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An Overview of Eritrea's Water Resources

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Abstract: Water is central to national development that includes many challenges in the vital sectors such as food, energy, health and economic development. Cognizant of this fact, the government and people of Eritrea have been diligently working towards developing the water resources sector. Policies pertaining to water resources, food security, environment, and water and drought calamities mitigation were formulated and being put into effect. Remarkable achievements made on water conservation and safe and adequate water supply coverage by Eritrea can be considered as an important milestone. However, frequent assessment of water resources potentials at different levels of the country is an aspect that is fundamental to effective water resources development and management. Past literature on this subject showed that large scale studies have not been carried out and small scale studies were limited in scope towards the national perspective. Therefore, the above lacuna calls for investigating if the present water management practices are adequate to meet the challenges and the institutional framework is comprehensive to support the system.
This paper attempts to review the country's water resources status and education system. The review is primarily directed towards a feasibility study entitled "Establishment of National Water Technology Institute (NWTI)" conducted in 2013. The report included a summary of relevant documents from different sectors. Major contributions of this include reports of the Ministry of Land, Water and Environment (MoLWE), the Ministry of Agriculture (MoA), consultation of experts and visits to selected sites by the study team. Findings from this review emphasised on the need for some fundamental and pre-emptive changes to be introduced in the management of the national water systems as well as establishment of a well organized National Water Technology Institute to carry out training, research, outreach and consultancy works.

Keywords: water resources, water institute, climate change, hydrometeorology, water supply.

I. INTRODUCTION

Eritrea, being located in Sudano-Sahelian Africa which is characterised by arid and semi-arid climate, possesses limited water resources. Rainfall is torrential, unpredictable that occurs irregularly, and is of high intensity over a short duration. Apart from the mean annual rainfall being low quantitatively, its temporal and spatial distribution is highly variable. Mean annual rainfall varies significantly across the country ranging from less than 200 mm in the arid coastal plains to about 700 mm in the southern central highlands. The eastern escarpment receives mean annual rainfall up to 1,050 mm [1].

Currently, the country is focusing on strengthening its economy by way of harnessing its natural resources. Top priority given to the development of water resources is evidenced by the fact that most development projects are related to water; food security, economic development, drought and flood mitigation. Accordingly, policies pertaining to water resources, food security, environment, and water and drought calamities mitigation have been formulated and put into effect. It is also worth mentioning the remarkable achievements that have been made in terms of water conservation including construction of water storage and diversion structures and groundwater explorations for different uses. For instance, water harvesting structures such as dams, ponds, and wells constructed from 1992 – 2003 were 84, 314 and 228, respectively [15]. As per the inventory of dams carried out by the MoA in 1999, out of the 187 dams with a capacity of less than 50,000 m^3, 72 were constructed in post-independence for domestic and irrigation uses. The major soil and water conservation activities carried out from 1992 – 2004 are presented quantitatively in the situational analysis document; hill side terraces, check dam and macro basin construction and maintenance, pitting for seedlings and planting and replanting[15]. Even though there are no published reports about the water storage structures constructed in the last decade, it is crystal clear that the Government of the State of Eritrea has been putting a lot of effort in constructing big, medium and small water storage structures; Gherset, Ghergera, Fanco and Kerkebet are some among others. Moreover, water use per capita throughout the nation and the coverage of safe and adequate water supply (average ~ 71%) has shown a drastic improvement [16].

Despite the aforesaid efforts, various sectors are believed to be potentially affected by the impacts of climate change. Environmental degradation has been prevalent; water bodies have dried up, forests disappeared, fertile soils eroded and the expansion of desertification has been observed during the past several decades. Various literatures reveal that increased flood recurrences along the downstream river banks of the major

Eritrean rivers are causing a significant damage to the livelihood of the rural communities and the environment. Drought has been hitting the country every 5-7 years in the past [13]. Moreover, global projections of climate change indicate that the East African region is among the most vulnerable to the adverse effects of climate change, mainly because of its least adaptive capacities [3].

To maintain the economic pace and social prosperity, it is imperative that enough safe water is available to meet the requirements of agriculture, industries, and the domestic sector in the years to come. Inadequate water planning and management, lack of water use awareness, and lack of implementation of desired measures may create a difficult-to-manage situation. Scarcity of water is already evident, varying in scale and intensity at different times of the year as a result of natural factors and human actions. For instance, intense competition among water users is pushing the groundwater table down in various parts of the country [13].

The quality of water resources in Eritrea is deteriorating. Action Plan for Integrated Water Resources Management (AP-IWRM) indicated that the bacteriological contamination of surface waters, sea water intrusion, sewage and industrial waste water pollution, wastes from agriculture and excessive sedimentation in reservoirs [16]. Moreover, due to the booming of the mining industry, water quality is likely to be impacted further unless handled meticulously. As such, the freshwater requirement ought to take the centre-stage on the economic and political agenda.

Applied research in the water sector is essential in informing decision makers in providing policy direction. Research based knowledge is required on water availability, water quality, hydro-geology, hydro-informatics, water productivity and efficiency, water resources development and management and global and national concerns such as climate change and their impact on health and environment. In addition, sustainable water resources development and management is dependent on the institutional capacity to generate new knowledge and develop new applications through training, research, outreach and consultancy. National Agricultural Research Institute (NARI) is the only institute associated with research activities related to the catchment protection, soil and water conservation, and water use efficiency for irrigated agricultures. Fragmentary water resources related education is also given in various Institutions of Higher Education (IHE). But, these institutions are not producing a highly trained workforce that can use new technologies to generate and disseminate up to date knowledge and conduct applied research in water resources areas. Thus, availability of a water institute that can solely undertake aid, promote and coordinate systematic scientific work and provide quality education, consultancy and outreach in all aspects of hydrology and water resources is highly desirable.

In the context of the background information presented above, the subsequent sections of the paper attempts to present a brief review of the water resources status with emphasis on the existing water resources challenges and education in Eritrea.

Data Collection

A major part of the data required for this study was collected from the database available with the Water Resources Department (WRD) of the Ministry of Land, Water and Environment (MoLWE). The data base included water resources related documents, sector study reports, water policies and institutional frameworks. In addition, discussions with the staff of MoLWE were held to see their views on the establishment of the National Water Technology Institute (NWTI). The foci of the discussions were mainly on the possible location and co-ordination among the different departments and information on existing skilled human resources. Reviewing regional and international water related institutions' experiences were the major inputs that helped the authors to understand the short-term and long term plans of the proposed Water Institute.

II. REVIEW OF WATER RESOURCES SITUATION

Water Policies And Laws

National policies pertinent to water resources are reported in the AP-IWRM viz. draft on Eritrean Water Resources Policy, Interim Poverty Reduction Strategy (I-PRSP), Food Security Strategy (FSS), Agricultural Policy, National Environmental Management Plan (NEMP-E), National Action Program under United Nations Convention to Combat Desertification (NAP-UNCCD), National Environmental Impact Assessment Procedures and Guidelines (NEAPG), Coastal Policy and its Guidance Document, and National Adaptation Programme of Action (NAPA) [16]. It is also a member of the Global Water Partnership (GWP) programme that aims at contributing to sustainable development and poverty reduction through using an Integrated Water Resources Management (IWRM) approach. Pursuant to the GWP guidelines, the WRD prepared the AP-IWRM in 2009.

East African water resources are characterised by many complex and interconnected challenges [4]. To resolve these problems, countries in the region formed a Nile Basin Initiative in 1999. In view of the above fact, Eritrea is committed to share hands with the international community to tackle problems pertinent to water resources.

The action plans that can strengthen the active involvement of the country in trans-boundary water issues are outlined in the AP-IWRM [16]. These actions target to strengthen the regional networking, improve knowledge on international conventions, treaties and improving collaborative IWRM by incorporating interests of trans-national stakeholders. In respect of this, the WRD has committed itself to develop the human and institutional capacity particularly on the newly established Trans-boundary Water Unit. This unit is entrusted to conduct a comprehensive study on regional, bilateral and international agreements, treaties, conventions and negotiations on trans-boundary water issues.

A water resources law for the State of Eritrea was proclaimed in 2010 and is yet to be put in to effect. The objective of the Water Resources Proclamation is to conserve and develop the water resource base of Eritrea; to promote and integrate all efforts by various institutions, in light of acceptable international norms and practices so as to achieve a sustainable socio-economic development and ecosystem stability [11].

Water Resources

There is much more limiting than water in Eritrea. Rainfall is highly variable spatially (Fig. 1a) and temporally, erratic and torrential and quickly forms heavy floods with little chance of penetrating into the ground [13]. The potentials of underground and surface water resources are still not clearly studied and documented [15]. Moreover, meteorological and hydrological information, which is critical for any water resource development activity, is at its rudimentary stage of development. Therefore, the annual share of water resources per capita is unknown.

The root causes of water related problems in Eritrea include highly uneven distribution of water availability, extreme catchment degradation, low investments on water storage and infrastructure, increasing water demand, pollution of freshwater, improper procedures and regulatory instruments, absence of water costs, lack of monitoring, assessment and evaluation of water resources, absence of enacted water resources policy, insufficient legislative and legal framework, inefficient institutional framework, weak financing mechanisms and inadequate professional and technical capacity. In addition, inadequate water conservation practices, inefficiency in water use, water reuse, prevalent system of water rights which gives unlimited ownership of groundwater to the landowner despite the fact that groundwater is a shared resource from common pool aquifers and disassociation of communities in water resources management are also prevalent challenges [16]. In the ensuing discussions, the conventional and non-conventional water sources are presented briefly.

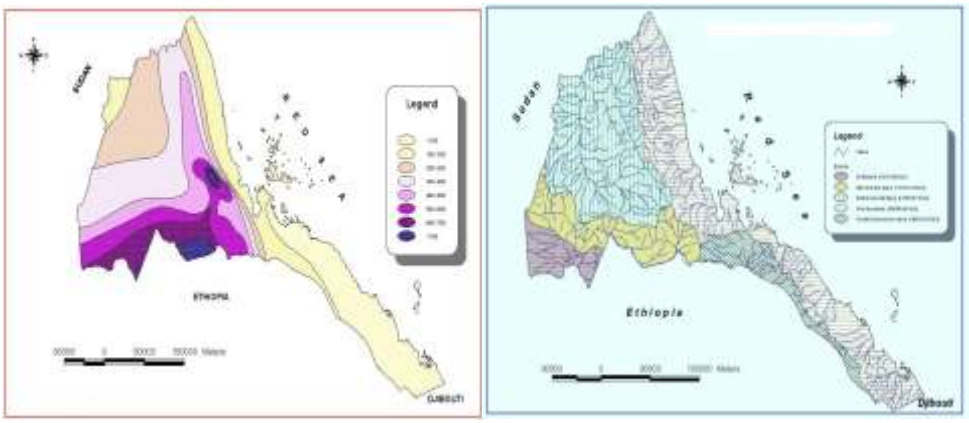
Conventional Water Sources

Eritrea has five main drainage basins; Mereb-Gash, Setit, Barka-Anseba, Red Sea and Danakil (Fig. 1b). Due to the geographic location of the country, thereupon its climate, the flows through these rivers are highly seasonal with the exception of Setit which is perennial. All the existing river basins support the agricultural sector. Their average annual yield is estimated to be 9.967×10^9 m^3 (Table 1). Four of the five major rivers flow into neighbouring countries namely Ethiopia and the Sudan. The Setit and Mereb-Gash basins are part of the Nile basin having a total area of 24,921 km^2 which is 20.4% of the total area of the country[7]. The Barka-Anseba and Danakil basins are riparian rivers which drain in to the Sudan and Ethiopia, respectively. Unfortunately, very little was done in the past to harness and utilize these rivers for developing irrigated agriculture and other infrastructure services. Nonetheless, there are concrete measures recently taken towards harnessing and utilizing these rivers; Fanco, Gerset and Ghergera are some among others (Fig. 2).

The Mereb-Gash is one of the country's major rivers. About 75% of the total catchment area lies in Eritrea. This river basin has the availability of limited discharge data and more importantly it probably has the highest potential for agricultural activities, both for rain-fed and irrigated agriculture, than the other river basins. Average annual discharge for the Mereb-Gash at Kassala and Setit over the years 1907-1929 were 430×10^6 m^3 and $8{,}000 \times 10^6$ m^3 respectively [17]. There exists an absolute mismatch of these estimates with the value given in Table 1.

Table 1: Major drainage basins and their estimated runoff yield [16]

Basin	Area (km2)		Average annual yield (109 m3)
	Eritrea	Total	
Mereb-Gash	17, 256	23, 176	1.423
Barka-Anseba	41, 920	41, 920	0.932
Red Sea	44, 376	44, 376	0.961
Danakil Basin	8, 905	10, 485	0.422
Setit	7, 292	68, 255	6.23
Total			9.967



a) b)

Fig. 1: a) River basins of Eritrea, and b) Mean annual rainfall distribution (*Source: WRD)*

Fig. 2: Recently constructed and on-going multi-purpose dams (*Photo: Anghesom A*)

To satisfy the demand on water, the natural supply of several rivers is regulated through storage reservoirs created by the dams built across the tributaries of these rivers. Accordingly, the government has been constructing big, medium and small storage infrastructure for different purposes [12]. There were about 187 dams (Table 2) with a capacity of over 50,000 m^3 each as has been mentioned in the introductory section. The total capacity of the dams reached 94 $\times 10^6$ m^3 in 1998. In the last decade or so, a number of medium and big

dams have been constructed and hence the total capacity and number of dams is obviously much larger than the above figures.

The complete absence of historical stream flow data and the limited number of hydro-meteorological records is the primary constraint in the planning and design of water resources development projects. In 1994, various institutions initiated a national meteorological and stream gauging network targeting areas with agricultural development potential [9]. The plan for the improvement of the network of hydro-meteorological stations are stipulated in the AP-IWRM [16].

Table 2: Dams in Eritrea and their water uses [12]

Type of water use	Number of dams	% of total dams
Domestic and Irrigation	79	42
Domestic	75	40
Irrigation	24	13
Unused	9	5
Total	187	100

Groundwater as a main source of water to meet the domestic, irrigation and industrial demands is extremely important in arid and semi-arid zones. It occurs in a wide range of rock types and usually requires little or no treatment; therefore, it is often the cheapest and simplest water supply option. In Eritrea too, groundwater is the main water source with the exception of few places such as Asmara and Adi-quala. However, the ground water potential, occurrence, distribution and quality in the country are unknown, apart from the limited information available from studies conducted in few localized sites. Groundwater withdrawals for different purposes are presented in Table 3.

Despite the above stated fact, FAO has estimated the annual groundwater potential of Eritrea [8] to be 500×10^6 m^3 vis-ä-vis 1.664×10^9 m^3 by WRD [15]. Neither of these estimates can be considered certain and hence this is a clear manifestation of the need for further detailed groundwater investigation. Geophysical profiling across several of the structures in both lowland and highland terrains reveals that conductive features are believed to relate to saturated zones in these fractures [5]. WRD analyses show that best yields are expected from alluvial and basaltic rocks; also marble may offer good permeability whereas Literites and Precambrian rocks showed poorer results.

Table 3 Groundwater withdrawals for different purposes in 2004 [8]

Type of water use	Total water withdrawal ($\times 10^6$ m^3/year)	Total water withdrawal (%)
Agriculture	550	94.5
Domestic	31	5.3
Industry	1	0.2
Total	582	100

The current water management practices are considered inadequate with the existing water supply shortage of the country [13]. Water tariff is only practiced in major cities, and there is no progressive water tariff charge in use. Moreover, there is no policy to levy tariff on irrigation water. The absence of such policy measures allows investors to exploit and lavishly consume too much water. Such uncontrolled exploitation of scarce water resources not only depletes the same, but also leads to salinity hazards. Uncontrolled exploitation of underground water resources, for example, exists in the Gash-Barka region and there are clear indications that underground water resources is getting saline and hence becoming unsuitable for irrigation purposes [13].

The groundwater in the Eritrean plateau and western lowlands has the best water quality with the exception of Asmara and its environs which are polluted by nitrates (50-150 mg/l of NO_4) whereas the central and north-western lowlands, the quality of water is fairly good. In the latter and in entire Red Sea catchment, fluoride concentrations of 7-17 mg/l is common causing some dental fluorosis [17]. Moreover, salt water intrusion and its impact on the natural environment created by high evapo-transpiration and irrigation practices becomes more pronounced in the Red Sea catchments [13,16]. In this region, soil fertility has been greatly affected and the development of groundwater has been constrained. Both these and the factors affecting water resources quality in general require careful investigation and conservation measures [17].

Non-conventional Water Sources

Eritrea is characterised by a high rate of population growth (~ 3%) which seems to exceed by far the rate of development and conservation of natural water resources. As a result of the booming mining industry, the forthcoming decades may witness a dramatic increase in the number of skilled and non-skilled labourers coming

from outside for work. Tourism industry is also expected to boom greatly in the future. The immediate consequence to the coupling between these factors is the steady decline in the share of water per capita. Additionally, the expected development in all sectors will undoubtedly be responsible for the increasing need of more water per capita compared to the situation at present. Another important factor is that a better conservation and management of the already existing water resources seem to be lagging far behind the search for new sources of water. As such, the country's quest for non-conventional water sources may be considered as an alternative.

Non-conventional sources are reuse of wastewater, desalination of saline water, non-rejuvenated groundwater, transport of water, rain harvesting and cloud seeding and virtual water. With the majority of non-conventional waters, there is no concrete evidence that indicates the historical background as well as the present status in Eritrea. Against the concept of the virtual water, sugar cane plantation project that requires a large amount of water appears to be implemented in the western lowland plains. The use of untreated waste water from Asmara sewerage for irrigation purposes does not justify as a reuse of waste water; the fact that there is no waste water treatment carried out in the outfall of the sewage. Moreover, the current economic situation does not allow the use of desalination water from sea though it was tried by the Russians before independence in Tio. Traditional rain water harvesting practices such as cisterns, wadis and low earth ridges for rain water harvesting agricultural lands were some of the widely practiced techniques. However, the government attempts to promote public awareness towards rain water harvesting through different approaches.

Hydrometeorology

Meteorological data collection in Eritrea started during the Italian colonial period. Before the 1930's more than 20 meteorological stations were operating throughout the country. When Eritrea was liberated in 1991, the water resources sector had been completely devastated by the consistent 30 years war for independence [13]. As such, only two stream gauging stations were operational leading to interruption in the hydrological records due to destruction of many of the old gauging sites. This is reflected in the presence of large gaps in the records (3 to more than 20 years) of annual rainfall data of the Eritrean cities and towns [1]. Apart from substantial breaks in the data time series, the erratic or unreliable measurements are responsible for the poor quality of available data. Time series of hydrological and weather data gaps have, therefore, made water related studies difficult.

The complete absence of historical stream flow data as well as of climatologically records has yet been the primary constraint in the planning and design of water resources development projects. Thus, to overcome this constraint, the WRD, MoA, NGOs and Civil Aviation Department made the old stations functional and also established new hydrological and meteorological stations (Fig. 3). The number of hydro-meteorological stations establishment has shown an increasing trend. Nonetheless, the attributes such as the location, distribution and type of instruments in each of these stations in many cases failed to satisfy the requirement for a national observation network. Moreover, owing to inadequate budget allocation and weak coordination among the different bodies, 90% of the existing stations lack frequent maintenance; thereby resulting their malfunctioning.

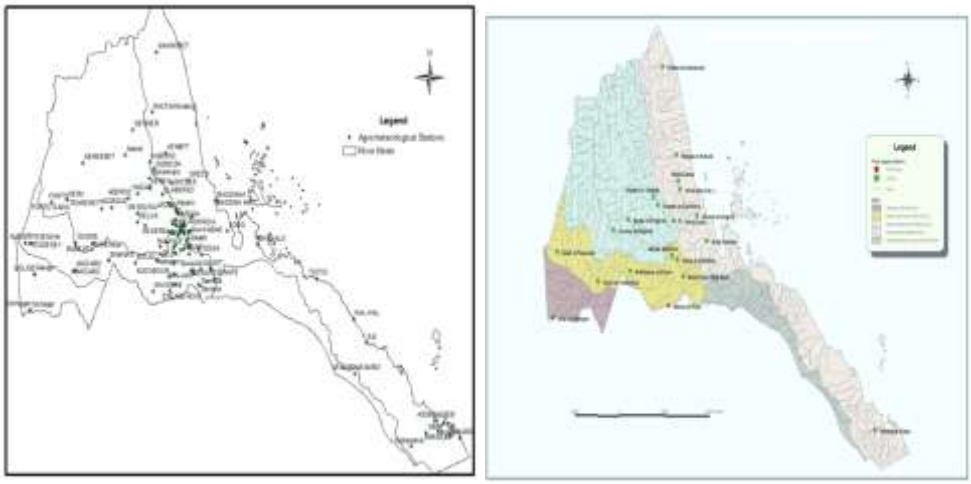


Fig. 3: Existing agro-meteorological and hydro-meteorological stations (**Source**: WRD)

Geographic Information System and Remote Sensing imagery processing tools that help us to communicate geographic or spatial information are powerful tools for mapping, monitoring, maintenance and modelling of the water industry. In this regard, there is a Water Resources Information Unit within WRD

responsible for water resources information database management system. However, inadequate data and skilled human resources, low level of institutional capacity has been some of the major constraints for data exchange. The improvement of the coverage and status of hydro-meteorological stations is one of the prioritised objectives of the WRD. It is planned to establish 7 first class weather stations, 21 river gauging stations and 244 rain gauges [16]. This is expected to strengthen and give the much-needed boost to the national capacity to collect, store, process, and disseminate qualitative and quantitative hydro-meteorological data.

Water Supply

An alarming scenario of fresh water scarcity is gradually unfolding in the country due to increase in population growth, economic activity, rapid urbanization, high competition for water among users, and improved standards of living of the population[15]. As such, the water demand for freshwater on both rural and urban areas is expected to increase in the future.

Organized water supply and sanitation programs have not yet covered the entire country. About 59.7% and 95% of the population has access to safe drinking water supply in rural and urban areas, respectively with the national coverage being 71%. This is expected to be 100% by the year 2020 [16]. However, in most of the cities and towns, the supply is grossly inadequate and the quality of water supplied through water supply networks is very poor. More than 80% of the population depends on groundwater as drinking water supply sources and will remain the main realistic domestic sources for the next 15 – 20 years [15]. With the increase in frequency of recurring drought, the groundwater scarcity is worsening even for drinking water in some parts of the country. Unaccounted losses for urban and rural piped water supply system are estimated in the range of 25% – 45% of the supply. The water need for all uses in 2009 was about $1{,}406 \times 10^6$ m^3 and by 2020 this is expected to rise to $2{,}540 \times 10^6$ m^3.

The minimum water requirements in rural and urban areas were 15 and 40 litres per capita per day (l/c/d), respectively [15]. On the other hand, the minimum domestic water demand recommended by WHO is 20 l/c/d. The average country wide domestic water consumption and national total water consumption for all uses in 2006 was estimated to be 17 and 39 l/c/d (Table 4), respectively. Their corresponding values were estimated to be 27 and 55 l/c/d in 2015 [15]. However, in view of the above national and international standards these figures are still short of meeting the requirements. According to WRD, this is due to lack of adequate water supply infrastructure, long walking distances to fetch water and insufficient supply from rivers, streams, and boreholes.

Table 4: Actual and projected water demand (2000-2015) [15]

Year	Population (× 1000)	Domestic demand (l/c/d)	Total demand (l/c/d)	Total demand (× 1000	Total seasonal peak demand (× 1000
2000	2,776	9	25	69	83
2003	3,030	13	32	97	116
2006	3,311	17	39	129	155
2010	3,726	22	48	179	215
2015	4,320	27	55	238	286

Agricultural water uses in Eritrea are for irrigation and livestock watering. The gross irrigated area was estimated to be 101,537 hectares in 2006; out of which 22.6% were irrigated by groundwater sources and 77.4% by surface water sources mainly spate irrigation and estate farms [15]. Currently, there is no information on the net irrigated area. The source of water in major and medium schemes is surface water while the dominant source in minor schemes is groundwater. Irrigated agricultural water need in 2006 and 2020 were estimated to be $1{,}311.4 \times 10^6$ m^3 and $2{,}396.5 \times 10^6$ m^3, respectively. Meanwhile, the total water requirement for livestock were estimated to be 44.0×10^6 m^3/year and 50.1×10^6 m^3/year, respectively for the same observation years [15]. Irrigated agriculture is expected to dominate the water demands on account of the on-going large irrigation projects and the policy of the Government towards food security - changing the traditional agriculture to modern technology based irrigated agriculture.

Water is one of the major elements and raw material for tourism, industry, mining, fishery, construction, service and commercial development. The projected annual water need by industrial and other economic sectors in 2020 based on the assumption that it is equivalent to 20% of the total water use by domestic, livestock and other uses [15]. Accordingly, the water need for industrial and other sectors were estimated to be 14.9 and 23.6 $\times 10^6$ m^3 for 2007 and 2020, respectively. The situational analyses document summarised the 2007 and 2020 water need for all purposes of the country as $1{,}400.9 \times 10^6$ m^3 and $2{,}538.2 \times 10^6$ m^3, respectively. There are many potential sites for micro and small hydropower and to some extent large-scale hydropower projects in the river basins of Eritrea but that requires detailed feasibility studies. Three potential hydropower sites have been identified [10] viz. Tekeze river (~ 23,000 Gwh per year), Anseba river (~120 Gwh

per year), and Setit river (~ 240 Gwh per year). But, electricity generation currently is totally restricted to diesel based thermal plants. There is no information about the conceived hydropower projects at present.

Water Quality

A water quality survey is very important to develop effective water pollution control regulations, assess the extent of the problem and provide baseline data for the establishment of a national water quality monitoring network. Under conditions of scarcity the quality of the resource is threatened by environmental hazards and there are potential signs that water pollution may become a real menace. It needs only a small amount of pollutant to degrade the quality of a modest water body. The degradation and depletion of water resources will only exacerbate the limited supply of water and will be a major constraint to national economic development.

Mining has good prospects in contributing to the economic development of a nation. As such, some companies have been given concessions in different parts of Eritrea for various mineral explorations. However, such developments may have intense effects on water quality. Whether or not the target mineral is toxic, it is often associated with toxic substances. The mining process usually produces large quantities of waste material, much of which is readily suspended in water to cause sedimentation. Mine wastes suspended in water are often retained in tailings dams which may be leaped out in extreme rainfall events, dumping large quantities of waste into streams. Sediments derived from mines may release contaminants over a long period of time. Unfortunately, there is no mention in the AP-IWRM related to mining and its environmental repercussions.

Agricultural areas where there is extensive irrigation, lead to broad-scale deterioration of water quality if not managed carefully. The input of irrigation water can lead to rising of the water-table and salinization, and irrigation tail-waters may transport large concentrations of nutrients and pesticides to their receiving waters. On the other hand, industrial developments can produce a wide variety of waste products in urban areas which are discharged into rivers. The effluents may be toxic organic, promoting bacterial growth.

Urbanization results in replacement of natural vegetation by buildings, roads and gardens; thereby are reducing rainfall access to the ground. Storm water reaches waterways much more quickly than in natural systems, leading to erosion of natural streams. Drainage water carries the effluent of urban society; fertilizers and pesticides, excreta of domestic animals, oils and associated chemicals from roads, and liquid and solid wastes.

In view of the above facts, coastal water sources are highly mineralized that range from 2,000 – 20,000 μs/cm. Salt intrusion is identified as one source of water pollution in the same [16]. Out of 548 water points surveyed for bacteriological contamination (Table 5) an average of 59.7% were found to be contaminated [15]. The causes of contamination are reported to be poor hygienic practices, low sanitation coverage, sewage infiltration to a pipe system or disposed into streams and dams. It is also reported that application of sewage sludge and solid waste materials from landfill sites as agricultural fertilizer is common in irrigated vegetable farming in the vicinity of Asmara. This is expected to be the main source for the transfer of toxic elements like heavy metals into the food chain. Industrial wastes mainly from the capital Asmara dispose their effluent directly to the natural drainage (Mai Bela) and become a serious threat to water supply sources located along banks of the stream [15]. All urban centers in Eritrea have practically no well-designed solid waste disposal sites which could be the causes for air and ground water pollution. As such, the need for properly constructed landfill sites is indicated and underlined in various literatures.

Table 5 Bacteriological contamination of water points in 2002 [15]

No.	Zoba	Contaminated (%)	Mildly contaminated (%)	Highly contaminated (%)
1	Southern Red Sea	58.53	8.53	50
2	Northern Red Sea	57.9	47.5	10
3	Anseba	41.65	6.25	35.4
4	Maekel	53.5	36	17.5
5	Gash-Barka	N/A	N/A	N/A
6	Debub	92.4	46.2	46.2

N/A: Not Available

Monitoring And Evaluation

There is a lack of resources related to the monitoring and evaluation component of water resources systems. At present, water projects are not properly monitored and evaluated; as a result many of the projects

are proved to be inefficient and ineffective in light of the intended purposes. There are many rural water supply systems, dams, ponds and other water harvesting structures that have been constructed in the country whose current situations are not yet evaluated. However, there are key documents that have been produced to guide such developments such as the AP-IWRM and the draft on Eritrean Water Resources Policy which has not yet been enacted. All these documents were produced to help develop better water resource management in the country and act as road maps for the country's water needs.

Operation And Maintenance

Installation of water resources projects in Eritrea is increasing. Except for some hand pump projects, the operation and maintenance of the existing water resources projects are not yet standardized. In spite of the efforts made by the WRD to properly operate and maintain, especially on the water supply systems, the current condition and management of water resources projects is very poor (Fig. 4). This is due to lack of skilled manpower for operation and maintenance as well as the absence of proper monitoring and evaluation plans. For instance, out of the 197 water lifting devices for domestic water supply systems installed in the Anseba Region, 122 are functional and the remaining 75 are non-functional. In other words, 38% of the water lifting devices at the domestic water supply sources are out of order (Table 6). According to WRD, Anseba branch, the main reasons are attributed to lack of spare parts, low incentive to operators, lack of co-ordination between different government bodies and lack of professional supervision during design and implementation. Moreover, lack of water use awareness of the public such as unwillingness to pay the tariff levied by the administration together with the aforesaid factors, communities are returning to unsafe water sources.

Table 6: Water lifting devices for water supply at Anseba Region

Type	Functional	Non-functional	Total
Water Supply System with Generator	35	14	49
Water Supply System with Electric	14	2	16
Water Supply System with motorized	0	0	0
Water Supply System with Solar pump	24	12	36
Hand pump	48	47	95
protected spring	1	0	1
Total	122	75	197

Fig. 4: Mismanagement of water systems (*Photo: WRD, Anseba Branch and Anghesom A.*)

Water Allocation And Costing

In Eritrea water is allocated to users without proper procedures and regulatory instruments. Decisions on water allocation, particularly the siting of the water resources development sites have been made by non water management bodies because of the absence of legal and regulatory frameworks[16]. In addition, inadequate decisions related to surface and groundwater abstractions were made without adequate data and information and this leads to the depletion of pockets of groundwater in the highlands as indicated in the previous chapters. Subsidies that discourage the efficient use of water, for example, none or too little pricing of water, are common in the agricultural sector. Therefore, this calls for a need to introduce an appropriate legal and regulatory framework, improving the knowledge level of the resources, the existing and projected demand and strengthen the capacity of water management institutions.

Sanitation Systems

Health problems in Eritrea are associated with poor hygiene and sanitation. About 80% of the preventable diseases reported by health facilities in Eritrea are related to poor environmental sanitation [6]. Poor sanitation coverage has resulted in the presence of many faecal-oral diseases, and contaminated surface and underground fresh water resources. The inadequacy of water supplies has further compromised people's hygiene and health status. However, recent reports indicate that many tangible achievements have been made in improving the sanitation and health facilities during the last decade as part of achieving the Millennium Goals.

Environmental Issues

Like the other parts of the Horn of African region, Eritrea has experienced its share of environmental degradation. In respect of this, the National Environmental Management Plan for Eritrea imposes on all Eritreans an obligation to use natural resources frugally; to reuse and recycle resources to the maximum and to minimize the depletion of non-renewable resources.Cases of pollution and contamination of both ground and surface water resources has been presented in the water quality section. Uncontrolled exploitation of ground water, poor irrigation water management practices, poor sanitation practices and animal waste disposal and industrial and sewage contaminations are some of the key regulatory and management failures that potentially expose the environment for further risk.

Water Resources Education In Eritrea

Existing Research, Training, Outreach And Consultancy

The establishment of water database, conducting applied research and dissemination of research outputs are very important procedures for effective management and planning of water resources. Research findings could be useful in the design and development of appropriate policies and in making timely and informed decisions about existing water resource potentials because water investments to a large extent require huge capital resources and are largely fixed. Thus, costly mistakes in investments in water projects could be avoided if they are based on careful research and data analysis. Despite the aforementioned facts, there is no water institute or organization in charge of undertaking water use and management related research.

Water resources education at IHE level is offered in a fragmented manner. Departments such as Civil Engineering, Agricultural Engineering and Land Resources and Environment offer to their undergraduate and postgraduate students few introductory water related courses. However, graduates from these areas are not expected to have an in-depth knowledge and skill in water resources planning, management and development without further training. It is unfortunate that in all engineering disciplines, post-graduate programs are yet to be developed. MoLWE (2007) indicated the minor trainings aimed at skill development of operators and technicians rarely given by WRD. Recently, Asmara Water Supply Department (AWSD) also conducted six month training course on water supply systems for some students who completed their high school studies.

There is no literature on either the historical background or present status of the consultancy and outreach services of water resources related organizations.

Way Forward

The WRD together with stakeholders is strongly advocating on the launching of NWTI that can play a leading role in addressing and overcoming the water resources development challenges. In 2013, a feasibility study on the establishment of a water institute was carried out and its approval is yet awaited. The objective of the NWTI will be mainly to train professionals at different levels who can undertake the data collection and processing, planning, assessment, development and management of water resources systems and sewerage. In addition, it is expected to spearhead applied research, consultancy and outreach programs, capacity building at different levels and act as a bridge to information exchange. Some of the IHE are considering the commencement of post-graduate programs in water related areas which may contribute in addressing the existing and future water management challenges.

The development of the water resources system in Eritrea is at its infant stage both in its potential and effectiveness. This could be attributed to the lack of skilled human power during planning, design, implementation, monitoring, operation and maintenance. In other words, many water resources systems are constructed without making a base on proper data and are being operated without proper management plans. The training, therefore, is envisaged to focus generally on water resources assessment, development and management, and sewerage in the short plan. In medium and long term plans the institute is expected to broaden its scope so as to address all the challenges discussed in the preceding sections by strengthening its linkages with national and international institutions.

III. CONCLUSION

The government of Eritrea has made a tremendous improvement in harnessing water resources through the construction of dams, ponds, wells and diversion structures to increase its availability in terms of time and location. For instance, apart from the small to medium size dams that have been constructed since independence, the recently completed and on-going big storage structures for multi-purpose uses such as Gherset, Fanco, Ghergera, Kerkebet, Adi-Halo, etc. justify the aforesaid point. Parallel effort is also on-going to make water to be available within the acceptable fetching distance through the construction and installation of canals and water pipe networks. Nonetheless, the review of various documents revealed that mismanagement and inefficient use of water resources is a dominant problem, attributed to various interrelated factors. Extreme catchment degradation, uncontrolled use of bore wells, pollution of freshwater, improper procedures and regulatory systems, absence of water costs and enacted water resources policy, lack of consistent monitoring, assessment and evaluation, insufficient legislative and legal framework, inefficient institutional framework, poor co-ordination among water related sectors, limited data and information sharing, weak financing mechanisms and inadequate professional and technical capacity are some among the others. In addition, the existing hydro-meteorological network and water quality monitoring stations are also insufficient to give detailed national scenario of surface and ground water resources. Fragmentary data collection, handling and processing are also common practices.

The review study conducted also concluded that large scale surface water and groundwater resource studies are yet to be carried out. The existing human resources and institutions are incapable to meet the knowledge and skills required for the assessment, development, co-ordination, management and protection of water resources systems in the country. In other words, the present water resources knowledge and information sharing is at its rudimentary stage and fragmented. This is due to the absence of water institutes solely responsible for addressing water resources challenges and disseminating systematic and timely information to the public and water resources professionals.Thus, the authors strongly believe that with increasing consumption of water in the country backed up by the growing population pressure, the per capita availability of freshwater in the coming years may cause further scarcity, unless some fundamental and anticipated changes are introduced in the management of the water supply systems. The first step towards this direction is to establish NWTI which deals with training of nationals, conducting applied research and offering outreach and consultancy services.

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