

Chapter 20

Water Conservation Through Decentralized Rainwater Harvesting Under Climate Uncertainty



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Abstract Water is essential to sustain life, and adequate, safe and accessible supply must be available to all. Millions of people throughout the world do not have access to clean water for domestic purposes. In many parts of the world, conventional piped water is either not available, unreliable or too expensive. One of the biggest challenges of the twenty-first century is to overcome the growing water shortage. Rainwater harvesting (RWH) has thus regained its importance as a valuable alternative or supplementary water resource, along with more conventional water supply technologies. Much actual or potential water shortages can be relieved if rainwater harvesting is practiced more widely. Severe water shortages and extremely fragile ecological conditions necessitate careful attention to water resources conservation and management. Nowadays, cumulative effects of climate change, population increase, development, and industrialization are leading to increased water demand which seeks careful and strategic management of the available resource. In the Ethiopian context, the average annual population growth is about 2.8% and twice of water demand increase. People collect and store rainwater in buckets, tanks, ponds, and wells. This is commonly referred to as rainwater harvesting and has been practiced for centuries. Rainwater can be used for multiple purposes ranging from irrigating crops to washing, cooking and drinking. In this paper, assessment and review are done on effects of climate change, population growth and development on water demand increase. Long-term average annual rainfall was accessed from meteorological data, and minimum numbers of houses data were taken from Ethiopian 2007 census data. Finally, possible amount of water harvested is estimated for domestic and other water uses.

Keywords Climate change · Rainwater harvesting · Ethiopia · Population growth · Water demand

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Introduction

Background

Water is increasingly recognized as a major component in economic development and poverty reduction. Several recent papers considering the importance of water in meeting the development goals have highlighted water's direct and indirect contributions, rather than just focusing on its central role in achieving the aim on environmental sustainability and the accompanying target on water supply and sanitation. This analysis illustrates the fact that water's interaction in the lives of the poor is complex in character and operates through multiple dimensions: improved livelihoods, security, reduced health risks, reduced vulnerability, and pro-poor economic growth. Further, as well as its significance in poverty alleviation, investment in water infrastructure and management has a major impact on national economies. Finally, there is increasing attention to the multiple values of water for society, including not only its importance in terms of ecosystem sustainability but also its cultural and social components (Dowa et al. 2010).

Ethiopia boasts a population of over 100 million people and which only 38% have access to safe drinking water sources and only 12% of the population use improved sanitation facilities. Ethiopia has found itself in an extreme water crisis situation, brought on mainly by severe drought, little governmental funding and assistance, and lack of water management and sanitation resources. The shortage of water and drought has brought an overwhelming spread of famine and food shortage (Hendrix 2012).

Even though there is sufficient water resource, due to the lack of water conservation and management system, millions of Ethiopians are forced to walk up to six hours in order to fetch water that is often source of disease. This is causing women and children to put water collection above all else, including school. It also is creating water-borne illnesses that infect and claim thousands of Ethiopian lives. Around 7.5 million Ethiopians suffer problems related to high fluoride levels. This number is only the tip of the iceberg when it comes to water-related disease in Ethiopia and without improving sanitation within the country; the numbers are set to only increase (World Bank 2012).

Like much of Africa, Ethiopia has become warmer over the past century and human-induced climate change will bring further warming over the next century at unprecedented rates. For the IPCC mid-range (A1B) emission scenario, the mean annual temperature will increase in the range of 0.9–1.1 °C by 2030, in the range of 1.7–2.1 °C by 2050, and in the range of 2.7–3.4 °C by 2080 over Ethiopia (UNDP 2007).

Climate Change and Variability

Currently, climate change is serious global challenge where developed countries contribute most to the climate impact and others becoming victims. According to

the IPCC, Africa is one of the most vulnerable continents to climate change and climate variability (CLUVA 2013).

Total reliance on surface water from major rivers makes the urban water supply highly vulnerable to changes in the flow and water quality of these rivers and subject to water pollution incidents. The National Assessment Report on Climate Change, 2007, indicated decreasing trends in runoff in the last 40 years in the main rivers due to climate change. The watershed of major rivers and tributaries has been experiencing higher frequencies of consecutive years of drought. In addition, water quality in major rivers is deteriorating due to urban developments in the catchments. Especially rift valley lakes and rivers water qualities are deteriorated to great extent due to climate change and liquid waste disposals from development and agricultural areas. In some cases, water is no longer potable. Both volume and quality of available surface water resource are adversely affected as a result of climate change and development.

Flooding and drought, the two extreme events which are caused by climate change, are the main natural hazards that require water conservation and management considerations. Flooding, the flow of excess water over areas which are habitually dry, is one of the major natural hazards which impact prosperity and safety of human settlements. Drought is a deficiency of precipitation from an expected or “normal” amount, and when extended over a season or longer period of time, available water is insufficient to meet demands. It can be meteorological drought, a deficiency of precipitation from an expected or “normal” amount over an extended period of time; agricultural drought, a deficiency in water availability for crop or plant growth; hydrological drought, a deficiency in surface and subsurface water supplies that lead to a shortage of water to meet normal and specific water demands.

Climate change is a primary contributor to hydrological drought through the increase in heating of the earth’s surface, resulting in a reduction of rainfall and cloud cover and, consequently, in greater evaporation rates. The resultant effects of drought are exacerbated by human activities such as deforestation, overgrazing, and poor cropping methods, which reduce the water retention of the soil and improper soil conservation techniques, which lead to soil degradation.

Surface temperature is expected to rise over the twenty-first century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer and that extreme precipitation events will become more intense and frequent in many regions (IPCC 2014).

For more than three decades, Ethiopia has experienced recurrent deadly droughts including those of the 1972/73, 1984 and 2002/03. Communities whose livestock is often the most devastated by drought are located in the Afar, Oromia, Somali, and Southern regions. Desertification, brought on by human land-use pressure and frequent drought, has consumed significant land area and continues to threaten arable land (NAPA 2007). According to the report, there is increasing trend of temperature and some decrease in precipitation trend. For the IPCC mid-range (A1B) emission scenario, the mean annual temperature will increase in the range of 0.9–1.1 °C by 2030, in the range of 1.7–2.1 °C by 2050, and in the range of 2.7–3.4 °C by 2080 over Ethiopia compared to the 1961–1990 reference condition.

Water Supply and Demand

Water Stress and Scarcity

Water scarcity and stress are becoming common phenomenon caused by climate change. “Water Security” is herein described as the nexus between the availability, accessibility, and use of water. The concept is defined as availability of and access to water in sufficient quantity and quality to meet livelihood needs of all households throughout the year, without considering the needs of other users. “Water stress” is shortage of water, whereas “scarcity” is defined from the perspective of individual water users who lack secure access to safe and affordable water to consistently satisfy their need for food production, drinking, washing, or livelihoods (Molden 2007).

Water scarcity is first and foremost a poverty issue. About 1.2 billion people live in areas of physical water scarcity, and up to one in three people in the world face water shortages. In 2025, about 1.8 billion people will live in regions with absolute water scarcity and about two-thirds of the world’s population in areas of water stress (FAO 2007).

Water Supply and Demand Imbalances

In the year 2000, about 7 of the 50 million people in rural areas (13%) and 8 of 11 million people in urban areas (73%) had access to safe drinking water. During the same period, access to basic services in sanitation was only 6% for rural and 62% for urban communities (Ndaruzaniye 2011). Water demand far exceeds supply by about 50%, and the water and sanitation distribution network reach only about 55% of the capital city, Addis Ababa, service area. Approximately half the population living in Addis Ababa has less than 12 h per day of water service, and a quarter have no service at all. Most people without water supply live in precarious conditions in Addis Ababa peripheral poor areas, which are now part of the city’s administrative area for the last decade.

Addis Ababa water supply is 50 L per capita per day (lpcd) or 35 lpcd taking into account 35% of water losses or waste. When compared to other African countries, most comparable cities in Africa are provided with at least 100 lpcd with a 3.5% population growth rate by 2012, whereas most of Ethiopian cities are getting average of 20 lpcd, and average annual population growth is above 4% (Ndaruzaniye 2011).

About 12% of households in Addis Ababa have flush toilets that discharge to sewers or septic tanks, 63% of households use individual or shared pit latrines, and 25% do not have access to sanitation facilities. The occurrences of diseases are highest in densely populated areas where water supply, sanitation, and nutrition are inadequate (World Bank 2007).

Decentralized Rainwater Harvesting

Water conservation means preservation or restoration of the available resource of water in different forms. Water conservation involves keeping, preserving, and restoring of surface, subsurface, and groundwater sources. In this chapter, we will present surface water conservation through rainwater harvesting. Since the rainwater will be harvested at household levels, it is said to be decentralized.

Where there is no surface water, where groundwater is deep or inaccessible due to hard ground features, or where it is too salty, acidic, or otherwise unpleasant or unfit to drink, another source must be sought. In areas that have regular rainfall, the most appropriate alternative is the collection of rainwater, called “rainwater harvesting.”

Falling rain can provide some of the cleanest naturally occurring water that is available anywhere. This is the result of a natural evapotranspiration process with risk of contamination only from airborne particles and from man-made pollution caused by the smoke and ash of fires and industrial processes, particularly those that burn fossil fuels.

Most modern technologies for obtaining drinking water are related to the exploitation of surface water from rivers, streams and lakes, and groundwater from wells and boreholes. However, these sources account for only 40% of total precipitation. It is evident, therefore, that there is considerable opportunity for the collection of rainwater when it falls, before huge losses occur due to evaporation and transpiration and before it becomes contaminated by natural means or man-made activities.

The term “Rainwater harvesting” is usually taken to mean the immediate collection of rainwater running off surfaces upon which it has fallen directly. This definition excludes runoff from land watersheds into streams, rivers, lakes, etc. Rainwater can be collected from roofs, and only to a lesser extent where it is collected from small ground, or rock (impervious), catchments (WaterAid 2013).

Rainwater can be collected from most forms of roof. Tiled roofs or roofs sheeted with corrugated mild steel and concrete slabs, etc., are preferable. Collected rainwater can be used for domestic, public, industrial, and other purposes. In addition, it can be used for groundwater recharge. The rainwater is then collected in gutters placed around the eaves of the building. The capacity of storage tanks is determined based on expected yield from the collection surface area and expected rainfall.

Description of Study Area

Climate of Ethiopia

Ethiopia has diverse climate influenced by latitude and altitude. There are five climatic zones, Wurch (cold to moist), Dega (cool to humid), Weynadega (cool

sub-humid), Kola (warm semiarid), and Berha (hot arid) as defined by altitude, rainfall, length of growing season, and mean annual temperature (Berhanu et al. 2014). Figure 20.1a shows Ethiopia's maximum air temperature spatial variation. Ethiopia's spatial rainfall distribution is very high having annual rainfall less than 200mm in the east, southeast, and northeast; and most of western highlands receiving mean annual rainfall of over 1200 mm (Berhanu et al. 2014). Figure 20.1b shows Ethiopia's annual rainfall spatial variation.

Population Growth

Ethiopia is one of the countries having rapid increasing trend of population. The current population is above 110 million based on the United Nations estimates. The country's population is equivalent to 1.35% of the total world population and ranks number 13 in the list of countries by population. The population density is 102 per km² in which 19.4% of the total population is living in urban areas. Figure 20.2a shows spatial distribution of Ethiopia's population density. Figure 20.2b shows urban, rural, and total population changes since 1980 with projection to 2025.

Water Demand

Even though there is an economic water scarcity in the country, there is great increase in water demand for domestic, industrial, commercial, institutional, and public uses due to the following major factors. According to WHO (2014), the minimum per capita water demand is around 20 lpcd which is the lowest marginal demand. The demand will increase with population growth, development and

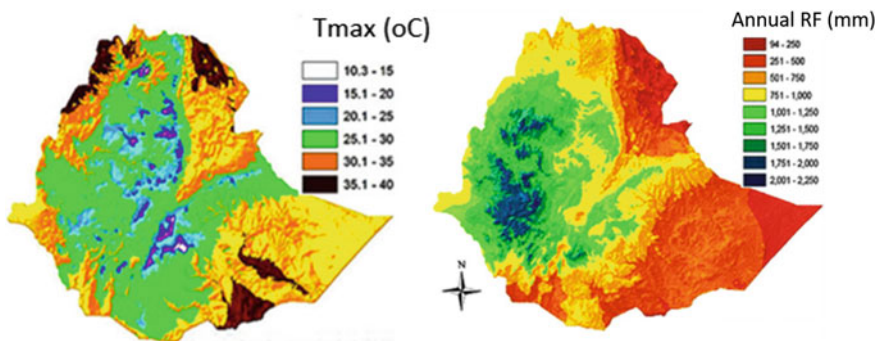


Fig. 20.1 Ethiopia's maximum air temperature (a) and annual rainfall (mm) (b)

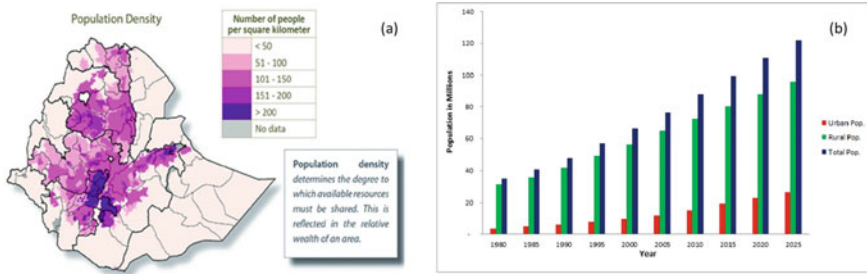


Fig. 20.2 Ethiopia’s population density spatial distribution (Rettberg et al. 2017) (a) and urban, rural, and total historical population growth (b)

industrialization, increased life standard, and climate change with increasing in temperature.

The Blue Nile Basin

The basin accounts about 23% of country’s land area and is the habitat of 37.6% of the total population. The basin has relatively higher population density compared to other parts of the country. The basin gets relatively higher amount of annual precipitation ranging from 800 to 2220 mm with an average amount of 1535 mm which indicates that there is high potential of rainfall harvesting for future integrated water use management (Johnston and McCartney 2010). Figure 20.3 shows the Blue Nile Basin with climatic zones.

Methodology and Analysis

The population and household data are collected from Ethiopian 2007 census and from United Nations world population report. The climate data such as precipitation and temperature are obtained from Ethiopian meteorological agency. The demand and supply data and standards are obtained from Ethiopian Ministry of Water, Energy and Electricity, from World Health Organization (WHO 2014) and literatures. Accordingly, the available data for computation and analysis are the following:

From 2007 Ethiopian Census data:

- The average number of individuals per household is 5.6 and taking max value as 7 for rural areas and 6 for urban areas.
- Ratio of households to housing units in rural areas is 1.05, whereas in urban areas is 1.1 and percent of current urban population is 19.8.

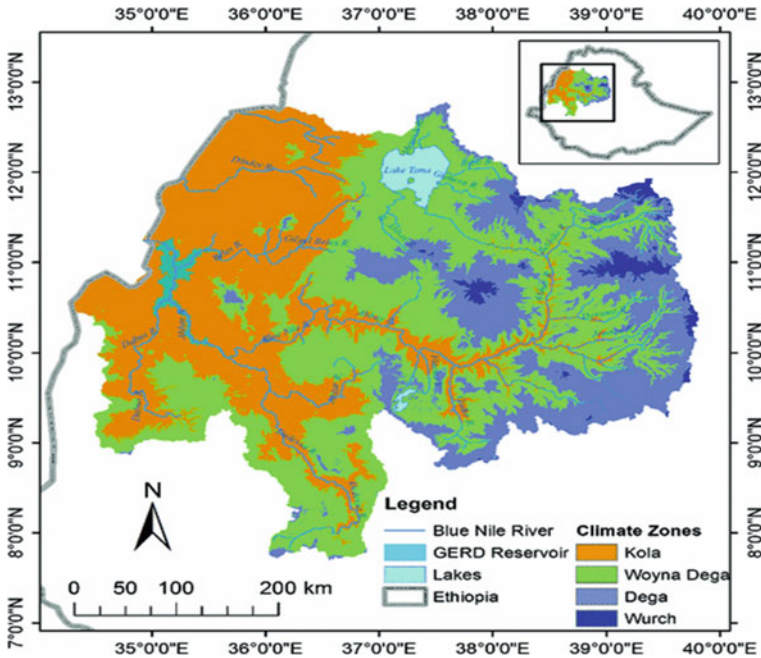


Fig. 20.3 The Blue Nile Basin and climatic zones (Abtew and Dessu 2019)

- In rural areas, the average area for housing is 40 m² and for those in urban areas is 36 m².

Based on the data obtained from Ethiopian Meteorological Agency, mean annual rainfall of 850 mm is taken for analysis even though more than 60% of the population lives in areas getting mean annual rainfall exceeding 1200 mm. In the Blue Nile Basin, 1300 mm annual rainfall is used.

According to WHO standard, minimum daily domestic per capita water demand for developing countries is 20 l/day in which only 10–15% is for drinking purpose. For analysis purpose, we have taken 30 lpcd for rural areas and 40 lpcd for urban areas which are above the standard. From total daily water demand, more than 26% is lost for toilets, 23% for washing cloths and dishes, 18.5% for showering and the rest for gardening purpose and losses.

In most of rural areas, there is additional shelter with minimum roof area 10 m² for cattle sheltering usually made from iron sheets, plastic, or other materials. Due to increasing life standard and climate change, annual domestic water demand increases by 1.5%. Current annual population growth rate is 2.48% for the total population in which 5.12% and 2.44% are growth rates of urban and rural areas, respectively. Table 20.1 shows Ethiopia's population growth between 1980 and 2015.

Table 20.1 Population and its corresponding growth rate data

Year	Total pop.	Urban pop.	Rural pop.	UGR	RGR	UAGR (%)	RAGR (%)
1980	35,239,974	3,668,755	31,571,219	0.273	0.1436	5.4604	2.8725
1985	40,775,997	4,670,398	36,105,599	0.2983	0.1631	5.9658	3.2615
1990	48,057,094	6,063,524	41,993,570	0.3004	0.1752	6.0076	3.5047
1995	57,237,226	7,884,886	49,352,340	0.2342	0.1491	4.6843	2.9825
2000	66,443,603	9,731,656	56,711,947	0.2288	0.14	4.5764	2.7994
2005	76,608,431	11,958,476	64,649,955	0.2614	0.1211	5.2272	2.4216
2010	87,561,814	15,083,947	72,477,867	0.2772	0.1055	5.5449	2.1102
2015	99,390,750	19,265,898	80,124,852	0.2676	0.1425	5.3524	2.8503

Pop population, *UGR* urban growth rate, *RGR* rural growth rate, *UAGR* urban annual growth rate, and *RAGR* rural annual growth rate

To estimate volume of harvested rainwater from rooftops, the rational formula is employed (Eq. 20.1).

$$Q = R * P * A \tag{20.1}$$

where

- Q* Mean annual harvested rainwater volume (m³)
- R* Runoff coefficient (unit less)
- P* Mean annual precipitation (mm)
- A* Surface area of rooftops (m²)

The runoff coefficient is considered to account potential losses due to splashing, evaporation, leakage, and overflow of rooftops and minimum value is taken as 0.8 (20% loss).

Results and Discussion

Ethiopia’s Potential of Rainwater Harvesting

As it is known that Ethiopia is the country of “Water Tower” and getting annual mean rain fall of 1100 mm, there is significantly high potential of rainwater harvesting from rooftops in both rural and urban areas of the country. As the census data indicates, there is rapid increases of population which will also contribute to increase in housing developments. Living standard of rural community can be improved from potential rainwater harvesting due to rooftop type and area changes and increased yield. Using hydrological analysis from the data collected, the following results are obtained. If appropriately managed and awareness is created, there is a potential to store about half billion m³ water from residential rooftops only. Table 20.2 shows total rural population (Pop), number of household (HH),

Table 20.2 Estimated contribution of harvested rainwater from total rural domestic water demand

Year	Pop	No. of HH	No. of HHU	RWH (m ³)	Per capita demand (lpcd)	Total demand (m ³)	RWH as % of total
1980	31,571,219	4,510,174	4,295,404	116,834,987	19.5	224,708,151	52
1985	36,105,599	5,157,943	4,912,326	133,615,278	21	276,749,416	48.3
1990	41,993,570	5,999,081	5,713,411	155,404,776	22.5	344,872,194	45.1
1995	49,352,340	7,050,334	6,714,604	182,637,231	24	432,326,498	42.2
2000	56,711,947	8,101,707	7,715,911	209,872,783	25.5	527,846,447	39.8
2005	64,649,955	9,235,708	8,795,912	239,248,813	27	637,125,307	37.6
2010	72,477,867	10,353,981	9,860,934	268,217,413	28.5	753,951,011	35.6
2015	80,124,852	11,446,407	10,901,340	296,516,459	30	877,367,129	33.8

number of housing units (HU), estimated annual rainwater volume (RWH), per capita water demand, total water demand and rainwater as percent of total water demand for from 1980 to 2015. Table 20.3 shows similar data for urban domestic water demand.

Tables 20.2 and 20.3 show that huge amount of water can be conserved and harvested from the rainfall. The magnitude of harvested rainfall depends on the number of housing units and the available areas of the rooftops. As the population increases, the available number of housing units will also increase even though the rate is not similar to the population and demand growth rates. The result and analysis did not incorporate the amount of rainwater harvested from rooftops of areas used for industrial, commercial, public, and other institutions. Only residential areas are considered. From Figs. 20.4 and 20.5, it shows that if potential available rainwater is harvested appropriately, it can fulfill above 40% of total domestic water demand in rural areas and 25% for urban community. In urban areas, harvested rainwater can satisfy the toilet water demand and water demands used for gardening and cleaning purposes which account above 35% of total water demand.

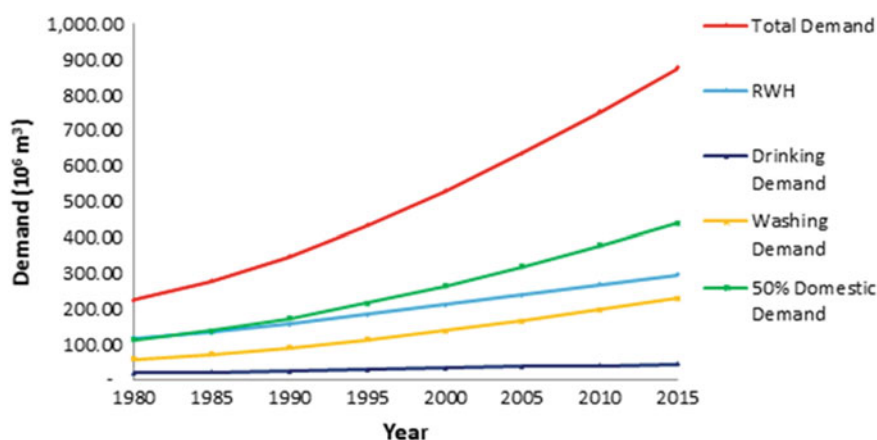
If appropriately collected and managed, rainwater that can be harvested from rooftops of industrial, institutional, commercial and public areas and can fulfill the demands for toilet, gardening, and cleaning purposes. In addition to this, municipal water stress and direct runoff magnitude from paved areas can be reduced through proper water harvesting mechanisms.

Blue Nile Basin

As it is shown in the figure below, there is increasing water demand for both rural and urban communities. Figures 20.6 and 20.7 show that more than 50% of total water demand can be fulfilled through rainwater harvesting in rural areas, whereas above 40% of urban domestic demand can be met through decentralized rainwater harvesting.

Table 20.3 Share of harvested rainwater from total urban domestic water demand

Year	Pop	No. of HH	No. of HHU	RWH (m ³)	Per capita demand (lpcd)	Total demand (m ³)	RWH as % of total
1980	3,668,755	611,459	555,872	13,607,746	29.4	39,369,410	34.6
1985	4,670,398	778,400	707,636	17,322,931	31.2	53,186,492	32.6
1990	6,063,524	1,010,587	918,716	22,490,162	32	70,821,960	31.8
1995	7,884,886	1,314,148	1,194,680	29,245,759	33.8	97,275,839	30.1
2000	9,731,656	1,621,943	1,474,493	36,095,597	35.4	125,742,727	28.7
2005	11,958,476	1,993,079	1,811,890	44,355,075	37	161,499,218	27.5
2010	15,083,947	2,513,991	2,285,447	55,947,731	38.3	210,866,037	26.5
2015	19,265,898	3,210,983	2,919,075	71,458,967	40	281,282,111	25.4

**Fig. 20.4** Available rainwater harvest (RWH) for rural water use compared to total water demand

Even though there is increasing gap with water demand, harvested rainwater has an adequate amount to fulfill drinking water demand and demand for cloth washing in rural areas if it is collected timely and properly. The result indicates that unsafe and non-healthy rural water supply from rivers, dug wells, and springs can be solved through integrated and well-managed water harvesting technologies.

Summary

Decentralized rainwater harvesting can significantly reduce the stress of water supply and unmet demands in rural and urban areas. In urban areas, collected rainwater can be used for toilets (sanitary use), cleaning and washing, and for

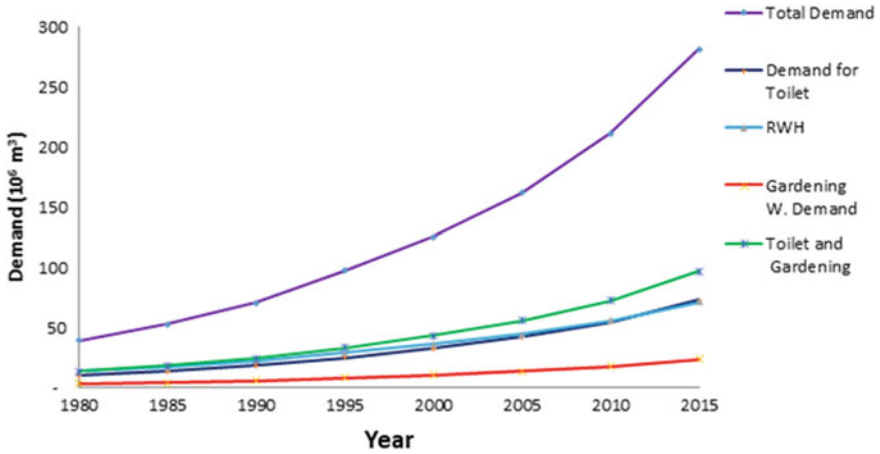


Fig. 20.5 Available rainwater harvest (RWH) for urban water use compared to total water demand

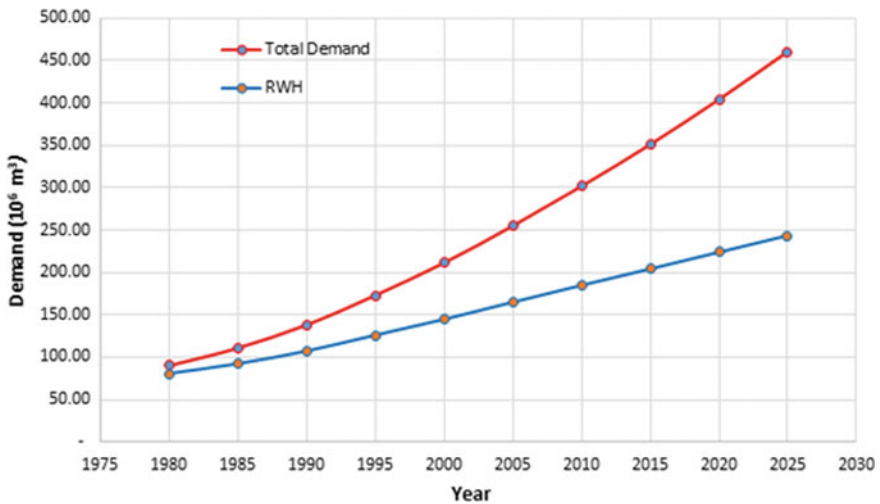


Fig. 20.6 Potential rainwater harvest for rural water use compared to total water demand

gardening purposes which consumes above 50% of total domestic water demand. In addition, it can be used as potable water for drinking and cooking if it is captured properly and neatly in those rural regions who are using unsafe surface water use. Furthermore, urban runoff problems due to increased impervious areas including more than 30% rooftops can be significantly reduced through rainwater collection. Decentralized rainwater harvesting through rooftops has great advantage to store

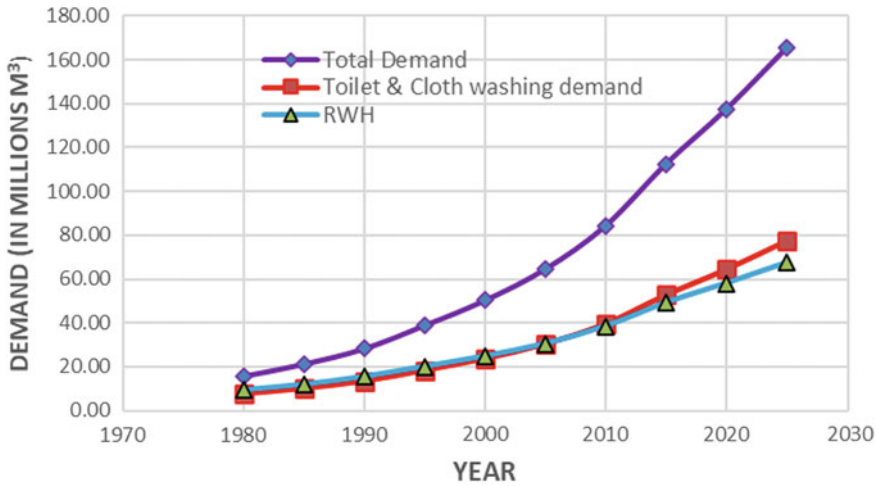


Fig. 20.7 Potential rainwater harvest (RWH) for urban water use compared to total water demand

potential rainfall using closed vessels (storages) without any loss to evaporation. Above ground rainwater harvesting is an alternative water storage in addition to ground water storage, especially at lowland areas with high evaporation.

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