main Nile. The Tekeze River rises in the north-western highlands of the country and contributes 13BCM of water to the Nile river system. The river is extremely torrential. Flowing directly northward, this river forms a boundary between Ethiopia and Eritrea before entering the Sudan, where it is known as the Atbara. In fact, the Atbara is the last and the most northern tributary to join the main Nile River before heading north to Egypt. The bulk volume of the river discharge is derived upstream of the Khashm El Girba reservoir in Sudan. Downstream to the reservoir, the conditions of the water course change to semi-arid and then arid.

The location and land use land cover of Tekeze-Setit-Atbara basin is given in Fig. 12 and 13 respectively and the percentage proportion of the different land use land cover is given in Table 19.

Source: Eastern Nile Technical Regional Office (ENTRO)

Figure 12: Location of Tekeze-Setit-Atbara sub basin of Nile basin

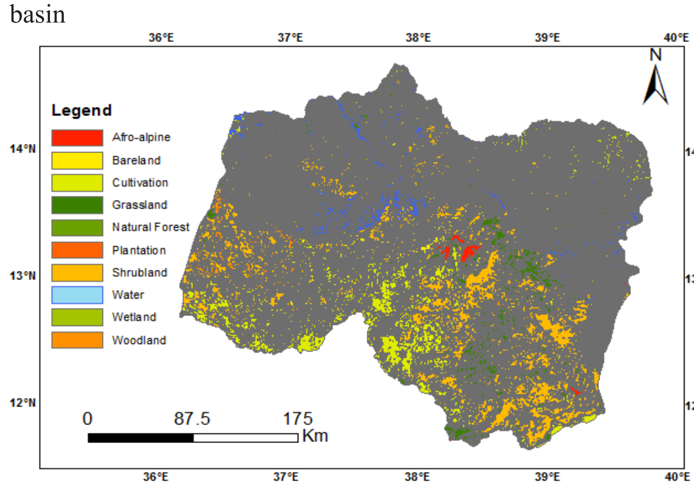
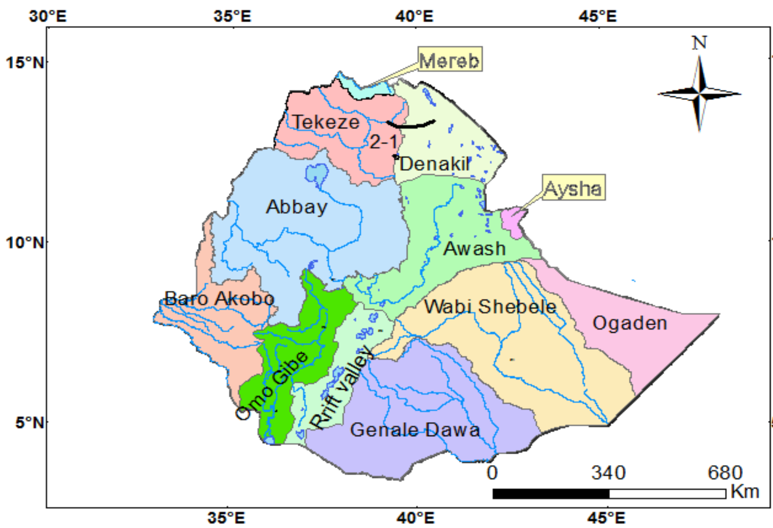


Figure 9: Blue Nile sub basin of Nile basin

Table 19: percentage area coverage of each land use in Tekeze Basin

S. No	Land use name	Area (ha)	Area (km²)	Area cover %
1	Afro-alpine	39419.71	394.20	0.47
2	Bare land	399451.93	3994.52	4.78
3	Cultivation	2247925.50	22479.25	26.88
4	Grassland	1759754.23	17597.54	21.04
5	Natural Forest	10549.22	105.49	0.13
6	Plantation	9460.59	94.61	0.11
7	Shrub land	3394915.60	33949.16	40.59
8	Water	9024.43	90.24	0.11
9	Wetland	28.00	0.28	0.0003
10	Woodland	493843.40	4938.43	5.90
	Total area	**8364372.61**	**83643.72**	**100.00**

The north-west to north-east transfer can carry surplus water from the Tekeze basin to the Denakil from where water can be used for a municipal water supply or irrigation. The proposed transfer route and the profile of the transfer route is shown in Fig. 14. The diversion and Receiving Point Coordinates and Elevations in the water transfer proposals from Tekeze basin to Denakil basin is given in Table 20.



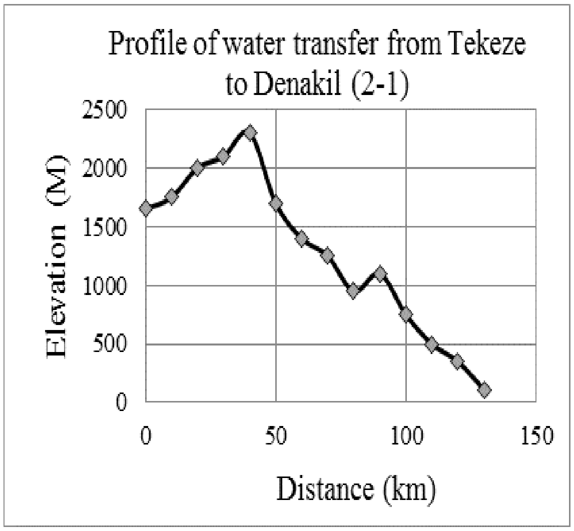


Figure 14: Proposed transfer of water from Tekeze basin to Denakil basin and Profile of the Transfer Routes

Table 20: Diversion and Receiving Point Coordinates and Elevations in the water transfer proposal from Tekeze basin to Denakil basin

Segment	IBWT Link	Diversion point elevation (m)	Coordinate (UTM)		Delivery point elevation (m)	Coordinate (UTM)		Distance (Km)
			Northing	Easting		Northing	Easting	
2-1	Tekeze to Denakil	1500	514404	1495596	400	665328	1498348	130

The mean annual flow of Tekeze river is about 8.2BCM. About 9.3BCM of extra water is stored behind the dam constructed and commissioned in 2009 for hydroelectric power generation. There are a number of suitable sites to construct more dams to create additional volume of water. As it is mentioned earlier the country's topography is suitable for the construction of high dams with insignificant environmental impacts. High dams can be built to store floods, and the elevation difference within short horizontal distances can be used for hydropower generation. The extractable groundwater availability of the basin is estimated to be about 7.2BCM in Raya plain of the basin. This makes total water availability of the basin about 24.7BCM. The current and projected population of the basin is estimated at 8.73 million and 13.08 million respectively. The present and projected per capita water availability of the basin is about 2830 m3/year and 1888 m3/year respectively.

Taping the flow of the Tekeze River and harvesting the flood during wet season in the basin that otherwise is lost as a runoff can boost the water resources of the basin. The increased storage dams in the basin can appreciably increase the dry season flow of the river which can augment the dry season flow at the downstream countries in addition to the benefits of surplus water transfer. Watershed level resource management is required for sustainability of water resources management in Tekeze basin. Management of wetlands in the basin are also important for water purification and, flood and erosion control. In addition, they can also provide a variety of ecosystem services Meter and Basu (2015)[7]. Then the increased availability of water by different management techniques can be stored and transferred to the Denakil basin to meet different water demands in the basin. The transfer of water from one basin to another and within and between different competing sectors helps improve the efficiency of water utilization. The country has high hydropower potential sites in excess of its domestic requirement, indicating that it has huge potential of earning revenue and boosting its economy by selling the power to downstream countries.

Denakil basin, located at the north-eastern part of the country is one of the water scarce basins of Ethiopia. The mean annual flow of the basin is estimated at 0.86BCM per year. The current and projected population of the basin is 2.85 million and 3.81 million respectively. The basin has a current and projected water availability of 422 m^3/year and 225 m^3/year. Surplus water from the Tekeze basin is proposed to be transferred to the Denakil where water can be used for different purposes. Assuming the transboundary nature of Tekeze basin and its future development potential, the volume of water proposed to be transferred to Denakil basin is limited to 2.1km^3/year. This volume of transfer to Denakil basin can improve the basin's per capita water availability from the current 422m^3/year to more than 1000m3/year. It has the potential to be a vital option for achieving more equitable distribution of water and optimal utilization. Further, it can play a major role in reducing the risk of flooding in the Tekeze basin while providing extra water to the Denakil area, where the surface and the groundwater is potentially limited. However, the use of water budgets to balance the available water resources with the actual or anticipated water use, require accurate and precise estimates of the basin withdrawals. In the basin withdrawal, an assessment of anticipated water transfer to the Denakil basin can also be considered and compared with potential yield of the Tekeze basin.

Reducing the frequency and/or severity of adverse consequences of droughts in the Denakil basin and floods in the Tekeze basin are the common goals of interbasin water transfer between the two basins. The transfer of water can also increase utilizable surface water resources and improve water accessibility to the deficit basin. Other goals may include improvements in recreation and / or inland navigation. Water transfer projects have other additional advantages. The skilled and unskilled labor during the implementation of a project and the training provided for regional or national workforce is a major advantage for future endeavors. A combination of interbasin water transfers, improved water use efficiency and an increased volume of water storages can help meet the growing demand for water. Hence, inter-basin water transfers not only enhance livelihood of rural community in command area if it is used for irrigation development, but also bring substantial multiplier effects to the region and in some cases at the national level too (WCD 2000)[25].

Conclusion

This paper has examined the importance of inter-basin water transfer from surplus basin to deficit basin in Ethiopia to address the recurrent drought and alleviate poverty in the country. Awash, Rift Valley, and Denakil basins are identified as the water scarce basins of Ethiopia to which water can be transferred from Baro Akobo, Abbay and Tekeze respectively. Irrespective of the water scarcity in these basins there is a high potential for agricultural development. The Rift valley and Awash basins are located in central part of the country while Denakil basin is located to the northeast part of Ethiopia. It is proposed to transfer about 5km^3 of water from Abbay basin to Rift valley, 2.1km^3/year of water from the Tekeze basin to the Denakil basin and 0.116km^3 from Baro Akobo basin to Awash basin in order to alleviate water scarcity of these three basins [26-36].

References

1. Adeba D (2016) Planning of inter-basin transfer for sustainable water management in Ethiopia. Dissrtation, Iindian Institute of Technology, Roorkee, Roorkee (India).
2. Okbazghi Yohannes (2008) Water Resources and Inter-Riparian Relations in the Nile Basin. *The Search for an Integrative Discourse* Published by State University of New York Press, Albany.
3. Webb P, von Braun J (1994) Famine and Food Security in Ethiopia: Lessons for Africa. NY: John Willey and Sons for IFPRI.
4. Dinar A, Wolf A (1994) International markets for water and

the potential for regional cooperation: economic and political perspectives in the western Middle East *Economic development and cultural chang*e, 43: 43-66.
5. Shiklomanov IA (1999) World water resources: Modern assessment and outlook for the 21st century. Federal Service of Russia for Hydrometeorology and Environment Monitoring: State Hydrological Institute.(Summary of the monograph World Water Resources at the Beginning of the 21st Century, prepared in the framework of IHP-UNESCO, 51.
6. Ghassemi F, White I (2007) Inter-basin water transfer: case studies from Australia, United States, Canada, China and India. Cambridge University Press.
7. Van Meter K, Basu N, McLaughlin D, Steiff M (2015) The socio-ecohydrology of rainwater harvesting in India: understanding water storage and release dynamics at tank and catchment scales. Hydrology and Eearth System Sciences, Aan interactive open-access Journal of the European Geoscience union.
8. Falkenmark M, Lundqvist J, Widstrand C (1989) Macro-scale water scarcity requires micro-scale approaches Proc., *Natural resources forum*, Blackwell Publishing Ltd, 258-267.
9. Kameri-Mbote P (2005) From conflict to cooperation in the management of transboundary waters: The Nile experience. Kameri-Mbote, P. (2005) Linking environment and security conflict prevention and peace-making in East and Horn of Africa. Washington DC: Heinrich Boell Foundation. Internet document http://www. ielrc. org/content/a0509. Pdf, 1-9.
10. Yoffe S, Wolf AT, Giordano M (2003) Conflict and cooperation over international freshwater resources: Indicators of basins at risr1. JAWRA Journal of the American Water Resources Association, 39: 1109-1126.
11. Uitto JI, Duda AM (2002) Management of transboundary water resources: lessons from international cooperation for conflict prevention. The Geographical Journal, 168: 365-378.
12. Ariel Dinar, Getachew Nigatu S (2013) Distributional considerations of international water resources under externality: The case of Ethiopia, Sudan and Egypt on the Blue Nile. Journal of Water Resources Economics 2: 1-16.
13. Kummu M, Ward PJ, de Moel H, Varis O (2010) Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. *Environmental Research Letters*, 5: 034006.
14. Raskin P, Gleick P, Kirshen P, Pontius G, Strzepek K (1997) Water futures: assessment of long-range patterns and problems. Comprehensive assessment of the freshwater resources of the world. SEI.
15. Meigh J, McKenzie A, Sene K (1999) A grid-based approach to water scarcity estimates for eastern and southern Africa. *Water Resources Management,* 13: 85-115.
16. Alcamo J, Döll P, Henrichs T, Kaspar F, Lehner B, et al. (2003) Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences Journal*, 48: 317-337.
17. Sullivan CA, Meigh JR, Giacomello AM (2003) The water poverty index: development and application at the community scale. Proc., *Natural Resources Forum*, Wiley Online Library, 189-199.
18. Adeba D, Kansal ML, Sumit Sen (2015) Assessment of Water Scarcity and its Impacts on Sustainable Development in Awash Basin, Ethiopia. Sustain. Water Resour. Manag., 1: 17-87.
19. Anthony Earle (2005) Hydropolitics in South Africa: What is the prognosis for peaceful development of shared water courses? African Water Issues Research Unit (AWIRU), CiPS, Unversity of Pretoria Pretoria, Soth Africa, FWU,Vol 3 Proceeding: “Topics of Integrated Watershed Management”.
20. Holler LL (2010) Inter-basin transfers:A promising,but currently flawad, solution to the world’s increasing water scarcity.
21. Kansal ML, Dereje A, Aditya T (2014) Challenges of sustainable development and management resources in Ethiopia World Environmental and Water Resources Congress 2014: 966-984.
22. Adeba D, Kansal ML, Sumit Sen (2016) Economic evaluation of the proposed alternatives of inter-basin water transfer from the Baro Akobo to Awash bain in Ethiopia. Sustain. Water Resour. Manag., 2: 313-330.
23. Yevjevich V (2001) Water diversions and interbasin transfers. *Water International*, 26(3).
24. Micheal Stephen N (2006) Interbasin Water Transfer Projects In North America. The North Dakota State Water Commission
25. WCD (2000) Dams and Development: A new framwork for decision making. The report of the World Commision on Dams. Earthscan, London.
26. Abu-Zeid M (1983) The River Nile: Main water transfer projects in Egypt and impacts on Egyptian agriculture. Long-Distance Water Transfer: A Chinese Case Study and International Experiences, Tycooly International Publishing Ltd.: Dublin, Ireland 1983. 15-34.
27. Bandyopadhyay J, Perveen S (2008) The interlinking of Indian rivers: Questions on the scientific, economic and environmental dimensions of the proposal." *Interlinking of Rivers in India: Issues and Concerns*, 53.
28. Biswas AK (1978) North American water transfers: an overview. *Water Supply & Management*, 2(2).
29. Greer C (1983) The Texas Water System: Implications for Environmental Assessment in Planning for Interbasin Water Transfers. *Long-Distance Water Transfer: A Chinese Case Study and International Experiences.*427: 907-567-53-3
30. Jain SK, Singh VP (2003) Developments in water science, *Water resources systems planning and management.* Elsevier. ISBN:0-444-51429-5
31. Lohit J, Haldar R, Khosa R (2013) Hillslope Runoff Processes and Modeling. International Journal of Earth Sciences and Engineering, Conference paper
32. Masse WB (1981) Prehistoric irrigation systems in the Salt River valley, Arizona. Science, 214: 408-415.
33. Micklin PP (1977) NAWAPA and Two Siberian Water-Diver-

sion Proposals: A Geographical Comparison and Appraisal. *Soviet Geography*, 18: 81-99.
34. Okamoto M (1983) Japanese water transfer: a review. *Water Resources Series (UNU). Vol.3* Long Distance Water Transfer: A Chinese Case Study and International Experiences (UNU, 1983)
35. White G (1977) Comparative Analysis of Complex River Developments. in Gilbert F White (ed.) Environmental Effects of Complex River Develpment (Boulder:Westview Press) 262.
36. Yates DN, Strzepek KM (1998) An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Climatic Change*, 38: 261-287.