  

Research Paper

# Life cycle cost analysis of water supply infrastructure affected by low rainfall in Ethiopia

S. Godfrey and G. Hailemichael

## ABSTRACT

This paper challenges the assumption that low cost CAPEX (capital expenditure) water supply infrastructure provides reduced life cycle costs when compared with higher cost CAPEX investments. The assumption is applied through a comparison of 10 years of financial data (2006–2016) from point source water supplies (accompanied by Emergency Expenditure – EMMEX investments – emergency water trucking, treatment and distribution) and piped water supply systems in two districts of the Ethiopian Central Highland region of Amhara. This study concluded that on average point source water supplies accessing shallow groundwater were non-functional for an average of 60 months in a project period of 10 years. To supplement the water supply demand during the non-functionality period, emergency water trucking and treatment was provided over a 10 year period at a per capita cost of USD 2,257. In comparison, the per capita cost of piped water supplies was USD 65 for a project period of 20 years. The study concluded that piped water supplies are less expensive than point source supplies when CAPEX and emergency water supply provision costs are considered under a life cycle cost analysis.

**Key words** | CAPEX, drought, EMMEX, Ethiopia, life cycle cost, water scarcity

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## INTRODUCTION AND LITERATURE REVIEW

Globally, there is a recognition that by 2025, 2.8 billion people in 48 countries of the world will face water stress (GWP/OECD 2015). By 2050, the number of countries facing water stress or scarcity could rise to 54, with a combined population of 4 billion people – about 40% of the projected global population of 9.4 billion (Gardner-Outlaw & Engleman 1997). Data from the Global Water Availability Model (GWAM) is noted by Hejazi *et al.* (2014) to further increase to 44% by 2095. In East Africa, Rowell *et al.* (2015) note that a number of climate models estimate an East African paradox. This paradox predicts an increase in rainfall over the coming decades which could lead to subsoil saturation, increased evapotranspiration and flooding. Mitigation measures to combat water scarcity require both changes to social norms such as wise water management as well as technology adaptation (Godfrey *et al.* 2010). Water scarce countries such as Australia have attempted to adapt their approach to water supply provision by focussing on climate resilient water systems (Amarasinghe *et al.* 2016). However, challenges in the provision of climate resilient water supplies include limited data on the cost effectiveness of these interventions and restricted published information on the means of policy modifications. Watts *et al.* (2012) developed a methodology to test the drought resilience of two contrasting English water resource systems. The paper concluded that a combination of significant behaviour change to reduce consumer demand combined with engineering measures were required during a peak drought period to ensure the continuity of supply. This however assumes that water supply

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planners have selected the most appropriate water supply option at the outset.

In the case of many developing countries, water supply coverage levels remained low during the Millennium Development Goal (MDG) period. In order to boost coverage, water supply planners and policy makers selected low cost 'point source' water supply options to boost minimal water supply coverage in the attempt to achieve the global MDG targets. Hutchings *et al.* (2016), in a study of rural wells with hand pumps in Bihar, India, note that there is a need for a move from a binary understanding of access to water supply to a holistic measure of service level that is climate resilient. This, argue Hutchings *et al.* (2016), will reduce the potential of politicization of water supply access data. India was not alone in the MDG era in politically supporting lower cost and non-climate resilient water supply technologies. Jowitt (2009) noted a disconnect between choices of water infrastructure, the UN MDGs and sustainable development.

Ethiopia has invested substantially in the water supply sector since 1990 and has improved access to water supply from 13% to 57% by 2015. A total of 49 million people have gained access to water during the 25 year period (WHO/UNICEF Joint Monitoring Programme 2015). Analysis of the water supply technologies used to achieve this target reveals that 40 million people have benefited from low cost, point source, water supplies that are largely dependent on rain-fed shallow aquifers. Ethiopia has also applied a number of quantitative tools to aid the development of water security policy (Robinson *et al.* 2012) and as demonstrated by Grey & Sadoff (2007), there is direct relationship between rainfall availability and GDP in Ethiopia. This implies that when communities are affected by drought their socio-economic wellbeing is hindered and there is an increased reliance on external (emergency) support.

In the period of the Sustainable Development Goals (SDGs), the water supply goals have become universal and require a higher level of both service and coverage. Ait-Kadi (2016) states that water supply is not only relevant for Goal 6 of the SDGs but is at the heart of the achievement of all SDGs. This view is supported by Thompson & Koehler (2016). However, despite this recognition, and the linkage to economic growth as seen in Figure 1 (GWP/OECD 2015), water supply planners, policy makers and practitioners in many parts of Africa are still installing and developing 'non-resilient' water supply options in rural communities that have a limited ability to withstand climate shocks. During the 2016 El Nino drought, it was estimated by UNOCHA that 36 million people in East and Southern Africa were left without water supply because of the lowering of groundwater tables (UNOCHA 2016). A large percentage of this population was in Ethiopia where almost 10 million people were affected by drought conditions.

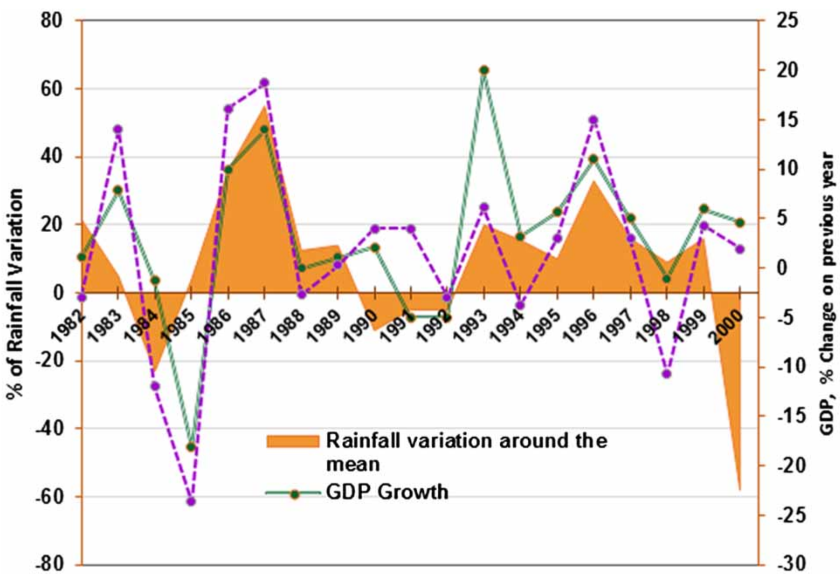


**Figure 1** | Linkage between gross domestic product and rainfall in Ethiopia (*Source:* Grey & Sadoff 2007).

## STUDY AREA

The study was conducted in Goncha Siso Enebsie and Enarj Enawga woredas (districts) in the East Gojam zone of the highlands of Amhara region, Ethiopia. Amhara region is one of the nine administrative regions in Ethiopia with a projected population of 20,769,985 (CSA-Ethiopia August 2013). Amhara region has ten zones, one special zone (Bahir Dar town), one special woreda (Argoba) and 137 woredas (equivalent to district). The region is frequently affected by drought. Figure 2 shows the emergency hot spot areas in Ethiopia during the height of the 2015/2016 El Nino drought and indicates that the Amhara region is one of the highly affected regions. The two study woredas for this paper are located in drought-affected areas in the western part of Amhara region (Figure 3).

Rainfall in the study area is unimodal with much of the rainfall being concentrated in the four months of the Krempt season (June–September) (Woldeamlak 2009). Analysis of the spatial and temporal behaviour of rainfall in the study woredas indicates that maximum and minimum temperature data obtained from five meteorological stations in the woredas from the years 1979 to 2008 have a considerable spatial variation (Taye *et al.* 2013). The effects of climate variability such as rising temperature and changes in precipitation are noted to affect the ecosystems, biodiversity and people. These conditions determine the carrying capacity of the biosphere (IPCC 2001). As a result, the availability of water from shallow groundwater sources is affected as they provide water for a short period after the offset of the rain.

Data from the two study woredas indicate that in the 2015/2016 drought, 80% of the point sources were non-functional during the period of low rainfall. Consequently, water supply needs were supplemented by transporting water by truck from areas as far as 150 km.

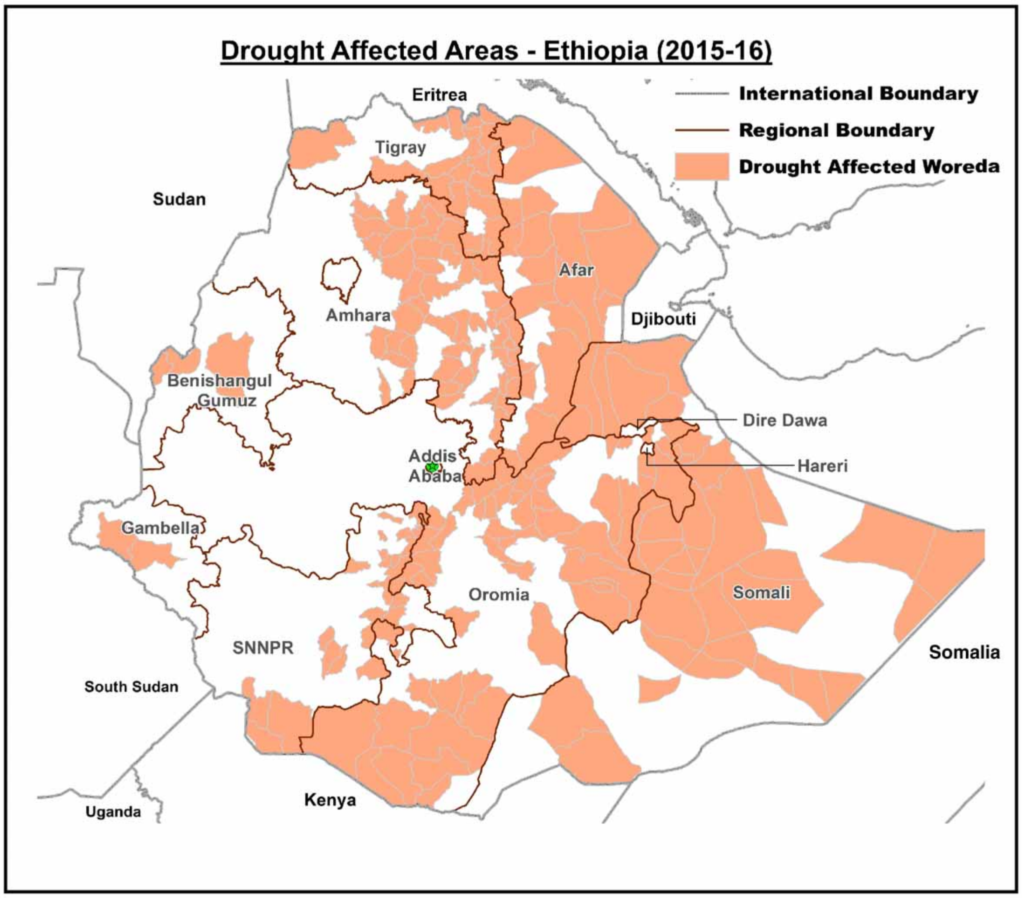


**Figure 2** | Drought-affected woredas (2015/16) (*Source:* UNICEF).

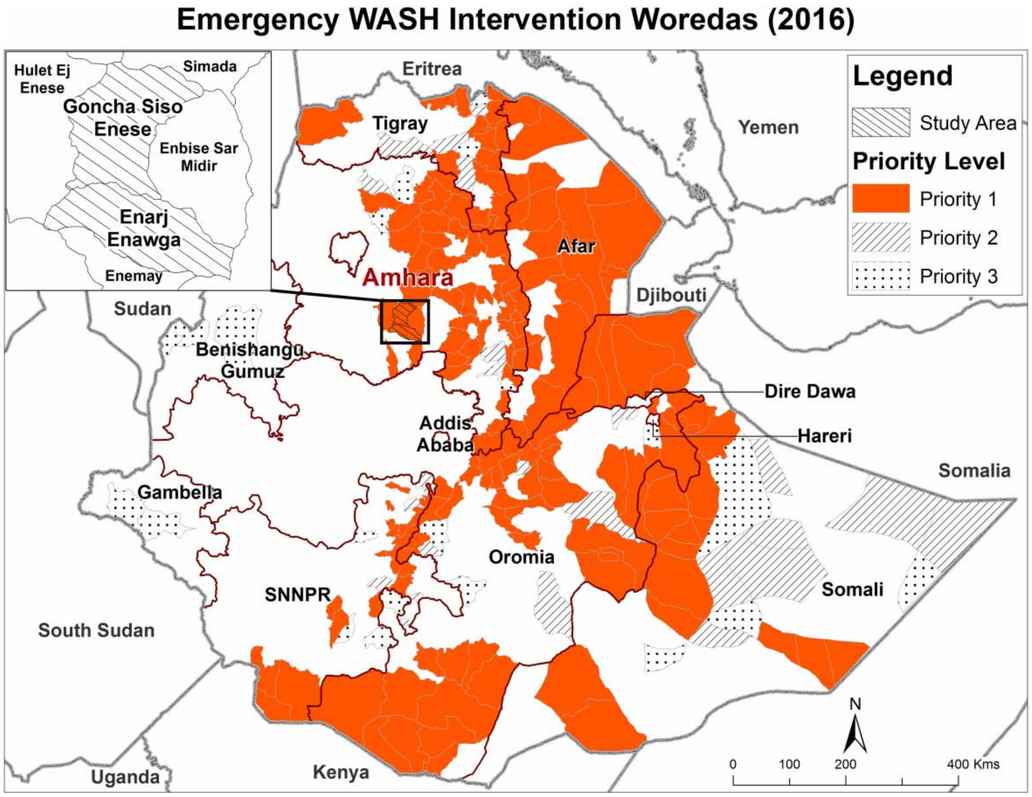


**Figure 3** | Location of study woredas.

Figure 4 shows prevalence of drought and requirement for emergency water supply in the study area in number of months from 2006 to 2015.

As per the National Water, Sanitation and Hygiene (WASH) Inventory conducted in Amhara region in 2015, point sources constitute on average 95% of the total water supply in the study woredas (Goncha Siso Enebsie and Enarj Enawga woreda).

The water supply technology options in the two woredas are generally categorized as follows:

1. Point sources. Hand dug wells (HDWs) are protected (improved) water supply sources that are dug manually, lined and installed with hand pumps. In the study area, the average depth of HDWs is 10 metres though there are few wells that have depths of 3 metres and depths of more than 20 metres. The context of the study could be extended to similar low cost water supply technologies like manually drilled wells or on spot springs (spring development from seepage springs with yield ranging from 0.05 to 0.2 litres/s).
2. Piped water supply systems also called rural piped systems (RPSs). Water supply systems from groundwater sources (deep borehole, high yielding springs, perennial rivers, surface storages, etc.). The water from these sources is pumped, treated, stored and distributed to users (see Figures 5 and 6).

## MATERIALS AND METHODS

The study employed a combination of data collection methods at the local level, including the following:

1. Key informant interviews with local government officers, discussions with communities and field observation.
2. Meta-analysis of available data on water availability and access, prevalence of drought, rainfall pattern, type of water supply schemes and resources required for

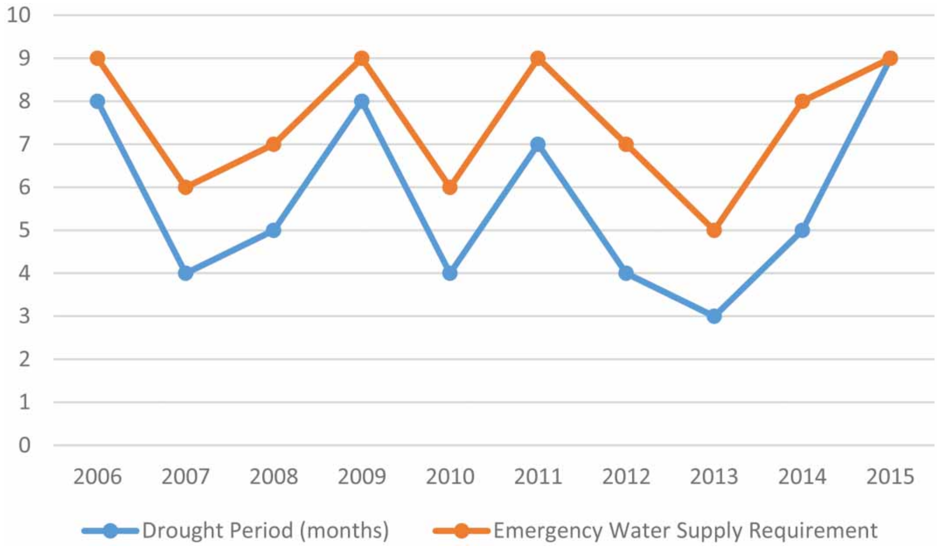


**Figure 4** | Emergency water supply (WS) requirement in the study area (months).

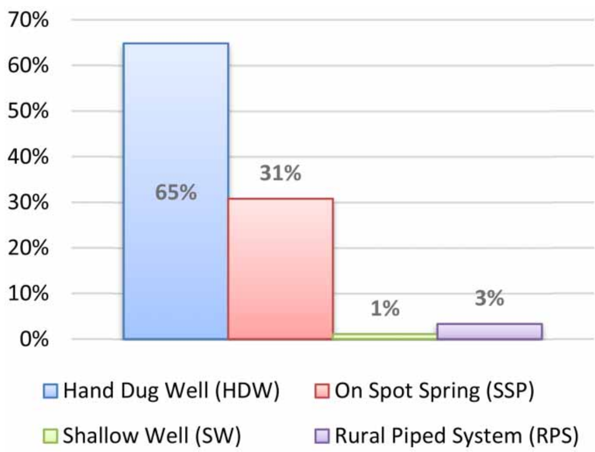


**Figure 5** | Types of water supply facilities: Goncha Siso Enebsie.

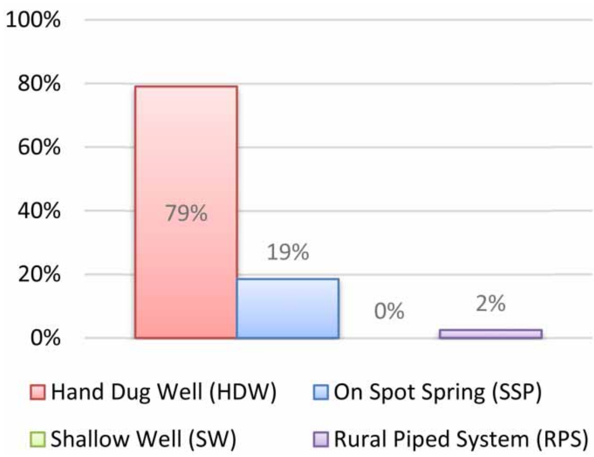


**Figure 6** | Types of water supply facilities: Enarj Enawga.

emergency response. The source of data for water availability and water supply sources is woreda water offices while the source of data for costs of emergency response is UNICEF. The analysis on the prevalence of drought and rainfall pattern is taken from previous studies.

The fundamental questions modelled were:

- What is the availability of water during a normal rainfall period and drought year from HDWs and RPSs considering a 10 year period (2006–2015)?
- What are the costs of emergency response during times of drought when there is no water from these sources?
- Are low cost technology options the best value for money in rural water supply programmes considering continuity of service including at times of drought emergency?
- What should be the public policy and strategy to improve resilience and reduce vulnerability during times of drought?

The prevalence of drought for the last 10 years (from 2006 to 2015) was analysed identifying periods of drought (indicated in months) and emergency response associated to these drought events. The total drought months in the life cycle of a point source (considered to be 10 years) are added up to obtain the total drought months in the life cycle of HDWs where emergency response is necessary. The cost of emergency response for these periods is calculated considering existing experience and cost for emergency response in Ethiopia.

Data on the type of water supply technologies, the water availability (continuity of service) during normal and drought periods is collected from the two district water offices. The data was further verified in the field by visiting water supply systems in sampled villages and carrying out discussions with communities. The current capital expenditure (CAPEX) was analysed and the cost of provision of emergency water supply (EMMEX) was evaluated based on the recent emergency response data from WASH cluster coordination and UNICEF WASH section (UNICEF 2016a).

The per capita cost and cost incurred for emergency response in the life cycle of the services (project design period) were evaluated considering all point sources and piped systems in the two woredas comprising a total of 242 water supply systems. Out of the 242 water supply systems, 207 are communal water supply systems and are considered for this study while the remaining 35 are private water supply systems.

Drought prevalence from 2006 to 2015 was analysed in order to ascertain the total duration of drought for the 10 year period (equivalent to the lifetime of a point source). Based on the number of months of water unavailability (total months during the project period), the cost of emergency intervention is calculated.

Life cycle costs are considered to be the full costs of delivering adequate water, to a specific population in a particular geographic area – not just for a few years but serving for the designed period.

Under this study life-cycle costing is divided into domains and for the case of this paper that include capital expenditure costs for fixed assets (CAPEX), emergency expenditure costs (EMMEX) and operation expenditure costs (OPEX) (Table 1).

The life cycle cost can be calculated using the formula CAPEX + EMMEX + OPEX/(Beneficiaries × DP) where beneficiaries are people using the water supply system and DP is the design period of the water supply system.

**Table 1** | Life cycle costing

| Life cycle cost domain | Description and example of domain |
|---|---|
| Capital expenditure costs for fixed assets (CAPEX) | Assets that include construction costs, supply and installation of electro-mechanical equipment and hydraulic systems. The cost includes contributions from communities in the form of labour, in kind (provision of construction materials and provision of storage facilities) |
| Emergency expenditure costs (EMMEX) | Cost of provision of water during drought when existing sources fail to provide water including water trucking, provision of water treatment chemicals, installation of water distribution systems (water tankers and water distribution points), supply of emergency water supply materials and arrangement for WASH emergency coordination and management |
| Operation expenditure costs (OPEX) | Cost of management and coordination of emergency response activities at national and regional levels. It includes cost of cluster coordination, technical staff at water distribution points, logistic support, real time monitoring of emergency response, management and others |

## RESULTS

Figure 9 shows EMMEX expenditures in the two woredas from 2006 to 2015 while Figures 7 and 8 show water supply types (%) and water availability during 2015/16 vs. normal years for the two woredas. Point sources (HDWs) provided water only for 9 months on average during a normal rainfall year and only for 3 months during the 2015/16 drought. The piped systems and shallow wells provided water throughout the year.

Drought is experienced regularly and during these periods emergency support is required. This study showed that a distinctive HDW is not providing water in an average of more than 55 months in a project period of 10 years. The emergency response during these periods is highly expensive and estimated to be USD 415,826. For communities living in

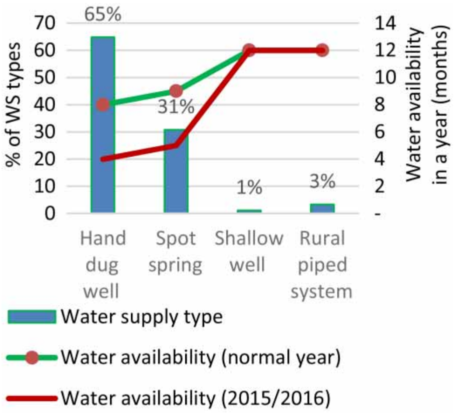


**Figure 7** | Water supply types (%) and water availability during 2015/16 vs. normal year in Goncha Siso woreda, Amhara Region.

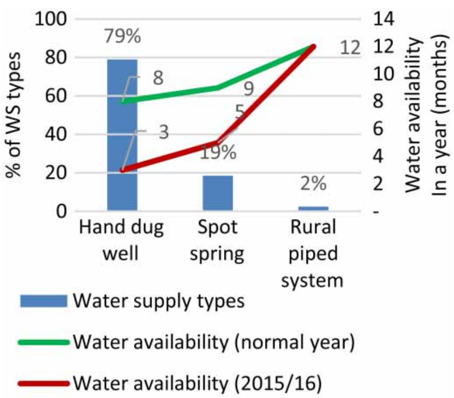


**Figure 8** | Water Supply types (%) and water availability during 2015/16 vs. normal year in Enarj Enawga woreda, Amhara Region.

emergency prone areas, the total CAPEX and emergency response cost for HDWs in a life cycle of 10 years is estimated to be USD 419,304. This amount is more than double the investment cost of a RPS that serves an average population of 3,000 and for a design period of 20 years. The CAPEX and emergency response cost for HDWs could be double this figure if we consider a design period of HDWs to be 20 years (instead of 10). The water supply source of piped systems are deep groundwater sources developed from perennial springs with yields of more than 1 litre/s or deep bore holes with a minimum yield of 2 litres/s. The average number of beneficiaries for a RPS is 3,000 people while for HDWs it is 250. Water distribution from RPSs is either from communal standpipes or connection to yards or plots. Connection to yards or plots reduces the time required for water collection, minimises the risk of microbial contamination and is the type of water source considered safely managed as per the SDG indicator for water. In the study area, communities using piped systems are not affected by drought even under the severe drought in 2015/2016 that affected almost all of the HDWs. Accordingly, emergency response to communities using piped systems is not required. Details of costs of emergency response are shown in Tables A1–A6 (see supplementary materials, available with the online version of this paper).

The study provided evidence that the cost of providing emergency water supply is very high to the extent that, during the life cycle of a HDW, the total capital cost of the well and the cost of emergency response through the project period (life cycle) is almost double the cost of piped systems. Properly designed and constructed RPSs have a longer service period and provide the additional amenity of being a source of water for water trucking to emergency affected areas.

Figure 9 shows that the life cycle cost for WS provision from HDWs serving an average population of 250 is about USD 419,304 while for RPSs serving an average population of 3,000 people the cost is USD 195,652. Therefore, the life cycle cost of HDWs is about double the life cycle cost of RPSs. It is also observed from the study that no cost is required for emergency response for piped systems as these systems were sustained through drought and continuously provided water.

In the case of average annual costs, HDWs are four times more expensive than RPSs (Figures 10 and 11). The service life (life cycle) for RPSs is twice as long as that of HDWs, contributing to annual cost effectiveness for RPSs.

The average annual per capita cost as seen in Figure 12 is significantly higher for HDWs than RPSs. This indicates that investing in RPSs for rural water supply programmes is more efficient in terms of cost, service and reliability than HDWs that could not provide water during drought periods and have a short life cycle. It can be noticed that investment in RPSs has a higher return in terms of cost effectiveness and quality of service than HDWs. Serving more than one village from one source (multi-village water supply system) is an added value of the piped systems that allow conveying water from an area where water is available to areas where there is no feasible water source in the village or within the vicinity.

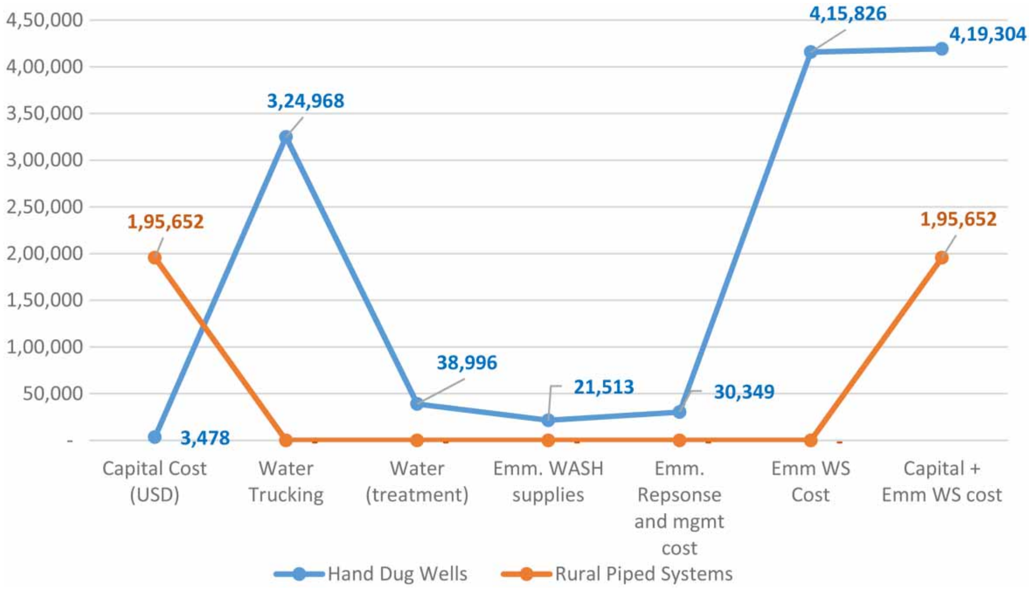


**Figure 9** | Detail life cycle cost for HDWs and RPSs (USD).

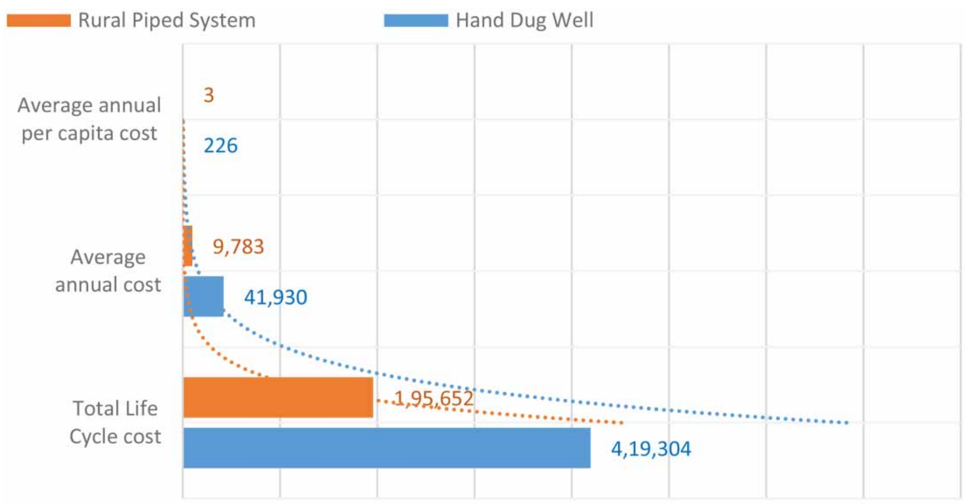


**Figure 10** | Per capita costs and life cycle cost for HDWs and RPSs (USD).

## DISCUSSION

The strategic concept of providing water supply using low technology options was considered to be the most appropriate in water supply programming in Ethiopia during the MDG period. The strategy allowed provision of basic water services with low per capita costs but without considering long-term effects on continuity of service and vulnerability to environmental hazards including rainfall variability and prevalence of drought.

Water supply planners and policy makers preferred low cost water supply options as a strategy to boost minimal water supply coverage in an attempt to obtain the global MDG targets. However, while low cost and low technology options are useful to increase access, they are observed to be unsustainable in extreme drought. This study showed the susceptibility of manually constructed dug wells to this

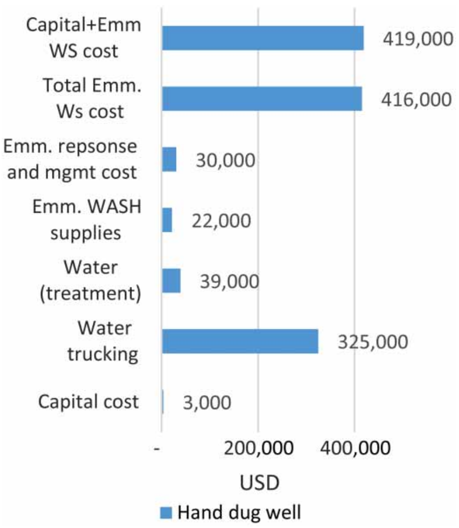


**Figure 11** | Life cycle cost for WS provision from HDWs (USD).

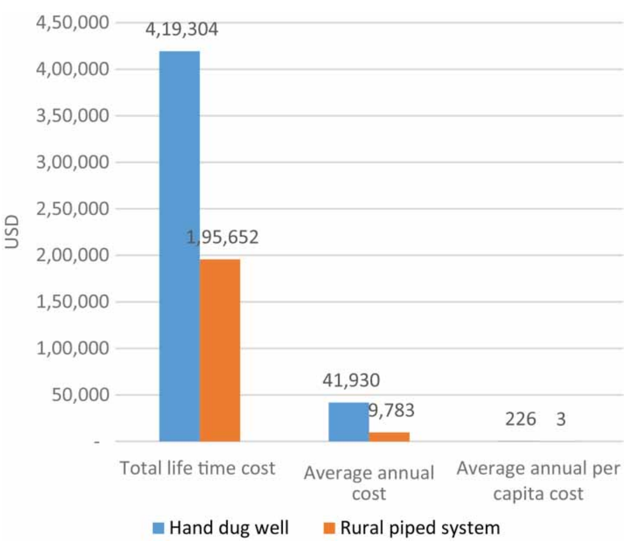


**Figure 12** | Life cycle and annual costs for water supply provision.

kind of extreme weather (droughts). Most of the wells do not provide water even during the driest period of a year with an average rainfall. Besides, consumption rates from these HDWs are smaller than the required per capita amount. The real time monitoring study conducted by UNICEF in specific drought-affected areas in the middle of the 2015/16 drought indicated that the daily per capita water consumption is less than 10 litres for 89.90% of the population (45.52% less than 5 litres per capita/day) while only 9.5% of the population are consuming more than 15 litres per capita/day (UNICEF 2016b).

Consideration of climate-related risks in current and future water supply programmes is necessary in order to mitigate risks associated with water insecurity. Besides, construction of low cost options in water supply programmes need only be considered cautiously alongside resilient water supply systems that withstand recurrent drought. Table A7 (available with the online version of this paper) shows that proposed drought risk management for rural water supply is necessary considering issues of resilient water supply options as perceived from this study.

## CONCLUSION

The SDGs pursue the ambition of universal access to *safely managed water supplies*. Evidence in this paper suggested that to maximise investments, wise technology selection is required in order to minimise potential life cycle costs. The study provided a comprehensive understanding of the life cycle cost implication of emergency response of water supply systems from HDWs when they failed to provide water due to the impact of drought. RPSs are usually constructed from water sources that are reliable (mostly from deep groundwater sources and perennial surface water sources like rivers) and are found to sustain supply during severe drought including the 2015/2016 drought. The conventional way of considering low technology options with the primary objective to boost water supply coverage is challenged by the prevalence of recurrent drought that resulted in drying of surface water sources and failure of shallow groundwater development systems. Water supply construction projects need to consider the possible risk of environmental calamities that result from recurrent drought. Such climate-impacted droughts are becoming more frequent in Ethiopia making communities highly vulnerable to water insecurity. Therefore, investments for water supply facilities must consider climate-related and other risks and emphasize resilient water supply systems that consider continuity of services even at times of hazards.

For areas where groundwater is not available, a source could be developed where it is feasible and the water conveyed to areas where groundwater development is either not feasible or is prohibitively expensive. Therefore focusing on only initial investment costs with the objective of boosting basic water supply coverage as the primary criterion to identify water technology options needs to be reconsidered. The study concluded that piped water supply systems with higher initial investment costs than HDWs are less expensive in terms of life cycle costs than point sources. With average annual costs of point sources four times more expensive than piped water supplies, this demonstrates the need to recognise resilient water supply systems in future water supply programming.

## DISCLAIMER

The views expressed in this paper are solely those of the authors and do not reflect the opinions of any organization or government.

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