Regression Model for Predicting Water and Energy Demand: A Case Study of Addis Ababa City in 2050

Bedassa Dessalegn Kitessa[1](✉), Semu Moges Ayalew[2], Geremew Sahilu Gebrie[1], and Solomon Tesfamariam Teferi[1]

[1] Addis Ababa Institute of Technology, Addis Ababa University, P.O. Box 385, Addis Ababa, Ethiopia
{bedassa.dessalegn,solomon.tesfamariam}@aait.edu.et

[2] School of Civil and Environmental Engineering, University of Connecticut, Storrs, USA

Abstract. Water and energy are so versatile that play great role in fulfilling the daily requirements of human life. Having knowledge on the future water and energy demand of the world, country, region and even a single city/town helps for planning and establishing water and energy policies. A regression model was used to estimate the energy and water demand considering the socio-economic drivers as parameters. An average population growth rate of 5.2% and a GDP growth rate of 11% were used as base scenarios to predict the residential, commercial and industrial energy demands. Population and GDP per capita based scenario was used to predict the transport (street-lighting) energy demand. The total energy demand for residential, commercial, industrial sectors and street-lighting was around 50 and 190 Peta Joule in 2030 and 2050 respectively. Additional, the energy requirement for water distribution, transmission, and water treatment was determined. Similarly, this scenario was used to determine residential, commercial and industrial water demand. The total water demand was predicted to be 0.4 and 0.68 billion cubic meters in 2030 and 2050 respectively.

Keywords: Socio-economic · Regression model · Water-energy demand

Acronyms

AA	Addis Ababa
AADMP	Addis Ababa Distribution Master Plan
AAWSA	Addis Ababa Water and Sewerage Authority
BCM	Billion Cubic Meter
BoFED	Bureau of Finance and Economic Development
CSA	Central Statistical Agency
DVRPC	Denver's Climate Resiliency Committee
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
ETB	Ethiopia Birr

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GDP	Growth Domestic Product
GTP II	Growth and Transformation Plan II
JICA	Japan International Cooperation Agency
MAE	Mean Absolute Error
MLP	Multilayer Perception
MUDHCo	Ministry of Urban Development, Housing and Construction
MW	Mega Watt
NRW	Non-Revenue Water
PJ	Peta Joule
RAE	Relative Absolute Error
RMSE	Root Mean Squared Error
UN	United Nation
UNDESA	United Nations Department of Economics and Social Affairs
USA	United State of America
WE	Water and Energy
WEKA	Waikato Environment for Knowledge Analysis

1 Introduction

The socio-economic drives such as population, per capita income, gross domestic product and technology affect highly the water-energy demand [1–3]. According to a UN report [4], the global population by 2050 is projected at 9.3 billion [5]. If one needs to extend the projections population beyond 2050, uncertain mortality and migration assumptions need to be considered. With continuing urbanization, the city population has grown rapidly and this led to an increase in water-energy demand [6]. Though the urbanization highly affects the water-energy demand, in developed countries where urbanization is not an issue, water-energy demands are highly influenced by GDP growth [7]. Energy is required to deliver an urban water supply at each stage (water transmission, treatment, distribution, etc.).

Availability and affordability of energy is a prerequisite for water supply (for pumping water in distribution, transmission, and water treatment) in Addis Ababa. In 2018, Legadadi and Gefersa water treatment plants consumed 6.76 GJ and 3.52 GJ respectively, while operating at an average of 22 h/day (Source: AAWSA). With a rise in population, urbanization, and commercial, industrial, institutional, residential activities, the demand for energy and water has been rising significantly in the city.

The growing population of Addis Ababa city, high urbanization rates and higher affluence stimulating consumption of goods and services are important trends driving the future development of impacts and city needs for energy resources. With 614 MW electricity demand in 2014, Addis Ababa's capital region accounted for around 42% of the country has an interconnected system peak load [8]. Energy demand forecasting is a systematic procedure for quantitatively defining future energy supply [9].

Deterministic and Stochastic Method are some of the prediction technique [9]. The deterministic method is a simple extrapolation of the historical demand not accounting for random variations of different driving parameters. As a result, it is less accurate in demand forecasting. In the Stochastic Method, the uncertainty of driving parameters like population number and economic growth is considered to give more value that is accurate.

Ethiopia's urban population will expect to triple by 2037 [10]. Studies done on the city's rate of urbanization have shown that the population to grow by 5% annually [10]. Moreover, the city's GDP is about ETB 90.9 billion ETB in 2015 and the GDP per capita income has grown from USD 788.48 in 2010 to USD 1,359 in 2015 [11].

Regression is the most widely used model and a stochastic approach for developing the relationship between variable y and variables x [12]. The trend line, energy and water are some of the domains in which linear regression is used. The goal of this model is to predict the response to n data points $(x_1, y_1), (x_2, y_2) \ldots (x_n, y_n)$ by a regression model.

WEKA [13] is a tool developed by Waikato University New Zealand and a collection of machine learning algorithms that are represented by the necessary actions that load the data and once the data is loaded there may be performed a regression on the dataset.

Water and Energy are basic for human life and it needs prediction of demand to plan the future water and energy supply. Electricity energy and water consumption in various sectors are investigated. Prediction tools are used for estimating water and energy consumption to predict water and energy demand. Water and Energy demand forecast can be divided into short-term, medium-term and long-term [14]. This paper aims to analyze water and energy consumption in Addis Ababa city to predict the long-term water and energy demand up to 2050 using the regression model (Stochastic Method). In the long-term, it is common to perform water and energy demand prediction using different drivers [14].

2 Methodology

The uncertainty effects of the demand drivers such as the GDP per capita, GDP and the population are considered in the stochastic prediction method. The data of these driving parameters are correlated to the historical consumption of water and energy data using a WEKA tool. Forecasting these three parameters are combined with the water-energy consumption using the regression equation, from the equation the future water and energy demand is predicted. The summary of the framework to predict the water and energy demand in 2050 for Addis Ababa city is indicated in Fig. 1.

2.1 Data Collection

Data including the GDP, GDP per capita and the population from CSA, water and energy consumption from AAWSA and EEU were collected respectively. The energy used for water depending on the data from AAWSA office is also used in this study. The commercial and industrial water demands are 53 and 47% of non-domestic water demand respectively [15]. Domestic or residential water demands include water required for drinking, cooking, bathing, washing utensils, washing clothes, flushing toilets, etc. Commercial water demand is affected by the number and types of commercial establishments. The water demand of Addis Ababa city is estimated from 2016 to 2030 by AAAWSA and considered as data to predict from 2030 to 2050 (Table 1).

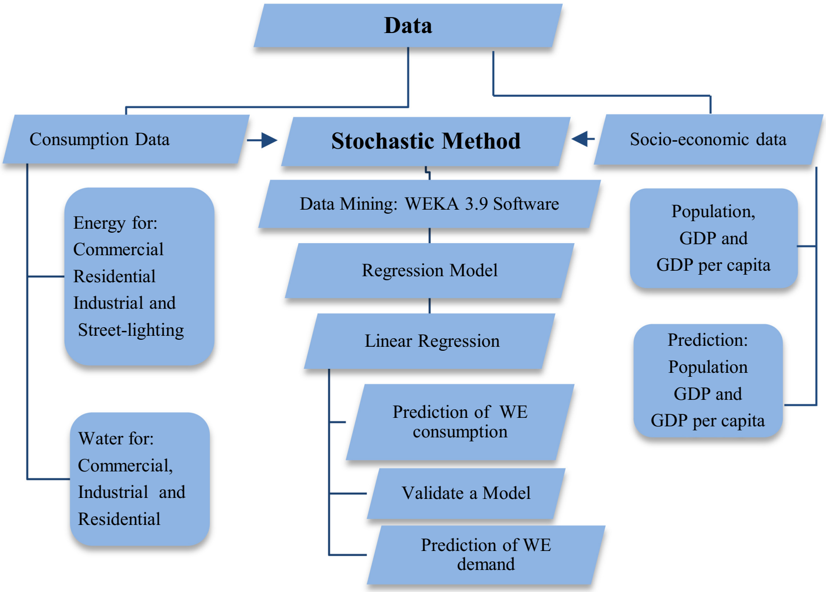

Fig. 1. Data and methodology framework

Table 1. Addis Ababa city water demand (BCM) (source: AAWSA, 2019)

Water demand	Year							
	2016	2018	2020	2022	2024	2026	2028	2030
Industrial	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05
Commercial	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.06
Residential	0.11	0.12	0.14	0.16	0.17	0.19	0.21	0.23
Total	0.17	0.19	0.21	0.23	0.26	0.28	0.31	0.34

The real loss is equal to 75% of NRW [16]. According to AAWSA, the real loss is computed from 2016 to 2030 and assumed to be decreasing from 2030 to 2050 considering there will be technology improvement for loss reduction.

The energy consumption of Addis Ababa city for street-lighting, residential, industrial and commercial sectors was collected from EEU office. Energy distribution loss (e.g., power loss) is the other main factor that influences the energy demand. Therefore, considering the distribution loss is important in planning the energy demand of Addis Ababa city. Distribution network in Addis Ababa's capital region has the following problems: Lack of capacity, poor reliability and quality of supply and high losses which are approximately 19% loss in distribution system occurs due to lack of capacity and equipment deterioration (Source: AADMP Volume 1 Part 2). The EEP has a plan to improve the distribution loss described in Table 2 through AADMP project.

Table 2. Distribution loss

Year	Distribution loss		
	Technical loss (%)	Non-technical loss (%)	Total (%)
2017	12.9	3	15.9
2034	8	1	9

The urban population growth rate is mainly due to the rise in migration toward the city and Addis Ababa has relatively better industries, infrastructure and facilities or mega-projects. Due to all these factors, its population growth rate is about 5.2% [17]. The annual GDP growth rate was about 11% and will continue up to 2050 as planned by the city administration [18].

2.2 Stochastic Method

The stochastic method (regression model) is used to predict the long-term water and energy demands using the WEKA tool. It is a widely used statistical technique for modeling the linear relationship between two or more variables. Regression is a used as a method in this study to develop a relationship between dependent variables denoted by y and independent variables denoted by x. The dependent variable is either water or energy consumption whereas the independent variables are the socio-economic drivers. Equation 1 gives the correlation between y and x of the regression model.

$$y = a_o + a_1x_1 + a_2x_2 + a_3x_3 + \ldots + a_nx_n \tag{1}$$

Where a_1, …, a_n and a_o are regression coefficients and constant respectively and x_1, …, x_n are independent variables (population, GDP and GDP per capita) and whereas y is dependent variable (water and energy consumption).

The accuracy of the model is validated using evaluation parameters such as Mean Absolute Error (MAE) [19], Root Mean Squared Error (RMSE) [20], Mean Absolute Error (MAE) and Coefficient of determination (R^2).

The steps followed to stochastically predict the water and energy demands are given as follows:

Parameter Forecast (GDP and Population): To consider the effects of uncertainty drivers (e.g., GDP, GDP per capita and population) on the water and energy prediction, knowing the values of these parameters is required.

Population Forecast: To predict the future population of the city, the growth rate (%) and the present population (Po) should be known. Addis Ababa's population is 3.6 and 3.7 Million in 2017 and 2018 respectively (CSA data). The population growth rate is taken into consideration to forecast the population by Eq. (2).

$$P_t = P_o + GR \times P_o \tag{2}$$

Where P_t is the annual population at a certain year, GR is the population growth rate (%) and P_o is the present or current annual population.

GDP Forecast: The growth rate (%) of Addis Ababa GDP and the initial GDP should be taken into consideration to predict GDP using Eq. (3).

$$GDP_t = GDP_o + GR \times GDP_o \tag{3}$$

Where GDP_t is the future gross domestic product, GR is the GDP growth rate (%) and GDP_o is the initial GDP.

Finally; the equation between the main socio-economic drivers and water consumption was developed using the WEKA tool.

3 Result and Discussion

Since the population is the main driver of water and energy demand, its projection has been made using the population growth rate, Fig. 2. The result shows the current population, 4.5 million, will rise to about 18 million in 2050.

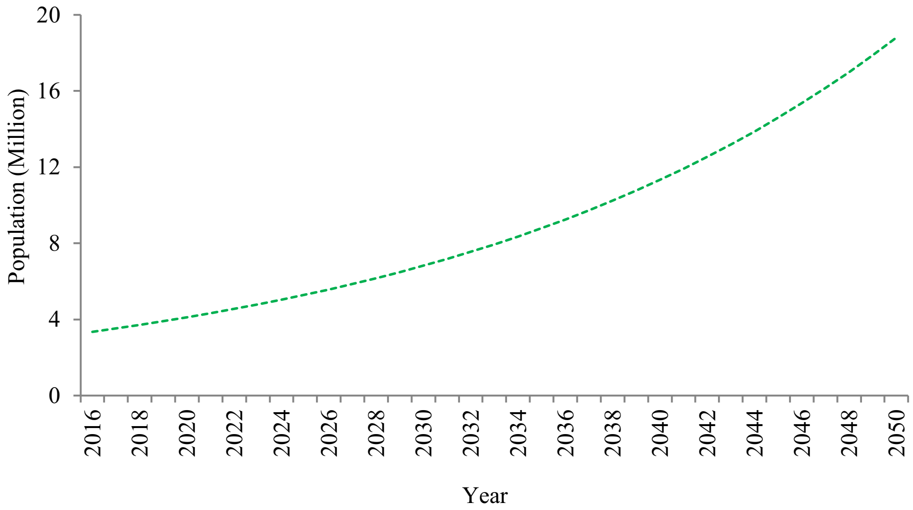

Fig. 2. Population forecast of Addis Ababa city

The city's GDP will grow annually on average by 11%, the GDP of the city up to 2050 was estimated and used to predict the water-energy demand, Fig. 3. In 2050 GDP is expected to reach 3600 billion ETB.

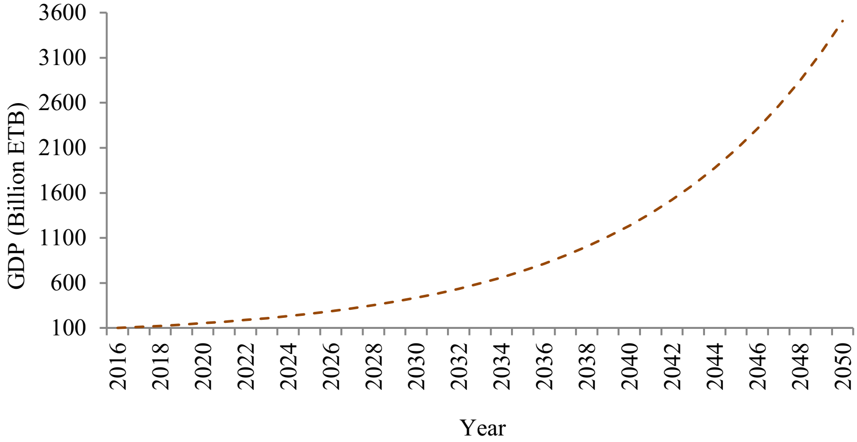

Fig. 3. GDP forecast using GDP growth rate

3.1 Energy Demand

With the rise in population, urbanization, commercial, industrial and institutional activities, the energy demand has been rising in Addis Ababa city.

Transport (Street-Lighting) Sector: The energy consumption was estimated for scenarios; scenario 1 (Population and GDP per capita), scenario 2 (GDP per capita) and scenario 3 (Population). The scenario's results are evaluated as indicated in Table 3. Equation (4), (5) and (6) were used for scenarios 1, 2 and 3 in their respective as given.

$$y = -0.42x_1 + 49.83x_2 \tag{4}$$

$$y = 5.54 - 0.1x_2 \tag{5}$$

$$y = 0.05x_1 - 0.13 \tag{6}$$

Where y is consumption (PJ), x_1 is a population (in millions), and x_2 is GDP per capita (in millions ETB per capita). The equation that governs to predict the energy consumption in street-lighting is Eq. (4).

Scenarios 2 and 3 are less in performance relative to scenario 1. Therefore, the consumption estimated based on population and GDP per capita or per capita income (PCI) scenario was considered as the best scenario, rather than GDP per capita (PCI) scenario and population scenario. Besides, scenario 1 is the best fit by the model to observed energy consumption. Figure 4 indicates the energy consumption for street-lighting.

Commercial Sector: The energy consumption for the commercial was estimated for three scenarios and scenarios are evaluated as in Table 4. Equation (7), (8) and (9) were developed for scenario 1, 2 and 3 respectively as follows:

$$y = 2.96x_1 - 7.61 \tag{7}$$

Table 3. Evaluation parameter for scenarios used in transport energy consumption

Scenarios	Drivers	Parameter				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population and PCI	0.98	0.0016	0.002	18.6	18.3
2	PCI	0.92	0.0036	0.0043	41.27	39.84
3	Population	0.92	0.0036	0.0043	41.14	39.79

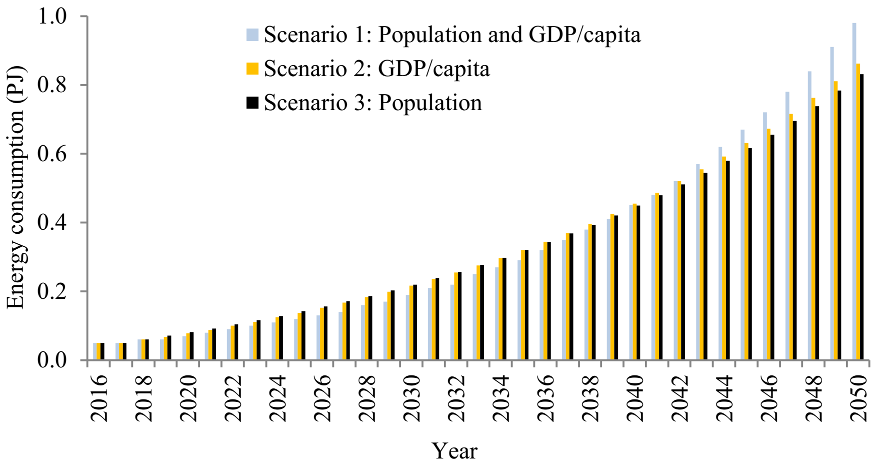

Fig. 4. Predicted energy demand for street lighting

$$y = 328.53x_2 - 7.06 \tag{8}$$

$$y = 1.48x_1 + 164.3x_2 - 7.34 \tag{9}$$

Where; y is consumption (PJ) for the commercial sector. The governing equation that fits historical data and used to predict future consumption is Eq. (8).

Table 4. Evaluation parameters for scenarios used in commercial energy consumption

Scenarios	Drivers	Parameters				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population	0.98	0.076	0.093	13.66	15.41
2	GDP per capita	0.98	0.077	0.094	13.79	15.62
3	Average	0.98	0.072	0.092	13.57	15.51

Scenario 1 and 2 results were nearly equivalent to the averages of two scenarios (scenario 3) which represent the future energy consumption for the commercial sector, Fig. 5.

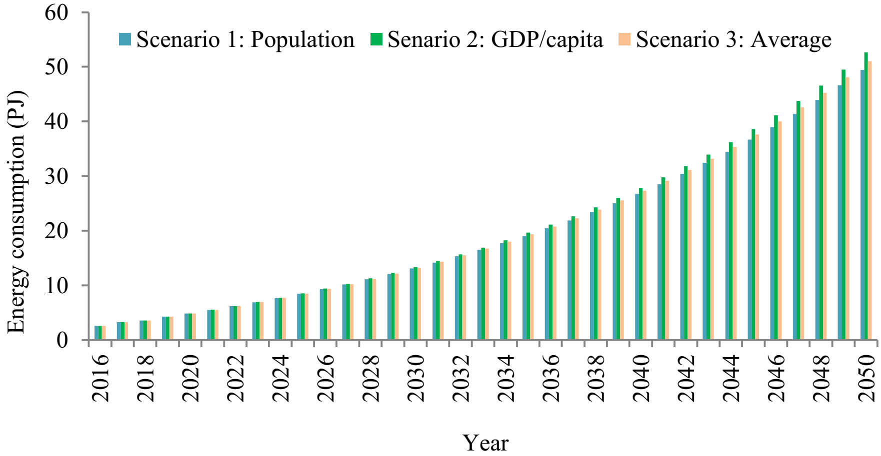

Fig. 5. Commercial energy consumption estimated based on scenarios

Residential Sector: The energy consumption was computed for scenario1, 2 and 3. Scenario 1 (population) and scenario 2 (GDP per capita) were estimated at approximately the same value of energy consumption in the residential sector. Therefore, the average of the two scenarios represents the residential energy consumption, because of the accuracy of estimation. The model has generated Eq. (10), (11) and (12) for scenarios 1, 2 and 3 respectively as follows.

$$y = 3.82x_1 - 9.27 \tag{10}$$

$$y = 424.68x_2 - 8.56 \tag{11}$$

$$y = 1.91x_1 + 212.34x_2 - 8.92 \tag{12}$$

Where; y is energy consumption (PJ) in the residential sector. Scenario 3 or Eq. (11) is used for the prediction of energy consumption in the residential sector. The performance of the scenario fit is given in Table 5.

Predicted residential sector energy consumption is indicated in Fig. 6.

Table 5. Evaluation parameter for scenarios used in residential energy consumption

Scenarios	Drivers	Parameters				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population	0.95	0.20	0.25	25.90	31.01
2	GDP per capita	0.95	0.21	0.25	26.02	31.06
3	Average	0.95	0.21	0.23	31.52	31.06

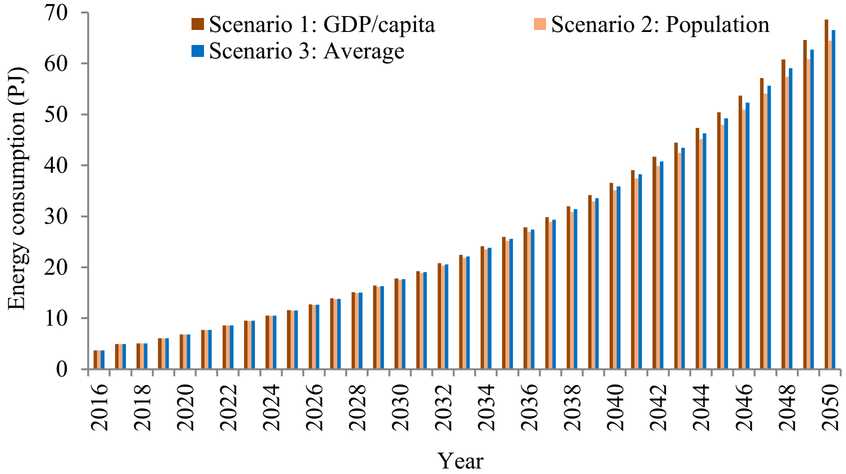

Fig. 6. Estimated residential energy consumption

Industrial Sector: The first two scenarios have nearly the same value; hence, their average has been taken to forecast energy consumption for the three scenarios respectively expressed in Eqs. 13, 14 and 15.

$$y = 4.01x_1 - 9.18 \tag{13}$$

$$y = 420.73x_2 - 7.69 \tag{14}$$

$$y = 2.01x_1 + 210.37x_2 - 8.44 \tag{15}$$

Where; y is consumption (PJ) for the industrial sector. The equation generated by a model based on scenario 3 or Eq. (15) is a general equation to predict future water consumption. The evaluation result for scenarios is shown in Table 6.

Table 6. Model performance of fit evaluation parameters

Scenarios	Drivers	Parameters				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population	0.96	0.19	0.24	24.21	28.20
2	GDP per capita	0.95	0.21	0.26	26.46	31.07
3	Average	0.95	0.21	0.23	31.32	29.07

Predicted industrial sector energy consumption is indicated in Fig. 7.

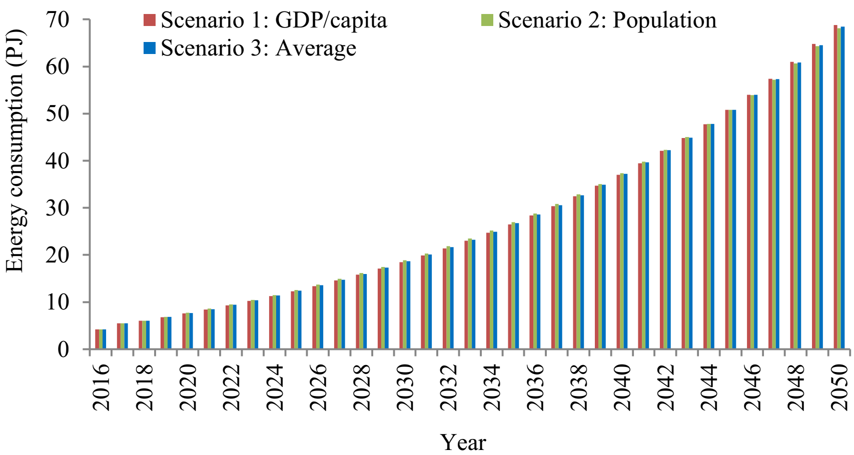

Fig. 7. Estimated industrial energy consumption based on scenarios

The energy demand was fitted using the coefficient of regression as shown in Table 7.

Where; a_1 and a_2 are fitting parameter coefficients for population and GDP per capita respectively.

Energy demand was estimated considering distribution loss. The distribution loss is 19% in 2016 and planned to improve distribution loss to 9% in 2034, AADMP [21] and it reaches 7% in 2050. The future energy demand is indicated in Fig. 8.

Energy for Water: Energy used for the urban water stage (distribution, treatment and transmission) was predicted. Consequently, energy demand for water sectors (residential, commercial and industrial) was also determined. Considering the 2016 year as a baseline, energy demand for water stages was predicted up to 2050 as indicated in Fig. 9.

The energy demand for water distribution (industrial, commercial and residential) is given in Fig. 10.

The power demand in AA capital region is expected to increase from 800 MW in 2014 to 3,600 MW in 2034 [21] and from 1212 MW in 2015 to 6109 MW in 2037 [22] with an annual growth rate of 8.1%. Figure 11 shows the values of the studies.

Table 7. Regression parameters in energy demand prediction

Sectors	Scenarios	Parameters	Value	Constant	Value
Transport	1	a_1	−0.5	a_o	0.03
		a_2	49.8		
	2	a_2	5.5	a_o	−0.1
	3	a_1	0.1	a_o	−0.1
Commercial	1	a_1	3.0	a_o	7.6
	2	a_2	328.5	a_o	−7.1
	3	a_1	1.5	a_o	−7.3
		a_2	164.3		
Residential	1	a_1	3.8	a_o	−9.3
	2	a_2	424.7	a_o	−8.6
	3	a_1	2.0	a_o	−8.9
		a_2	212.3		
Industrial	1	a_1	4.0	a_o	9.2
	2	a_2	420.7	a_o	−7.7
	3	a_1	2.0	a_o	−8.4
		a_2	210.4		

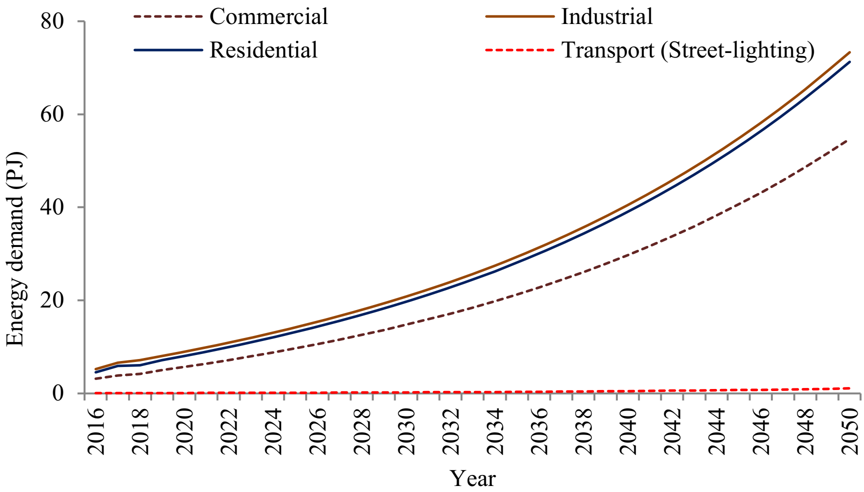

Fig. 8. Estimated energy demand for sectors

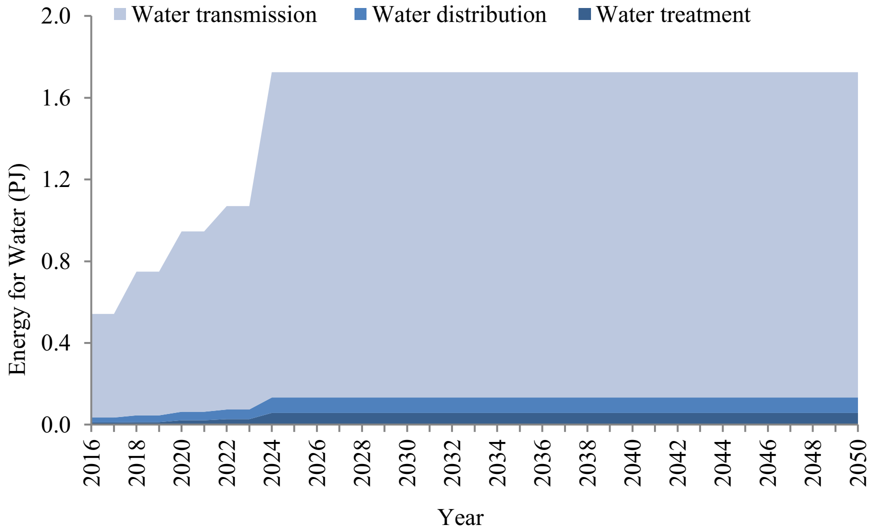

Fig. 9. Estimated energy demand

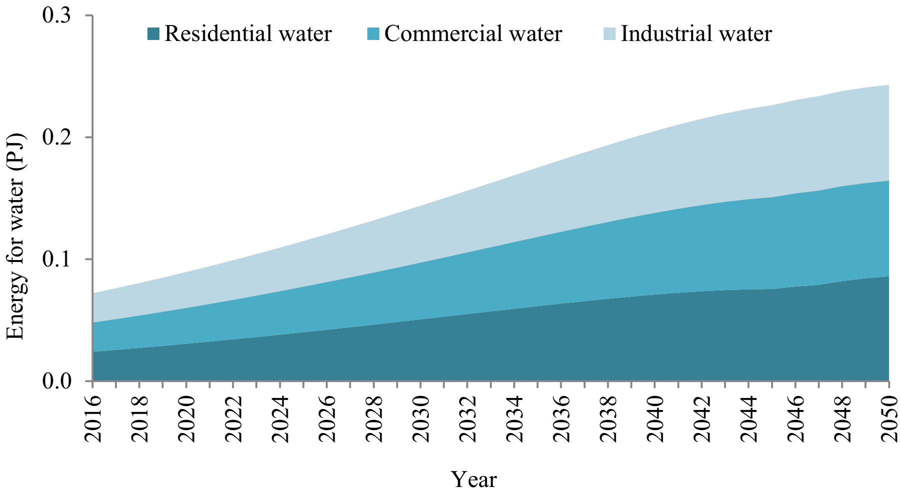

Fig. 10. Estimated energy demand for water distribution in sectors

The MAE, RMSE, RAE and RSE (%) of the predicted (Model) energy demand from 2016 to 2034 are 1.22, 1.42, 7.74 and 7.77% respectively as compared to the EEP study. The predicted energy consumption result becomes as indicated in Table 8.

The high value of model error corresponding to commercial, industrial, residential and street-lighting are 5, 10, 9 and 6% respectively, which are insignificant to the actual.

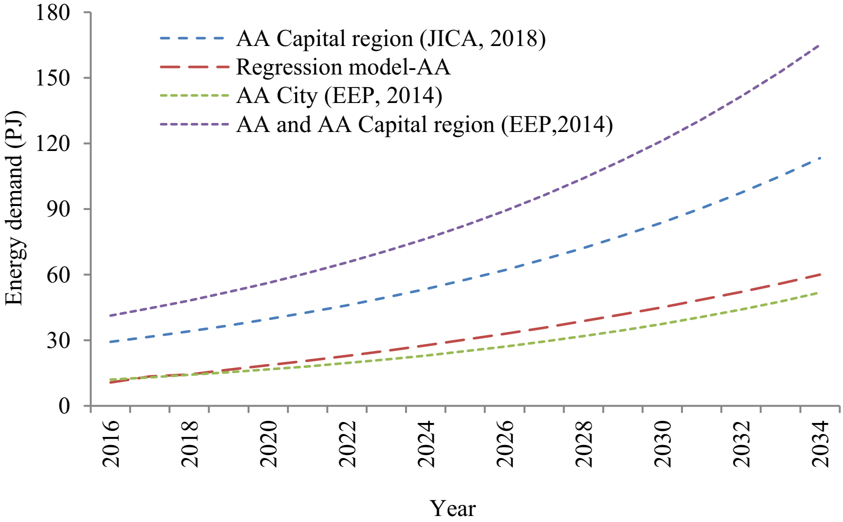

Fig. 11. Studies on energy demand prediction

Table 8. Energy (PJ) consumption results from a model and actual

S/n	Commercial		Industrial		Residential	
	Observed	Model	Observed	Model	Observed	Model
1	2.1	2.0	3.9	4.1	3.2	3.6
2	2.6	2.5	4.6	4.2	3.9	4.3
3	3.1	3.3	5.3	5.5	4.8	5.0
4	3.7	3.6	6.0	6.1	5.3	5.7
5	4.2	4.2	6.8	6.8	6.1	6.4

3.2 Water Demand

In African cities, urban water demands are non-homogeneous within the same urban area and levels of water service vary from standpipes to household connections (Wallingford, 2003). The water demands can be classified as domestic (residential) and non-domestic (commercial and industrial).

Commercial Sector: Water consumption was estimated using the best-fit independent variable (scenarios) as shown in Table 9. The generated equations by the model for prediction of consumption for scenarios 1, 2 and 3 are given using Eq. (16), (17) and (18) respectively.

$$y = 10.72x_1 - 0.03x_2 - 0.004 \tag{16}$$

$$y = -0.47x_1 + 0.001x_3 - 0.0017 \tag{17}$$

$$y = 0.025x_1 + 0.0006x_3 + 0.0095 \tag{18}$$

Where; y is water consumption (in BCM) for the commercial sector, x_1 is a population (in billion), x_2 is GDP (in 1000 billion ETB), and x_3 is GDP per capita (in 1000 ETB per capita). Equation (16) is the governing equation for the estimation of future commercial water consumption.

Table 9. Validation parameter of a model for commercial sector water consumption

Scenario	Drivers	Parameter				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population and GDP	0.98	0	0	0.4	0.37
2	Population and PCI	0.97	0.002	0.0023	24.3	23.3
3	GDP and PCI	0.96	0.002	0.0025	27	26

The estimated commercial sector water consumption is indicated in Fig. 12.

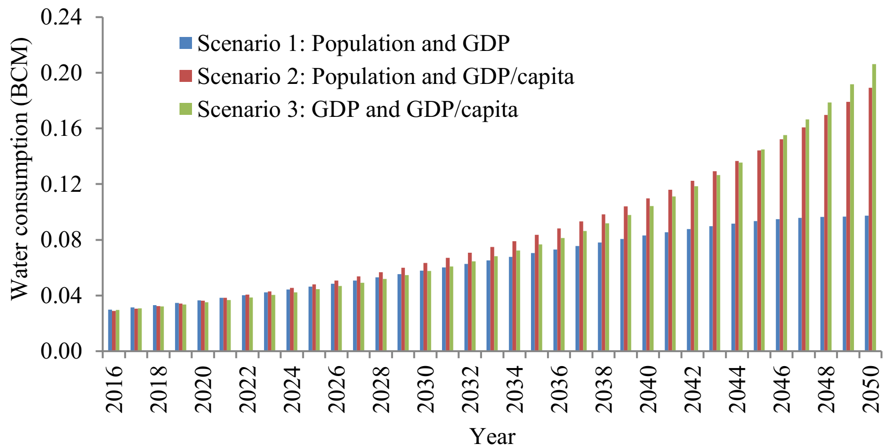

Fig. 12. Predicted water consumption for commercial

Industrial Sector: The water consumption a scenario with their statistical evaluation was determined as indicated in Table 10. Generated equations for independent variables considered in water consumption prediction are given by Eq. (19), (20) and (21) for scenarios 1, 2 and 3 respectively.

$$y = 9.38x_1 - 0.026x_2 - 0.0036 \tag{19}$$

$$y = -0.13x_1 + 0.0007x_3 + 0.0068 \tag{20}$$

$$y = -0.033x_2 - 0.0011x_3 - 0.002 \tag{21}$$

Equation (19) is the governing equation for predicting future industrial water consumption.

Table 10. Evaluation parameter for the model in water consumption

Scenarios	Drivers	Parameter				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population and GDP	1	0	0	0.39	0.37
2	Population and PCI	0.9	0.0022	0.0024	34.03	31.4
3	GDP and PCI	1	0	0	0.45	0.42

The regression model captured the industrial sector water consumption that was computed by AAWSA cases; when population and GDP are considered as a scenario (scenario 1). Therefore, scenario 1 is the best assumption for industrial water demand prediction. Estimated water consumption is shown in Fig. 13.

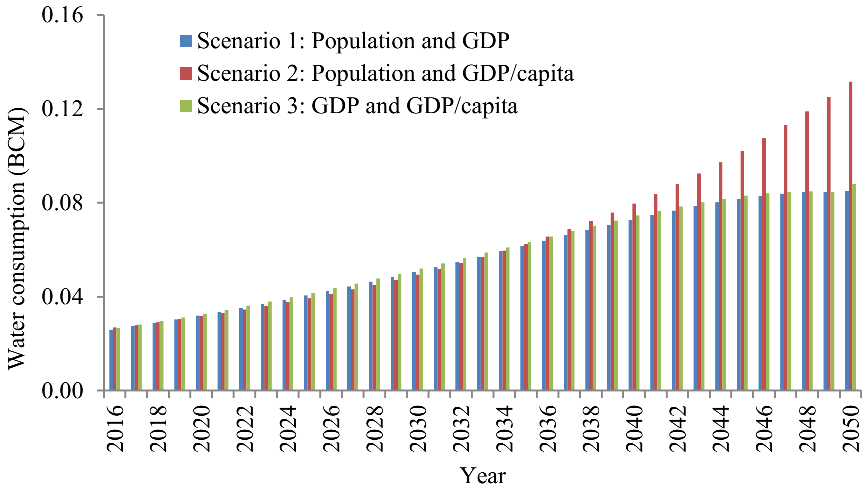

Fig. 13. Industrial sector water consumption

Residential Sector: Evaluations of a scenario for residential sector water consumption was determined as indicated in Table 11. The equation for scenarios 1 and 2 are given by Eqs. (22) and (23) respectively.

$$y = 50.73x_1 - 0.18x_2 - 0.047 \tag{22}$$

$$y = -0.37x_1 + 0.0038x_3 - 0.0003 \quad (23)$$

Where; y is water consumption (in BCM) for the residential sector. For residential water consumption; Eq. (22) is the best for both fitting historical data and estimating future consumption.

Table 11. Metric evaluation parameter for model scenarios

Scenarios	Drivers	Parameter				
		R^2	MAE	RMSE	RAE (%)	RRSE (%)
1	Population and GDP	1	0.0003	0.0003	0.9	0.8
2	Population and PCI	0.9	0.0026	0.0031	7.8	7.9

The model more captured the baseline residential water consumption, when population and GDP scenario (scenario 1) is considered. Scenario 1 is a paramount independent variable for industrial water consumption forecasting. The future water consumption for the residential is given in Fig. 14.

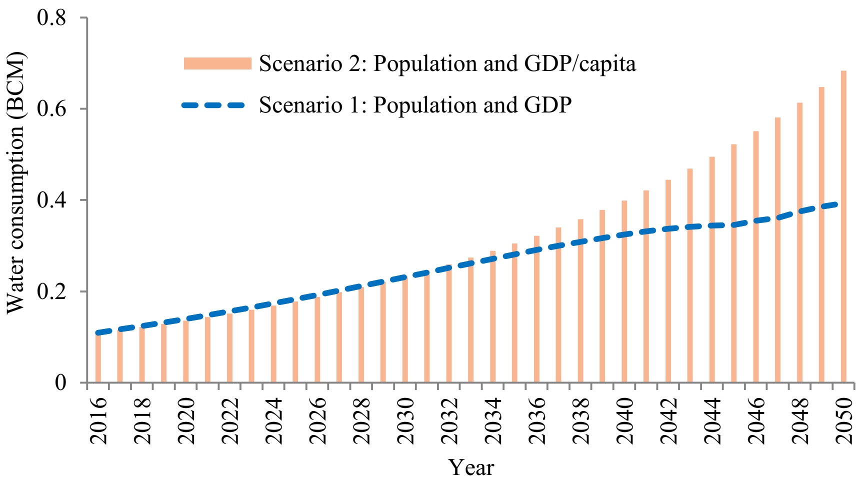

Fig. 14. Estimated residential sector water consumption

The regression parameters used to fit the water demand is indicated in Table 12.

Where; a_1, a_2 and a_3 are coefficients of regression for independent variables of population, GDP and GDP per capita respectively.

Distribution loss is understood in demand estimation and needs technology improvement for water loss reduction. The NRW should be less than 25% according to the World Bank recommends and is decreasing to 23% in 2030 for Addis Ababa [23] and decreases

Table 12. Regression parameters used in water demand prediction

Sector	Scenario	Parameters	Value	Constant	Value
Commercial	1	a_1	10.7	a_o	−0.004
		a_2	−0.03		
	2	a_1	−0.5	a_o	−0.002
		a_3	0.001		
	3	a_2	0.03	a_o	0.01
		a_3	0.001		
Industrial	1	a_1	9.4	a_o	−0.004
		a_2	0.03		
	2	a_2	−0.1	a_o	0.007
		a_3	0.001		
	3	a_2	−0.03	a_o	−0.002
		a_3	0.001		
Residential	1	a_1	50.7	a_o	−0.05
		a_2	−0.2		
	2	a_1	−0.4	a_o	−0.0003
		a_3	0.004		

to 22% in 2050. The real loss is 75% of NRW. The real loss for NRW of 23 and 22% is 17.5 and 16.75% respectively.

Water demand for sectors (residential, industrial and commercial) was estimated based on water loss and scenario-1 as indicated in Fig. 15.

The commercial water consumption growth rate decreased from 4.34% in 2030 to 0.72% in 2050. Also for industrial, it was decreased from 4.34% in 2030 to 0.47% in 2050. For the residential, the growth rate trend decreases from 4.49% in 2030 to 0.33% in 2045 and finally growth rate alter between 1.8% and 2.8% from 2046 to 2050. Commercial and industrial sector water consumption has a decreasing growth rate from 2030 to 2050. In 2030; the residential, commercial, and industrial water demand was 68.1%, 17% and 14.8% of total water demand respectively and in 2050 for the respective sector is 68.2%, 16.9% and 14.8% of total water demand.

According to AAWSA, the water demand for 2018, 2022 and 2025 is 0.29, 0.37 and 0.39 BCM respectively and consequently, the predicted demand in this paper is 0.27, 0.32 and 0.36 BCM for the respective year. This study result shows an insignificant gap with the AAWSA's result.

The estimated water consumption by the regression model using the training test data set and the actual data is given in Table 13.

From Table 13, the lower and higher value of the relative error of the model compared to the AAWSA case is 0.29 and 2.4% respectively, this shows the variation of insignificant value.

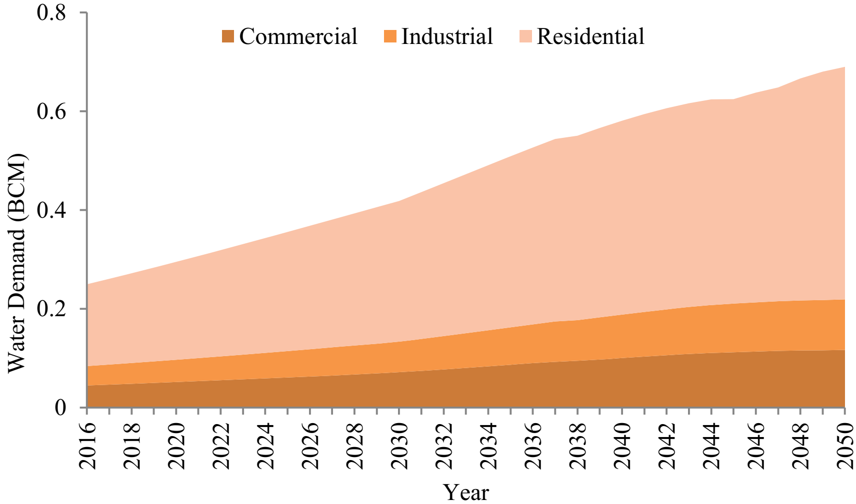

Fig. 15. Predicted water demand for sectors in the city

Table 13. The fit for the regression model using the training data set

S/n	Total water consumption (BCM)	
	AAWSA	Predicted (Model)
1	0.17	0.16
2	0.19	0.18
3	0.21	0.21
4	0.23	0.23
5	0.26	0.25
6	0.28	0.28
7	0.31	0.31
8	0.34	0.33

4 Conclusion

Energy and water consumption data were collected from EEU and AAWSA offices respectively. The energy used for water was also gathered from the AAWSA bureau, while socio-economic drivers were taken from CSA and BoFED. In this paper water and energy, demand was estimated for different scenarios based on socioeconomic drivers. A regression model was used to estimate water and energy consumption using the WEKA tool. Losses (Energy and water distribution) were considered in estimating water and energy demand. Energy used in water (for distribution, transmission water treatment) was estimated based on baseline data and quantity of water.

Socio-economic drivers were forecasted for population considering population growth rate and GDP growth rate. Energy demand was forecasted considering an average consumption estimated based on population scenario and GDP per capita scenario and distribution loss for the residential, commercial and industrial sectors, while street lighting sector demand is based on population and GDP per capita scenario. The average scenario (population scenario and per capita income scenario), considering the two scenarios give an acceptable estimation. These scenarios estimate almost equivalent results and taking the average scenario was appropriate. The population and GDP scenario was used to estimate the water consumption and demand for all sectors used in the study.

All scenarios used in water and energy consumption estimation were selected based on best-fit statistical evaluation parameters. The best-fit scenario to historical consumption is the best estimator of future water and energy consumption and demand. When population growth rate and GDP growth rate are capturing up to 2050 as a socio-economic driver, a regression model using the data mining tool (WEKA) is likely to use for the prediction of water and energy consumption. In the WEKA tool, it was conceivable to consider any parameters, which are supposed to be the drivers for water and energy demand. Considering water and energy distribution loss as an additional factor to the socio-economic factor in demand estimation, the water-energy demand for sectors was predicted in this paper. According to AADMP, the energy distribution loss is 15.9% in 2017 and planned to decrease to 9% in 2030 by improving disruption loss and it reaches 6.65% in 2050. In the years 2030 and 2050, the electrical energy demand was estimated to be 13.2 and 51.03 PJ for the commercial sector; 18.6 and 68.4 PJ for the industrial sector; 17.6 and 66.5 PJ for the residential sector whereas it was 0.19 and 0.98 PJ for the transport sector. Respectively, for the two years mentioned above, the water demand in billion cubic meters was estimated to be 0.071 and 0.12 for the commercial sector; 0.06 and 0.10 for the industrial sector; 0.28 and 0.47 for the residential sector.

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References

1. Oyedepo, S.O.: Energy and sustainable development in Nigeria: the way forward. Energy Sustain. Soc. **2**(1), 1–17 (2012)
2. Stillwell, A.S., King, C.W., Webber, M.E., Duncan, I.J., Hardberger, A.: Energy-Water Nexus in Texas (2011)
3. Sefifi, H., Sepasian, M.S.: Electric Power System Planning. Springer, Heidelberg (2011)
4. UNFPA: State of the World Population: People and Possibilities in a World of 7 Billion. UNFPA, New York, USA (2011)
5. UNDESA: World Population to 2300. United Nation, New York, USA (2004)
6. Yin, Z., Jia, B., Wu, S., Dai, J., Tang, D.: Comprehensive forecast of urban water-energy demand based on a neural network model. Water-Open Access J.: MDPI (2018)
7. Csereklyei, Z., Humer, S.: Modeling primary energy consumption under model uncertainity (2012)
8. World Bank: Enhancing Urban Resilience: city strength resilient cities program (English). Addis Ababa (2015)

9. Sulivan, R.: Power System Planning. McGraw-Hill (1977)
10. World Bank: Ethiopia Urbanization Review: Urban Institutions for a Middle-Income Ethiopia (2015)
11. BoFED: Poverty level assessment of Addis Ababa, Addis Ababa (2016)
12. Kaw, A., Eric Kalu, E.: Numerical Methods with Applications, 2nd edn. lulu.com (March 7, 2011), eBook (Mathematice for College) (2010)
13. Hall, M., Frank, E., Holmes, G., Pfahringer, B., Reutemann, P., Witten, I.: The WEKA data mining software: an update. ACM SIGKDD Explor. Newsl. **11**(1), 10–18 (2009). https://doi.org/10.1145/1656274.1656278
14. Genethliou, D., Feinberg, E.: Load Forecasting, New York (2012)
15. Getnet, A.: Evaluation of Addis Ababa Water Supply System Using Integrated Approach, Addis Ababa (2019)
16. World Bank: Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. PPIAF, Washington, DC (2006)
17. MUDHCo: National Report on Housing and Sustainable Urban Development, Federal Democratic Republic of Ethiopia (2015)
18. UN-Habitat: United Nations Human Settlements Programme, Addis Ababa, Ethiopia (2017)
19. Fortin, J.G., Anctil, F., Parent, L.-É., Bolinder, M.: Site-specific early season potato yield forecast by neural network in Eastern Canada. Precision Agric. **12**(6), 905–923 (2011). https://doi.org/10.1007/s11119-011-9233-6
20. Veenadhari, S., Misra, B., Singh, C.D.: Machine learning approach for forecasting crop yield based on climatic parameters. In: 2014 International Conference on Computer Communication and Informatics, Coimbatore, India (2014)
21. JICA: Addis Ababa Distribution Master Plan (2018)
22. EEP: Power Demand Forecasting, Addis Ababa (2014)
23. AAWSA: Consultancy service for Addis Ababa water distribution and operation management and hydraulic modeling (2019)