



Management strategy for safe drinking water in developing countries – A case study for Assela, Ethiopia

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ABSTRACT

The study was focused to prepare a management strategy for improving the water supply and sanitation of the town Assela, Ethiopia. The data were gathered through questionnaires, laboratory experiments, and personal observations. 260 households were selected by using a stratified random sampling technique. Data analysis was completed using a statistical package for social science and the pressure head in the distribution system was analyzed using EPANET-2 software. The findings revealed that the average domestic water consumption was 12.8 L/ca.d, which only satisfied 64% of the minimum urban water consumption limit of 20 L/ca.d. About 15.8% of the analyzed nodes were supplied with water at a low-pressure head (<15 m). Most of the physicochemical parameters analyzed exhibited values within acceptable limits, except for residual chlorine. Regarding biological parameters, only 75% and 62.5% of water samples were within the acceptable limits for fecal coliforms and total coliforms, respectively. The sanitation level in the town was only assessed as 66.9%. A management strategy involving a two-phase implementation was suggested to improve treatment and disinfection; extend water supply network; augment water supply and increase all water usage above 20 L/ca.d by 2025 and to 30–60 L/ca.d range before 2035.

Keywords: Water scarcity; Safe drinking water; Water management; Developing countries

1. Introduction

Water is the indispensable ingredient for all forms of life on earth. It makes up the majority of the body weight and plays a crucial role in bodily functions such as flushing out waste materials from the body; regulating body temperature and helping the functions of vital organs including

the brain. Furthermore, it is essential for personal and community hygiene. Water also sustains essential functions of community life, such as agricultural, industrial, and even recreational activities. Therefore, depending on the socio-economic and cultural level of the population, the quest for water is quite dynamic and escalates from the bare minimum level safe drinking water to satisfactory hygiene; recreation;

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provisions for the water demand of agriculture and industry, which are all satisfied with different quality expectations and requirements.

Even though 70% of the earth's surface is covered with water, only 1% is available for human consumption that is unevenly distributed over spaces and time. While uneven spatial distribution of water cause in some regions catastrophic floods, many vast areas suffer long periods of drought, water scarcity, and extreme aridity [1]. According to United Nations Development Programme, 780 millions people in 43 countries live currently with water scarcity; this is especially true for Sub-Saharan Africa which houses approximately 25% of the global population that faces water scarcity [2].

The scarcity of water, unfortunately, forces people around the world to use unsafe water for drinking and other domestic uses [3]. Like water, sanitation is also a basic need and a way to ensure acceptable health conditions for populations. Parallel to water, lack of proper sanitation is a serious health risk and a cause of offense to human dignity [4,5]. World Health Organization (WHO) stated that people are forced to defecate in open fields, in rivers or near areas where children play and food is prepared because they do not have access to improved sanitation [6].

In Ethiopia, access to proper sanitation and water is limited due to physical and socio-economic constraints. The water supply service level, in terms of coverage, quantity, and quality, is very low due to factors such as topography, sources of water distribution systems and lack proper treatment systems [1]. According to the WHO/UNICEF, Joint Monitoring Program [7] the average national water supply coverage of Ethiopia was estimated as 57% (97% in urban areas and 42% in rural areas) where the national sanitation coverage was assessed as 26.3% [8]. A study conducted at Yirgalem town showed that water supply service could not meet the water demands of the town with existing capacity; the water supply was 1,430 m³/d while the demand was estimated about 3,063 m³/d, showing that the total abstracted water from the three sources covered only 46% of the water requirement of the town [9]. The study also projected that the total water demand of the town will increase to 5,535.75 m³/d over the 20 years. A similar study conducted at Ayana town showed that the quantity of water supplied and actual demand was 224.31 and 619 m³/d, respectively. The water supply coverage of the town was only 56.4% and per capita, water use was 9.76 L/ca.d, which was lower than the minimum requirements of basic consumption. The study indicated that the water supply was unreliable; inadequate; the water tariff was too high and could not be afforded; understaffing and monitoring were a serious problem in the entire town and 87% of the respondents were unsatisfied with the water supply service [10].

Regarding the water quality of the country, Regassa [10] reported a strong acidic character with a pH value ranging from 4.63 to 5.46, which is not acceptable for drinking purposes based on the WHO standard [11]. Assessment of bacteriological and physicochemical qualities of urban water source and tap water distribution system of Ziway town [12], Bahir Dar town [13], Nazareth town [14] showed bacterial contaminations in terms of indicator bacteria such as total coliforms and fecal coliforms. A similar study conducted

in Dire Dawa town demonstrated that about 83.34% of the water sample was positive for indicator bacteria. The bacteriological quality in most sites was in the dangerous range of pollution for drinking especially by fecal coliforms (11–100 CFU/100mL).

In this context, this study was carried out for the town of Assela, quite poorly equipped to serve adequate and safe water to its inhabitants. The source of the existing water supply of Assela town is the Ashebeke river, which is highly exposed to polluted runoff water from an agricultural field in the upper stream. The sanitation situation of the town is also in poor condition. The population in Assela was forced to live with frequent and regular disruption of water supply for days. Therefore, the main objective of this study was to assess the existing situation on water supply and sanitation in the town to design a strategy that could be translated into an action plan, to increase the water supply to an acceptable level and to safeguard necessary water quality for sanitation. The outcome of the study is expected to set a typical example for many towns in Ethiopia and developing countries.

2. Materials and methods

2.1. Description of study area

Assela town is located in the southeast of the country in the Oromia Regional State of Arsi Zone. It is situated at an average elevation of 2,300 m and located between the latitude of 7°57' N and 39°07'30" E as shown in Fig. 1. Assela town has a subtropical highland climate. The average annual temperature of the study area is 17°C, and the average annual precipitation is 832 mm.

The town's only source of drinking water is the Ashebeke river with a maximum yield of 7,200 m³/d. This system was designed to serve only 68,436 people till to 2009, but it is still not upgraded. According to the Central Statistics Agency (CSA) [16], the population of the town was determined as 99,570. The existing treatment plant is a rapid sand filter having a maximum capacity of 300 m³/h. Currently, water is supplied to people through four modes of services: House connection (HC), own yard connection (OYC), shared yard connection (SYC) and public tap. In the case of HC (also called an in-house connection), the users have a piped water connection located inside their house and have a connection to the main distribution system. OYC users do only have access to water connections at a certain place in their yard, the piping is not inside the building. SYC represents a similar mode to own yard where the water is shared by two or more households. Public tap is the main water source for households where the connection is not existing. This mode of water supply is especially provided in low-income areas where the households cannot afford the private connection. Remarkably, approximately only 5% of the households have been equipped with a water supply system, most of the households have no direct connections (21% public taps, 36% shared yard, and 37% OYCs).

2.2. Data collection and analysis

The study used household survey questionnaires, laboratory experiments, and personal observations to collect the necessary data.

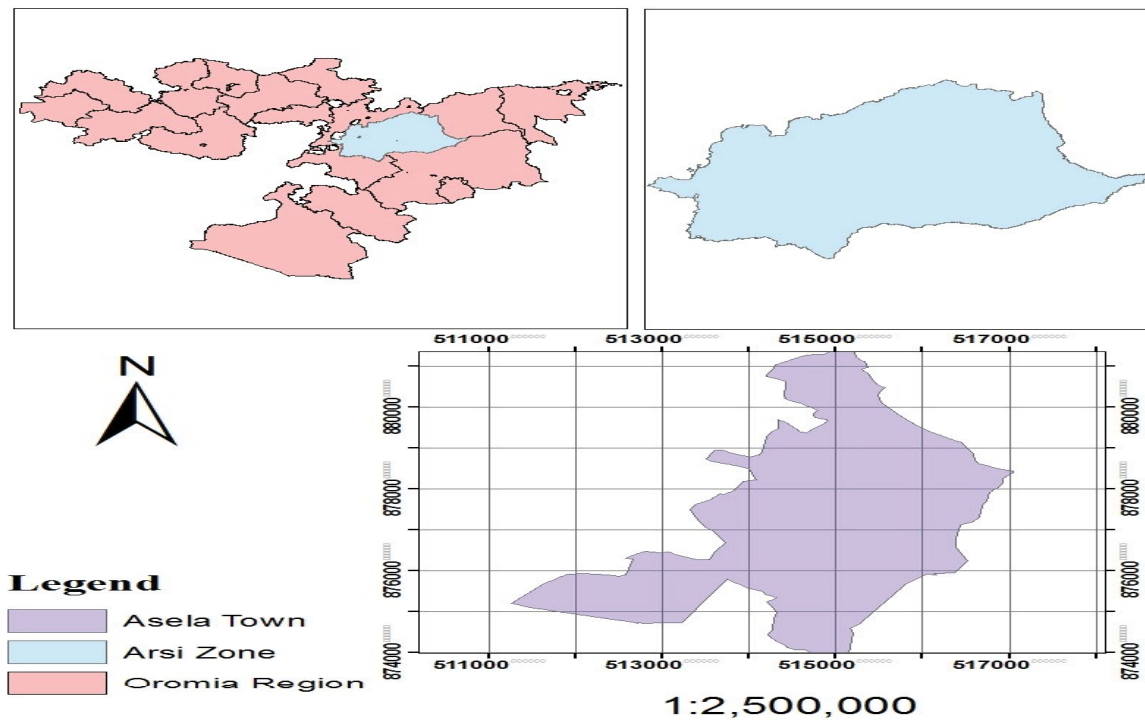


Fig. 1. Map of the study area.

The sample size of the respondents was determined by using the following Kosecoff and Fink [17] formula (Eq. (1)).

$$n = \frac{(Z_{\alpha/2})^2 p(1-p)}{e^2} \quad (1)$$

where n is the sample size, p is the proportion of water supply coverage of the area, $Z_{\alpha/2}$ is at 95% confidence level corresponds to the value 1.96 and e is the proportion of sampling error tolerated at 5%.

Within this framework, 246 households were selected, this value was increased up to 260 by considering 5% of contingency for non-respondent. The data obtained from randomly selected respondents were analyzed using the statistical package for social science.

The magnitude of sampling was determined based on Ethiopian standard [18]. The standard indicates that at least one sample is required for 5,000 people if the total population of the area lies between 5,000–100,000. Considering the population of the town as 99,570, a total number of 20 triplicate samples were decided to be taken from different sampling points: one from the inlet and outlet of the treatment plant, one from storage reservoir, eight samples from different points of the pipeline, eight samples from the household container (HHC) and one sample from the public tap. The procedure for sampling was applied as described in Standard Methods [19].

The samples were analysed for temperature, electrical conductivity (EC), turbidity, pH, free chlorine residual (FCR), total hardness (TH), total dissolved solids (TDS), nitrate, iron, manganese, total coliforms, and fecal coliforms following Standard Methods [19]. A comparative evaluation was

conducted based on the WHO guidelines and the Ethiopian standards for drinking water quality.

2.3. Population projection

The projection of the population was estimated by using the geometric increase method [20]. The following equation was used to estimate the size of the population:

$$P_n = P_0 \left(1 + \frac{r}{100}\right)^n \quad (2)$$

where P_0 = initial known population; P_n = population after n years; r = geometric growth rate; n = number of years of the concerned period.

In this study, the average yearly growth rate was assessed as 2.0 using the data created by CSA of Ethiopia for administrative regional states in 2007 [15]. Previous population censuses were used to make a reliable projection for future years.

2.4. Analysis of water distribution network

The hydraulic behavior of the water distribution network was analyzed by using computer software called EPANET 2.0. The size, type, length, and age of pipes were inserted into the software as input data together with the global positioning system coordinates of reservoirs and junctions. The output of the water model software reflected the essential hydraulic components, such as pressure heads at the junctions, head losses, velocities, and flowrates of the pipes. Hazen–Williams equation was used to calculate the heat losses.

3. Results and discussion

3.1. Water supply analysis

3.1.1. Water supply

The surveys conducted on 260 randomly selected households demonstrated that domestic water consumption was limited to 12.8 L/ca.d in Assela town. According to Ethiopian standards [21], the quantity of domestic water in urban areas of a developing country has to be a minimum of 20 L/ca.d. This indicates that the water supplied only satisfies 64% of the minimum urban water consumption limit without considering the distance traveled to fetch water. This strong deficit is an unavoidable result of the population increase in town and also of not having an upgraded network. The survey results also revealed that the average quantity of water necessitated by the respondents was expressed as 30.2 L/ca.d, a value approximately 2.5 times higher than the supplied one. This is an indication that the residents have access to only 42.4% of the potable water requirement. The water accessibility was defined as the major indicator of hygiene sanitation especially for medium towns like Assela [22].

3.1.2. Water loss

Water loss is often referred to the difference between the water produced and the water billed or consumed [23]. The loss mostly arises from the aging networks and leaking pipes. The data obtained from the Assela water treatment plant proved that the current average amount of water produced was 4,743m³/d, which was 57.5% of the maximum plant capacity (300m³/h). Fig. 2 demonstrates the balance between the volume of water supplied from the water treatment plant and consumed by the customers for seven consecutive years. The figure indicates that the loss of water increased from 15% to 29% within the years. It has been reported that the water currently reached the consumers was accounted for 74% of the total water produced [24]. A loss of 25% is recognized as acceptable within the concept of unavoidable annual real losses for South Africa [25].

3.1.3. Water supply interruptions

One of the main problems of water management in developing countries is the interruptions to water supply. The

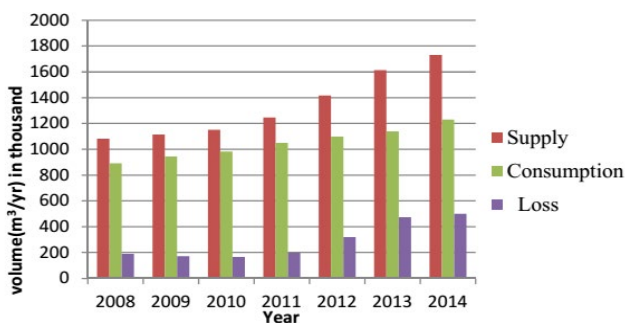


Fig. 2. Water production, consumption, and loss for the years 2008–2014.

evaluation of the surveys outlined that 29.6% of the respondents suffered on the water interruptions two-three times in a week, 39.1% four to five times per week and 19.4% once a week. Only 11.9% of respondents were supplied without interruption. This indicates that there is no regular rotation or shift for water interruption; some residents in some areas receive uninterrupted water supply, whereas some are affected by water scarcity days long. As a solution to the water shortage, 65% of the citizens declared the water vendors, 30% of the neighboring houses and only 5% the pond/reservoirs as alternative water sources. Vendors are the most expensive water source since they charge several times higher than the regular price. People are exposed to pay extra costs to cope with the frequent and long-time water shortage.

3.2. Water distribution network analysis

The distribution network was analyzed by its pressure heads using 38 (junctions) nodes and 39 pipes as illustrated in Fig. 3. The optimum range of operating pressure heads for water pipelines is to be maintained between 15–70 m for safe, reliable and economical operation. The hydraulic analysis by Epanet outlined that the optimum range of operating pressure head was only achieved in 52.6% of the area. The pressure head at 15.8% of the identified nodes was determined below 15 m, whereas 31.6% of the nodes were operated at a level above 70 m. The conditions in the network were assessed in a period representing the average water consumption. The peak hours and off-hours were exempted from the evaluation.

Low-pressure head systems directly affect the satisfaction of the consumers due to the lower amount of water supplied, and make the system more vulnerable to negative pressure heads and cause possible intrusion of contaminants [26,27]. High-pressure head systems cause pipe burst and increase energy use. It is very important to sustain the optimum pressure head in the pipes for efficient operation. The velocity is also an important operational parameter in the distribution network. The analysis indicated that the velocity in the major parts was below 0.3 m/s resulting in sediment accumulation in the pipes [28].

3.3. Water quality analysis

Samples collected from 20 different points as illustrated in Fig. 4 were analyzed for physicochemical and fecal and total coliforms. The qualities of pipelines and HHCs were represented by the average values of 8 different samples taken. The results were evaluated regarding WHO [11] and Ethiopian [18] drinking water regulations.

The physicochemical parameters analyzed to identify the water quality at different points of the town demonstrated that all parameters except FCR and temperature were in compliance with both drinking water limits (Table 1). The results showed that the current treatment plant was efficient to reduce the turbidity from 18 NTU at the inlet down to 4.7 NTU in the effluent. The values of the turbidity in the pipe and HHC indicated that the water was not infected from an external pollutant on the way to the ultimate consumer. The same tendency could also be mentioned for EC, sulfate, and TH.

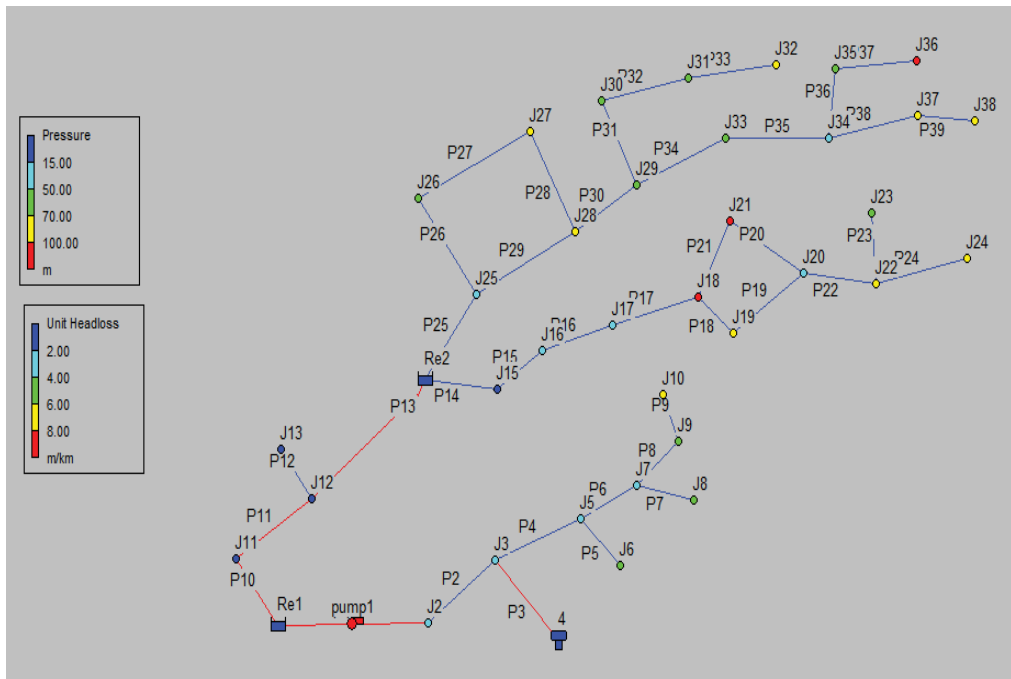


Fig. 3. Pressure heads in water distribution network.

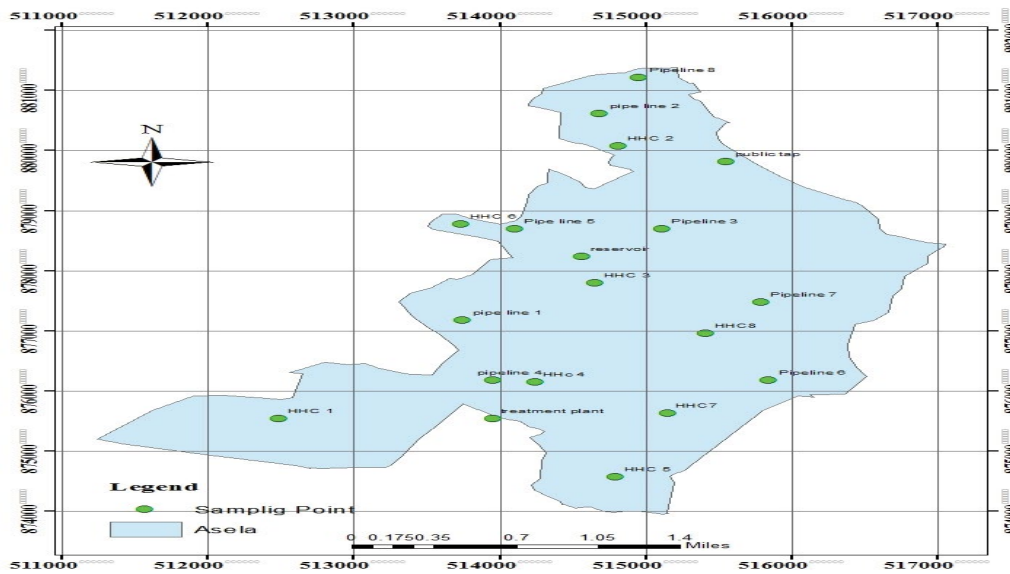


Fig. 4. Water quality sampling points.

It should be noted that FRC was at a suitable level in the effluent of the treatment plant, but was partly decreased in the reservoir and mostly reduced in the pipes and depleted in the HHCs. This could be explained by a possible existence of ammonia nitrogen in the water depleting chlorine or the turbidity level at all sampling points more than 0.5 NTU or bacteriological pollution.

A value of 0.5 NTU is recommended for effective disinfection [29]. It is evident from Table 1 that at all water sampling points, the turbidity in water was measured more than the desirable limit for effective disinfection of 0.5 NTU.

Temperature as one of the main parameters of water quality was not in compliance with the restrictions defined. A study conducted by Mengestayhu [30] showed that only one sample out of 35 tap water samples was within the acceptable limits for temperature. Higher temperatures may cause faster regrowth of coliforms [31] and higher disinfectant requirement [11,23].

Fecal (FC) and total coliforms (TC) were considered as the basic parameters within the frame of biological quality analysis. The water should be free of bacterial contaminants for safe drinking. The analysis on the water source indicated

Table 1
Characteristics of water

Sampling points	pH	Turbidity (NTU)	EC (µs/cm)	Sulfate mg/L	TDS mg/L	TH mg/L	Iron mg/L	Mn ²⁺ mg/L	Nitrate mg/L	FRC mg/L	Temp. (°C)	FC CFU/100 mL	TC CFU/100 mL
WHO	6.5–8.5	5	1,000	250	1,000	300	0.3	0.1	50	0.2–0.5	<15	0	0
ES	6.5–8.5	7	–	250	1,776	300	0.3	0.8	50	0.2–0.5	<15	0	0
Inlet	7.8	18	485	200	354	2.79	0.3	0.02	6.4	0.0	22	5.4	7.8
Outlet	6.7	4.7	221	27	114.4	2.84	0.2	0.03	5.5	0.3	21	0	0
Reservoir	6.6	4.8	171	24	109.4	2.7	0.04	0.04	5.8	0.2	17.5	0	0
Pipe (avg.)	6.6	4.36	165.3	21.7	107.6	2.68	0.21	0.03	5.6	0.02	16.1	0.3	0.45
HHC (avg)	6.7	4.41	183.6	21.75	117.5	2.65	0.19	0.03	3.1	0.0	16.8	0.4	0.8
Public tap	6.6	4.6	152	22	97	2.02	0.15	0.03	5.2	0.0	17	0	0

fecal coliforms content of 5.4 CFU/100 mL and total coliforms of 7.8 CFU/100 mL, which revealed that the source was infected by fecal pollution. 8 samples taken from different points of the pipes had a different scheme, the fecal pollution was confirmed only by two samples, whereas total coliforms were detected in three samples. Moreover, in the HHCs, only 5 containers (62.5%) and only 4 containers (50%) of 8 were free of fecal coliforms and total coliforms, respectively. Fortunately, the public tap was free of coliforms. A study conducted by Mengestayhu [30] at Addis Ababa exposed that only a few (17.1% and 31.4%) out of 35 pipeline water samples were within the acceptable limit of WHO and national standard for TC and FC counts, respectively. The contamination in the HHCs arose mainly from the poor sanitation and poor management of the network.

3.4. Population and water demand projections

Using the increasing trend in the previous years, the current population of 100,000 is expected to be around 115,000 in 2025 with an increased rate of 2% and 133,000 in 2035 by assuming a rate of 1.5% between 2025 and 2035. The current population is served with a limited water supply of 13 L/ca.d.

Within the concept of sustainable water management first, the distribution of the population served by direct connection as described in Department of Health [32] and secondly, the reel water demand to satisfy the human needs were increased considering the socio-economic standards of the town and the master plan for Assela town [33]. The estimated demands are shown in Table 2 together with the suggested values developed by the Ethiopian Ministry of Water Resources (MoWR).

- The projection given in Table 2 outlines that the approach to raising the water utilization rate complies with the strategy taken by the MoWR. It should be noted that the projection in water utilization was arranged in a more conservative way to assure the applicability of the proposed management strategy to meet the basic water needs of people living in Assela town. The values gathered for Assela will be used to define a management strategy where the right combination of supply-based and demand-based measures are determined.

4. Management strategy

The water situation in the Ethiopian town Assela, as described and evaluated in this study, describes a level quite

Table 2
Water utilization projections by mode of services

Mode of service	Water demand (L/ca.d)		
	2025	2035	(MoWR)
House connection (HC)	40	60	70
Own yard connection own (OYC)	30	40	40
Shared yard connection (SYC)	25	30	30
Public tap users (PTU)	20	–	25

Table 3
Basic information related to two-phase improvement strategy

Period	Current (this study)				2025				2035			
	Population		Water supply		Population		Water supply		Population		Water supply	
	%	ca	L/ca.d	m ³ /d	%	ca	L/ca.d	m ³ /d	%	ca	L/ca.d	m ³ /d
House connection	4.4	4,400	ND ^a	ND	9	10,350	40	415	25	33,250	60	1,995
Yard connection (own)	38	38,000	ND	ND	40	46,000	30	1,380	37	49,210	40	1,970
Yard connection (shared)	36	36,000	ND	ND	41	47,150	25	1,180	38	50,540	30	1,520
Public tap users	21.6	21,600	ND	ND	10	11,500	20	230	–	–	–	–
Total		100,000	12.8 ^b	1,300		115,000		3,205		133,000		5,485

^aND: not determined;

^baverage.

unacceptable, even in terms of minimum human requirements for decent hygiene conditions: (i) The town currently houses a sizable population of approximately 100,000 people; (ii) the average quantity of water effectively reaching people is below 13 L/ca.d, lower than the 20L/ca.d threshold prescribed by WHO; (iii) the river water is treated by a rapid sand filter and chlorination system with presumably a nominal capacity of more than 6,000 m³/d, but delivering only 1,300 m³/d; the water distribution system can only secure intermittent supply, mostly with low-pressure head (iv) only 4.4% of the population have house-connection to the water supply network, and (v) the quality of water reaching people is low, occasionally with no residual chlorine and coliform levels exceeding safe consumption standards.

Defining a workable water management plan is beyond the scope of this study. However, the collected information enables to suggest the following basic principles to be incorporated into a comprehensive management plan that needs to be undertaken shortly. First of all, it should be noted that a two-phase improvement strategy should be envisaged based on the socio-economic conditions of the country. It is suggested that the first phase should target the year 2025 and the second phase the year 2035. The plan should essentially envisage to (i) improve treatment and disinfection, (ii) upgrade and expand the water distribution network, (iii) augment the treated water supply, way beyond the 20 L/ca.d threshold, which would ensure safe sanitation conditions.

Extrapolation of the existing trend at a population increase of 2% yields a population forecast of 115,000 for 2025 and of 1.5% a population of 133,000 for 2035. Basic information defining goals and extent of the proposed improvement strategy are summarized for each phase in Table 3.

They may be further clarified as follows:

4.1. Improvement and expansion of treatment facilities

While the concept of direct sand filtration and chlorination may be acceptable, the existing system is long outdated; despite its nominal capacity of 270 m³/h, that is, more than 6,000 m³/d, it can barely deliver around 1,300 m³/d intermittently. Upgrading and expansion of the system should be considered on a modular basis, each module with an

effective working capacity of 1,500 m³/d and it should start immediately with the first module including a full chlorination unit equipped with appropriate dosing system; a storage unit with at least the same capacity and pumping that would deliver pressured water to the network.

4.2. Upgrading and extension of the water distribution network

The major goals of the improvement strategy are suggested as the increase of HCs to at least 9% of the population by 2025 and 25% by 2035. This would also involve decreasing public tap connections to 10% of the population in the first phase and terminate this type of water supply by 2035. This would entail the extension of the water distribution network and improve the piping quality, where necessary to control water losses to the extent possible.

4.3. Augmentation of the treated water supply

The major objective to be implemented in the first phase would be to increase the unit water utilization rate above the level of 20 L/ca.d, to ensure a minimum level of hygiene for public tap users together with a gradual increase of water consumption up to 40 L/ca.d. Consequently, the minimum level of properly treated water supply should be adjusted to 3,205m³/d. In the second phase, the recommended water supply should meet a higher unit consumption demand in the range of 30–60 L/ca.d., corresponding to a daily water supply of 5,485m³/d. The modular structure of the treatment scheme should also be increased to meet this demand.

5. Conclusions

This study provided conclusive proof that the quantity of water that could be supplied to the town Assela in Ethiopia was far below the acceptable level of personal hygiene.

Despite socio-economic constraints, the basic principles of an improvement strategy were formulated to implement a two-phase action plan targeting the years 2025 and 2035. Within the context of this action plan, new sources should be developed with compatible treatment schemes and reliable infrastructure that would increase the quantity and quality

of water supply first above 20 L/ca.d and then to the range of 30–60 L/ca.d.

It is believed that the suggested improvement strategy for water management will set a good example for all residential areas in similar situation in developing countries.

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