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Technical Note

Analyzing the Sustainability of Urban Water Supply and Distribution System; In Case of Assosa Town Water Supply and Distribution System, Benishangul Gumuz National Regional State, Western Ethiopia

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ABSTRACT

The main objective of the study is to analysis sustainability of water supply and distribution system of Asossa town. While conducting this research, both primary and secondary data were collected and software such as water GEMSV8i, ArcGIS version10.4.1 and GPS Garmin72 were used. The water supply source of the study area yields 46.1 l/s but only 23.6 l/s of water used. The simulated result of extended period simulation showed that the performance of hydraulic parameters were pressure 21.05 % for pressure value <15 m, 72.8 % for pressure value 15-60 m and 6.15 % for pressure value >60 m head and the velocity of pipe flow showed that 84.86 % for velocity <0.6 m/s, 15.14 % for velocity range 0.6-2 m/s. Based on the simulated result, reliability value 0.728 and 0.151, vulnerability value 0.251 and 0.538 and resiliency value 0.322 and 0.1 were obtained for both pressure and velocity, respectively. The overall sustainability index was 0.375 but 0.19 for velocity and 0.559 for pressure. Therefore, sustainability of existing water supply and distribution system of Assosa town is not sustainable. It is mandatory to redesign the Assosa town water supply and distribution system in order to make it sustainable.

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INTRODUCTION

Water is the precious gift of nature, the source of prosperity, most crucial for sustaining life, basic to most economic activities and its role in human survival and health is well known [1]. The adequate provision of urban services, and in particular, three water related services water supply, sanitation provision and drainage are vital in the quest to eradicate poverty and ultimately provide the environment for sustainable development [2]. How well a water supply and distribution system can satisfy its diverse objectives can be determined by evaluation of its functional performance [3]. With increasing global change pressures coupled with existing un-sustainability factors and risks inherent to conventional urban water management, cities of the future will experience difficulties in efficiently managing scarcer and less reliable water resources. In order to meet the future challenges, there needs to be a shift in the way we manage urban water systems [4].

The sustainability of water supply projects and the benefits they deliver are some of the overriding concerns of the water sector [5]. In many developing countries, there are serious constraints in meeting the challenge to provide adequate water sustainably for all urban residents in Ethiopia [6]. The existing water supply and distribution system of Assosa town was established for an estimated population of 19,000. But the current population were 24,214; it was served beyond the life and low coverage in the town.

MATERIALS AND METHODS

Description of study area

Assosa is located at 670 km west of Addis Ababa, capital city of Ethiopia, between 667115.24 m and 671674.44 m Easting (UTM) and 1111251.36 m and 1116893.86 m Northing (UTM), with elevation 1552 m amsl. The average annual rainfall of Assosa is 1172 mm and annually average, maximum and minimum temperature of the town varies between 22.7 °C - 24.5 °C, 24.3 °C-33.9 °C and 14.6 °C 17.8 °C, respectively. The major economic activities are mainly related to selling and buying agricultural products, retail trade of consumable goods, hotel activities and gold mining. Based on Central Statistical Agency of Ethiopia (CSA, 2007) reported [*catalog.ihsn.org › Home › Central Data Catalog*] the population number of the Assosa town is 24214. The town receives its water supply from five ground water borehole.

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The annual water production in 2017 was 846111 m^3 as recorded by water meters at source out let. The storage facilities used by the town have three concrete services tanks. Two tanks were located outside the town in south direction at a hill area (Enze Mountain) within same place while one tank was located in north direction. Figure 1 illustrates the map of study area for the present research.

Study design and period

This study was done by both descriptive and experimental study design. A study was describe deeply about the sustainability of existing water supply and distribution network and experimentally redesign water supply distribution network by using software package WaterGEMS V8i. Data collection processes were carried out within two months (June and July 2018), while the collected data were analyzed from August up to September 2018.

Data collection process

a) Primary data collection

To conduct the study primary data collection processes were conducted by both observation and field survey. Observations of the study area, location of leaked pipes and coverage area of existing distribution networks. Data from field survey such as Universal Transvers Mercator (UTM) locations of borehole, storage tank, junction and valves have been collected by using Geographical Positioning System (GPS Garmin 72).

b) Secondary data collection

Secondary data have been collected from the responsible organization like Benishangul Gumuz Water and Energy office, Oromiya Water Works Design and Supervision Enterprise, Assosa town water supply and sewerage authority and Assosa town municipality. Bile data has been collected from Water Supply and sewerage authority and aggregated

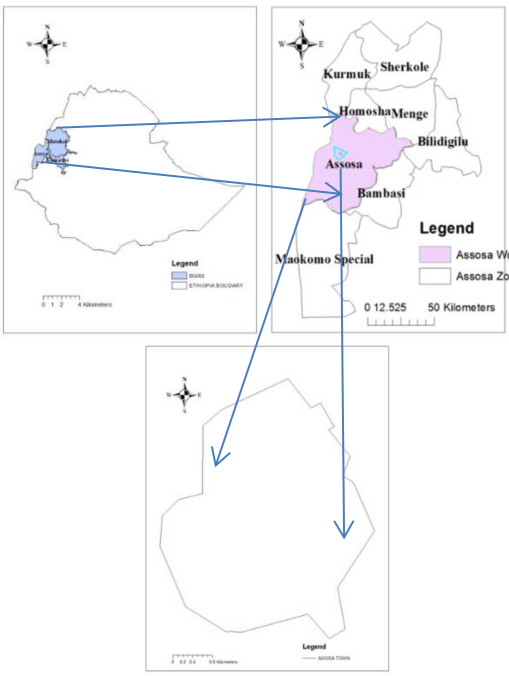

Figure 1. Map of the study area

for the year 2017. The yields of each borehole have been collected from Benishangul Gumuz Water and Energy office. The town master plan was taken from town municipality office. The town water supply data such as pipe length, diameter, material types, reservoir, and tank section were collected from the town water supply and sewerage authority. For analysis of water demand of study area the standard were based on the Federal Democratic Republic of Ethiopia Ministry of Water Resources and Energy 2006 report and Oromiya Water Works Design and Supervision Enterprise 2010 report [6].

Materials

a) Tools used

GPS Garmin72 tool was used to collect the required elevation data, Northing and Easting of junction, tank, pump and air release valve.

b) Hydraulic model: WaterGEMS V8i

Design of distribution network for continuous water supply can be easily achieved with the help of software WaterGEMS V8i, which was used for water distribution modelling and management [7]. For this study, the design methodology adapted to analysis sustainability of distribution network water supply system software waterGEMS V8i has been used.

c) Additional software used

Microsoft Excel 2010 sheet was used to organize data, to forecast population and asses water demand. Also the reliability, vulnerability and resiliency of water supply and distribution system were analysed using Microsoft Excel 2010 based on result of WaterGEMS V8i software package.

Data processing and analysis

The methods of data analysis carried out in two ways. The first method was by comparisons of existing water supply with design period water demand, water demand assessment were based on Oromiya Water Works Design and Supervision Enterprises. The other method was based on technical parameter like nodal pressure and velocity parameters determination by using WaterGEMS V8i software. The standard values of nodal pressure and velocity were identified. The values which have been under standard values (15 - 60 mH_2O for pressure and 0.6 – 2 m/s for velocity) were taken as satisfactory and below and above standard values were taken as unsatisfactory. In order to determine the sustainability index (SI) for the water supply, reliability, resiliency, and vulnerability performance indicator have been selected.

a) Population forecasting

For fast growing city geometric method of population forecasting is preferably used [8]. According to Armstrong [9] geometrical population forecasting method is expressed as follows:

$$P_n = P_O * (1 + r)^n \qquad (1)$$

where,

P_n = population at year n;

P_O = base year population;

r = population growth rate; and

n = projection year.

b) Domestic water demand
Domestic per capita water demand was estimated taking into consideration of population number of design period and category of the town, expected increase in per capita consumption and population of users with time and domestic water consumption variation based on the mode of service connections and based on litter per capita per day consumption of service connection taken from Ministry of Water and Energy (MoWE) [10].

c) Non-domestic water demand
14 % of total domestic water demand was used for the analysis of public or institutional water demand. 16 % of the total domestic water demand was used for the determination of commercial water demand. Based on the number of livestock present in the study area the amount of water required for livestock were 5 % of domestic water demands [11].

Normally it is mandatory industrial area can supply water by them, but there is small industrial area like poultry, by assumption 8 % of domestic water demand was used for determination of industrial water demand. 12 % of total water demand was used required for fire fighting area. 25 % of total water demand was used for projection of unaccounted for water [11].

d) Total water demand
This refers to the total water demand required for the study area. The analysis of total water demand was done by summing up of all domestic, non-domestic water demand and unaccounted for water.

e) Modelling process
Hydraulic models are often used to validate the design of water distribution system (WDS) [12]. The modelling was performed using the following steps:
1. Input data arrangement and checked;
2. Initial setup (the unit was set to SI unit);
3. Network schematic (connect junction and pump by pipe);
4. Data entering model builder and flex table;
5. Nodal demand calculation;
6. Validate and run process; and
7. Sustainability analysis based on result.

f) Sustainability index calculation
A sustainability index (SI) is a term that indicates the performance of a water system with respect to predetermined thresholds of a satisfactory state [13].

Mathematically the satisfactory and unsatisfactory states for velocity and nodal pressures scored 1 for satisfactory and 0 for unsatisfactory conditions.

P_j ; t = unsatisfactory (o) P_j ; t < P_{min} or Pj ; t > P_{max}
Satisfactory (1) P_j ; t ≥ P_{min} and Pj ; t ≤ P_{max}

where;
P_j, t is the pressure at node j in at time t;
P_{min} is the minimum pressure; and
P_{max} is the maximum pressure. For velocity the same formula was used by substituting velocity in pressure in the formula.

The sustainability index (SI) is a weighted combination of reliability, resiliency, and vulnerability which may change over time and space [13]. The following definitions of reliability, resiliency, and vulnerability follow the work of Hashimoto and Stendinger [14].

Reliability (REL) is the probability that the WDS is in a satisfactory state defined as follows:

$$REL_K = \frac{times\ satisfactory\ occurs}{total\ of\ time\ steps} \quad (2)$$

where k refers to pressure or velocity.

Resiliency (RES) represents how fast the system recovers from a failure defined as follows**:**

$$RES_K = \frac{times\ of\ satisfactory\ follows\ unsatisfactory}{total\ of\ times\ unsatisfactory\ occurs} \quad (3)$$

Vulnerability (VUL) is the magnitude or duration of an unacceptable state of WDS in a certain time scale. Hashimoto and Stendinger [14] stated that the vulnerability could be measured by dividing the cumulative extent of unsatisfactory values to the sum of all values in the simulation period. In this study, vulnerability is defined as follows:

$$VUL_K = \frac{\sum unsatisfactory\ values}{\sum all\ values} \quad (4)$$

According to Sandoval et al. [15] Sustainability index then can be calculated by the following formula:

$$SI = [REL \times RES \times (1 - VUL)]^{1/3} \quad (5)$$

The main feature of the SI is that it ranges from 0 (i.e. the lowest degree of sustainability) to 1 (highest degree of sustainability). Another property is that if any one of the performance criteria is zero then the overall SI will be zero.

RESULTS AND DISCUSSIONS

Population forecasting

Table 1 summarizes geometrically population projection of the study area up to design period (2035). By using geometric population forecasting methods the population number of Assosa town at 2035 is 71814.

Water demand assessment

a) Domestic water demand projection
Domestic water demand is the daily water requirement for use by human being for different domestic purposes like drinking, cooking, bathing, gardening, etc. According to Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub-sector [16] report the towns and cities of Ethiopia were categorized based on population number for effective design of water supply distribution system. As which is discussed in Table 1 the design period population of Assosa town were 71814, which has been categorized under catogry-3. Based on the category the town which was tried to described in the above, the models and levels can be categorized as Public Fountain (PF), Yard Own Connections (YOC), Yard Shared Connections (YSC), and House Connections (HC).

From Table 2, we noticed that domestic water demand (DWD) was adjusted by climate factor (CF) and socio

TABLE 1. Population forecasting of Assosa town

Year	2007	2010	2015	2020	2025	2030	2035
Growth rate	4.36	4.3	4.2	4.0	3.8	3.7	3.6
Population	24214	27490	33834	41322	49985	60058	71814

economic factor (SEF). This means water is more used at hot area than cold ones. In addition reach people consume more water than poor ones. These are adjusted by multiplying the adjustment factors with total domestic water demand. The current adjusted domestic water demand of Assosa town has been 1186624.5 l/d while design period water demands of study area were 3284757 l/d. This indicates the water demand of the down will be increased by 2098133 l/d.

b) Projected non-domestic water demand assessment
This refers to the water demand required for non- domestic (NDD) area like public and institutions (PID), commercial (CD), livestock (LD), fire (FD) and industrial area (ID).

Since 2017, there were no water supplied for livestock and fire-fighting, but for the future Assosa Town Water Supply and Sewerage Authority have a plane to supply water for livestock and fire-fighting. Table 3 describes, water demands for commercial area were more than water demand for other non-domestic area. This indicates the area covered by commercial was greater than other areas. The design period non- domestic water demand were increased by 1308234 l/d as compared to 2017 non- domestic water demand. This can indicates the amount of water supplied for non-domestic area will increase from year to year.

As discussed in Figure 2 the domestic demand (ADWD) throughout the year is higher than non-domestic demand (NDD) categories. Non- domestic demand are found to have a lower contribution to total water demand, all categories has shown increase between 2017 and 2035. Since 2017 the water supplied for domestic was 688242.2 l/d greater than water supplied for non-domestic area.

c) Projected average, maximum and peak daily water demand
Water demand is a summation of all consumptions given in the preceding sections and it would determine the capacity needed from the sources. As summarized in Table 4, Average daily demands (ADD) of the study area for 2020, 2025, 2030 and 2035 were increased by 8.99 , 50.97, 94.23 and 147.41 % respectively as compared to 2017 average daily water demand. While maximum daily demand (MDD) and peak hour demand (PHD) were increased by 8.98, 50.94, 94.2 and 147.38 % to 5.33, 45.90, 87.73 and 139.11 %, respectively.

Water demand and supply analysis

According to the information obtained during discussion with the experts of water supply office the other problem of water supply is the source of power for pump motor or shortage of power supply. That means, the supply of water to the town was dependent on electric power. When electric power was available, the sources produce a total volume of discharge 46.1 l/s at pump operation hours which is equal to 26.89 l/s in 24 hours. Therefore the total volume of water entered to storage tank within 24 hours is 2323.3 m^3. When the electric power was off day`s the supply of water from source has stand by generator start to operate for only 14 hours per a day so that the daily production of water decreases by 11.2 l/s during pump operation time.

As discussed in Table 4, the projected maximum daily demand of the design period was 82.11 l/s, but there are five

TABLE 2. Projected domestic water demand

Connection types	Unit	Year				
		2017	**2020**	**2025**	**2030**	**2035**
HC	l/d	240195	305122	439868	601181	805753
YOC	l/d	266109	331733	482455	654993	873258
YSC	l/d	135975	170371	257173	350619	469017
PF	l/d	227042	251940	287614	280831	258387
DWD	l/d	869322	1059166	1467110	1887623	2406415
CF	-	1.3	1.3	1.3	1.3	1.3
SEF	-	1.05	1.05	1.05	1.05	1.05
Adjusted DWD	l/d	1186624.5	1445761	2002605	2576605	3284757

TABLE 3. Projected non- domestic water demand assessment

Water demand	Unit	Year				
		2017	**2020**	**2025**	**2030**	**2035**
PID	l/d	166127.4	202407	280365	360725	459866
CD	l/d	189859.9	231322	320417	412257	525561
LD	l/d	0	72288	100130	128830	164238
FD	l/d	0	173491	240313	309193	394171
ID	l/d	142395	115660	160209	206129	262781
NDD	l/d	498382.3	795169	1101433	1417133	1806616

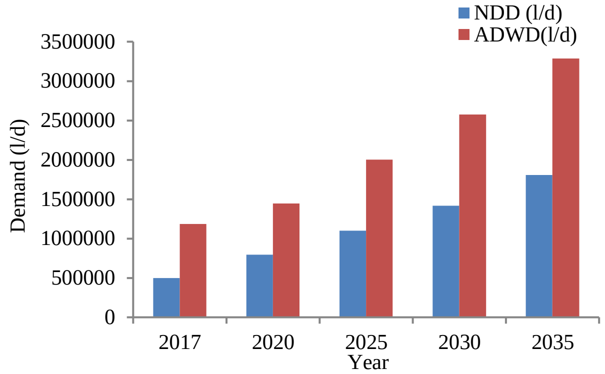

Figure 2. Variation of domestic and non- domestic daily water demand

TABLE 4. Projected average, maximum and peak daily water demand

Water demand	Unit	Year				
		2017	**2020**	**2025**	**2030**	**2035**
ADWD	l/d	1186624.5	1445761	2002605	2576605	3284757
NDD	l/d	498382.3	795169	1101433	1417133	1806616
UFW	l/d	283950	361441	500652	644152	821190
ADD	l/d	2323296	2602371	3604690	4637890	5912563
ADD	l/s	26.89	30.12	41.72	53.67	68.43
MDDF	-	1.2	1.2	1.2	1.2	1.2
MDD	l/s	32.27	36.14	50.06	64.40	82.11
PHDF	-	1.8	1.8	1.8	1.8	1.8
PHD	l/s	50.08	65.05	90.10	115.92	147.79

existing water supply source of the town with total yields 46.1 l/s. This can indicate that the amount of water which is supplied for town is less than the design period required amount of water. As discussed on Figure 3, by comparing the existing water supply with the design period water demand the town water supply and distribution system is said to be unsustainable.

Hydraulic modeling

a) Pressure of existing water supply distribution network

At low peaks through night hours the pressure in the system becomes high and the leakage loses expected to increase whereas at high peaks the pressure becomes small and the leakage losses expected to decrease. Table 5 describe the pressure of distribution system at night time.

The result of simulation run was obtained after model constricted from the input of existing data a total node of 114 was reported from the project inventory dialog box software. As described in table 5, 27.2 % nodes have been observed out of the recommended serviceable pressure (15 mH_2O to 60 mH_2O), low water pressure coverage. This is due the topographical problems of the town.

b) Velocity of water in the existing water distribution network

Table 6 summarizes the velocity of water in distribution network at high water consumption, morning. As indicated in Table 6, 84.86 and 15.14 % of the pipes are below and within the permissible range (0.6 m/s up to 2 m/s) of velocity respectively. This is due to, the diameter of pipes distributed in Assosa town water supply and distribution network was not satisfactory for effective flow of water. And also pump power, which deliver water from source to service reservoir, was not effective.

Sustainability analysis

a) Reliability analysis of existing water supply distribution network

The number of pressure and velocity under permissible or satisfactory range were 83 and 23, respectively.

$REL_K = \frac{\text{times satisfactory occurs}}{\text{total of time steps}}$

$REL_P = \frac{83}{114} = 0.728$ (Reliability due to pressure)

$REL_V = \frac{23}{152} = 0.151$ (Reliability due to velocity)

Average reliability $= \frac{0.728+0.151}{2} = 0.4395$

This reliability value indicates that the probability of distribution system under satisfactory condition has been 0.4395.

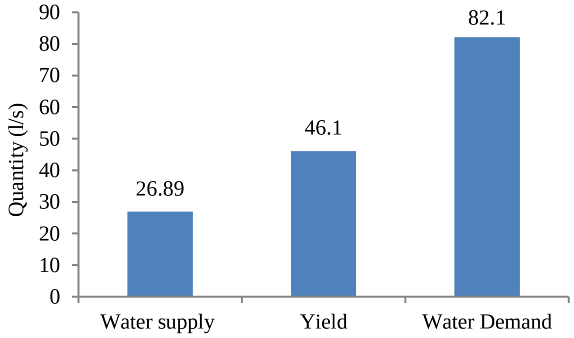

Figure 3. Existing water supply and future water demand

TABLE 5. Simulated result of pressure at low consumption hour (4:00 AM)

Pressure range value	≤ 15 mH_2O	15-60 mH_2O	≥60 mH_2O
Number of nodes	24	83	7
Percentage	21.05	72.8	6.15

TABLE 6. Simulated results of velocity at high consumption hour (8:00 AM)

Velocity range (m/s)	Count	Count (%)
≤0.6	129	84.86
0.6-2	23	15.14
≥2	0	0

b) Vulnerability analysis of existing water distribution network

The summation of pressure and velocity value which have been below and above satisfactory value were 762 mH_2O and 28.17 m/s, respectively.

$VUL_K = \frac{\sum \text{unsatisfactory values}}{\sum \text{all values}}$

$VUL_P = \frac{762}{3037} = 0.251$(Vulnerability due to pressure)

$VUL_V = \frac{28.17}{52.33} = 0.538$ (Vulnerability due to velocity)

Average vulnerability $= \frac{0.251+0.538}{2} = 0.395$

This vulnerability value indicates that the magnitude or duration of an unacceptable state of WDS in a certain time scale has been 0.395.

c) Resiliency analysis of existing water supply distribution network

The number of satisfactory value of pressure and velocity which were follows unsatisfactory values have been 12 and 7 respectively. Whereas the number of pressure and velocity values under unsatisfactory condition have been 31 and 129 respectively.

$RES_K = \frac{\text{times of satisfactory follows unsatisfactory}}{\text{total of times unsatisfactory occurs}}$

$RES_P = \frac{12}{31} = 0.38$ (Resiliency due to pressure)

$RES_V = \frac{7}{129} = 0.05$ (Resiliency due to velocity)

Average resiliency $= \frac{0.38+0.05}{2} = 0.211$

This resiliency value indicates that the probability of how fast the water supply distribution system recovers from a failure has been 0.211.

Sustainability index

The sustainability index (SI) represent the aggregate sum of the performance of water supply distribution network based on the values of technical performance indicators especially pressure and velocity.

$SI = [REL * RES * (1 - VUL)]^{1/3}$

$SI = [0.728 * 0.38 * (1 - 0.251)]^{1/3}$

$SI = 0.559$ (Sustainability index due to pressure)

$SI = [0.151 * 0.05 * (1 - 0.538)]^{1/3}$

$SI = 0.19$ (Sustainability index due to velocity)

$SI = \frac{0.559+0.19}{2} = 0.375$

The overall sustainability index was 0.375 but 0.19 for velocity and 0.559 for pressure. The overall sustainability index was computed by taking average value of velocity sustainability index and pressure sustainability index. Therefore, the existing water supply distribution system of Assosa town is not sustainable.

To overcome such problems, the existing water supply and distribution system require design like, re distributing the layout, identifying rechargeable aquifer or finding other source area, substituting leaked pipes by new pipes, balance the amount of water supply with the community water demand, additionally construction concrete service reservoir or tank, install good performance motor or generator with effective pump power.

CONCLUSIONS

The future population and water demand of the town has been projected up to the year 2035 using year 2007 as base year. The existing water distribution system of Assosa town was established for an estimated population of 19,000. But as compared with the current population (24,214), it was served beyond the life and low coverage in the town. The current water production of Assosa town was found as 46.1 l/s, besides comparing with the forecasted maximum water demand of design period (82.11 l/s) the water supply of the town was not sustainable.

The performance of the distribution system has shown 15.14 % with in allowable velocity which is too low and pressure of consumption nodes have performance of 72.8 % nodes have acceptable pressure limits between (15-60 mH_2O).

The average reliability, resiliency and vulnerability value of existing water supply distribution network of sustainability performance indicators were 0.4395, 0.211 and 0.395, respectively. The overall sustainability index was 0.375 but 0.19 for velocity and 0.559 for pressure. Therefore the existing water supply system and distribution network of Assosa town was not sustainable.

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Persian Abstract

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چکیده

هدف اصلی از این مطالعه، تجزیه و تحلیل پایداری سیستم آبرسانی و توزیع آب شهر آسوسا است. در حین انجام این پژوهش، داده‌های اولیه و ثانویه جمع‌آوری گشته و از نرم‌افزارهایی مانند water GEMSV8i، ArcGIS نسخه ۱۰.۴.۱ و GPS Garmin72 استفاده شد. منبع آبرسانی منطقه مورد مطالعه ۴۶/۱ لیتر در ثانیه می‌باشد اما تنها ۲۳/۶ لیتر در ثانیه از آب استفاده می‌شود. نتیجه شبیه‌سازی شده از شبیه‌سازی دوره طولانی نشان داد که عملکرد پارامترهای هیدرولیک ۲۱/۰۵ ٪ برای head کمتر از ۱۵ متر، ۷۲/۸ ٪ برای مقدار ۶۰- ۱۵ متر و ۶/۱۵ ٪ برای مقدار بیشتر از ۶۰ متر. و سرعت جریان لوله ۸۴/۸۶ درصد برای سرعت ۰/۶ متر بر ثانیه، ۱۵/۱۴ ٪ برای محدوده سرعت ۲-۰/۶ متر در ثانیه بود. براساس نتیجه شبیه‌سازی، میزان اطمینان از فشار و سرعت به ترتیب ۰/۷۲۸ و ۰/۱۵۱، میزان آسیب‌پذیری ۰/۲۵۱ و ۰/۵۳۸ و مقاومت انعطاف‌پذیری ۰/۳۲۲ و ۰/۱ به دست آمد. شاخص کل پایداری ۰/۳۷۵ ولی برای سرعت ۰/۱۹ و برای فشار ۰/۵۵۹ بود. بنابراین ، پایداری سیستم‌آبرسانی و توزیع موجود شهر شهرک آسوسا پایدار نیست و طراحی مجدد سیستم آبرسانی و توزیع آب شهر آسوسا به منظور پایداری آن ضروری است.