Developing Domestic Water Security Index in Urban Cities, Bahir Dar City, Ethiopia

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Abstract. Water security is one of the global indicators in sustainable development goals, which becomes the cross-cutting issue worldwide. Studies have been performed at global, national, and city levels to assess the water security issues. Since assessment of water security at domestic scale has not been done yet in developing countries like Ethiopia, it is essential to develop an appropriate framework for the assessment of domestic water security at the city scale and apply it for urban cities of Ethiopia. The study therefore aimed at developing the domestic water security assessment framework and apply the framework to assess domestic water security index for cities in Ethiopia. The developed framework comprises of three dimensions: water supply, sanitation and hygiene; eleven indicators and fifteen variables. These indicators were defined using driver, pressure, state, impact and response (DPSIR) approach. The variables of the indicators were defined by specific, measurable, attainable, relevant and time bound (SMART) criteria and were used to identify and select the composite of the appropriate indicators and variables. Analytical hierarchy process (AHP) and equal weighting methods were used to compute an index by giving different and equal weighting factors for variables, indicators and dimensions respectively. The developed framework was applied for Bahir Dar city to quantify its domestic water security index for the year 2017/18. Generally, Bahir Dar city is found under medium (2.8) domestic water security status with high (3.41), medium (2.29) and very low (1.0) indices of water supply, sanitation and hygiene dimensions respectively.

Keywords: Domestic water security index · Framework · Analytical Hierarchy Process

1 Introduction

Water is at the heart of sustainable development. Its significance for human survival, socio-economic development, and healthy ecosystems cannot be overemphasized [1].

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The threefold increase of the global population during the 20th century has triggered a simultaneous six-fold increase in water use [2]. This has an adverse impact on water security, especially in urban areas. In 2012, approximately 50% of the world population lived in cities, and by 2030 this will be 60% [3]. Securing drinking water supply is one of the fundamental components in urban water security. In related to this, delivery of clean water, adequate sanitation and hygiene is one of the sustainable development goals (SDG6). However, meeting drinking water demands is becoming a big challenge globally, particularly in developing countries due to an increase in consumption that is driven by urbanization, rapid population growth, economic growth, and change in local climate [4]. Thus, water is becoming a critical resource for world's growing urban areas [2].

The recently adopted SDGs has a dedicated global water security. As a result, a number of countries have incorporated national goals in their mid- to long-term policies in order to meet the global targets [1]. Improving water security is, therefore, rapidly becoming a key point on the policy and development agenda both at national and international levels [1]. The definition of water security should be based on the concept of how the city can be water secured [1].

According to Vorosmarty [5], the scale is also critical in assessing water security in analyzed that different disciplines tend to focus on different scales. Hoekstra [6] also described that the concept of water security is used from the household to the global level. Moreover, water security assessment at the national scale can mask significant variations in security at the local scale [5].

Provision of water for human domestic use can be viewed as a fundamental example of water Security [3]. According to Asian Development Bank [7] household water security is the foundation and cornerstone of water security to eradicate poverty and support economic development by providing all people with reliable, safe water, sanitation and hygiene services should as giving a top priority. DPSIR and SMART approaches are a corner stone criterion to select indicators and variables [1].

Definition of Domestic Water Security is therefore the cornerstone to build the assessment of domestic water security on the selected area. It has been defined in relation with how the city become domestically water secured or the water security in household level. As reviewed from literatures, domestic water security has been assessed as one dimension of water security assessment and it is defined as the basic part of water security.

Drinking water supply with adequate quality and quantity, sanitation and hygiene are the basic needs to keep safe human health [8]. However, many countries particularly developing countries are suffering to fulfill those basic needs and water infrastructures. Moreover, urbanization, industrialization, climate change etc. affects water resource. SDG (7) goal dictates to achieve domestic water security; there should be universal and equitable access to safe and affordable drinking water for all and access to adequate and equitable sanitation and hygiene for all and end open defecation [9].

Domestic water security definition for this study: "Every person has to be easily accessed water supply, improved sanitation and hygienic facilities with an affordable price, and drinking water have to be safe quality, sufficient quantity with insignificant water wastage at any time: the sanitation system should be safely managed and every person should be free from water related diseases". The aim of this study is to develop a framework for assessing domestic water security at city scale and to measure the domestic water security index of Bahir Dar city in year 2018/2019.

2 Domestic Water Security Framework Development

2.1 Components of Framework

There are three main components of the domestic water security framework to be developed for the assessment of water security at household level: dimensions, indicators, and variables. Dimensions are main components of domestic water security. Indicators are used to represent the dimensions and answer what to measure. Variables are used to measure indicators. Dimensions was selected from the definition of domestic water security and are water supply, sanitation and hygiene.

Selection of Indicators and Variables: After defining domestic water security and selecting dimensions, the second step is to select indicators that reflect the main characteristics of the key dimensions [10]. Indicators are tools that provide information about something [11]. They are used to express the nature of key dimensions and their selection will depend on the purpose and specific application of the assessment [10]. Variables are used to quantify the indicators and can answer the question “How to measure”. They should be acceptable and reliable and are sensitive to changes over space and time [1].

The indicators had been selected from the DPSIR framework, SMART criteria [1]. On the applied DPSIR framework, the impact is the problem on domestic water security and the driver is the cause for the pressure or stress created on. The state is the change due to the stress created or changing the domestic water security status and the response represents the possible solution for solving the problem on domestic water security or to achieve domestic water security.

As the dimensions of water security are water supply, sanitation and hygiene, the driving forces for these dimensions in the Ethiopian context are, anticipated population growth and low-income level. Due to these driving forces, there is a pressure created on the urban community, which is high water demand for drinking, sanitation purpose and hygiene; higher demand of sanitation and hygienic services. The impact of the state of the three dimensions are generally low livelihood security and public health problem. The responses or the solution for those problems are improving water supply system, putting rules and regulations on water, sanitation and hygiene, encouraging good water use habits, personal hygienic practices and wastewater reuse. Monitoring quality of water, water loss, sanitation system management, implementation of hygienic practices are also parts of the responses.

The framework (Fig. 1) was developed by identifying the domestic water security dimensions, indicators and variables.

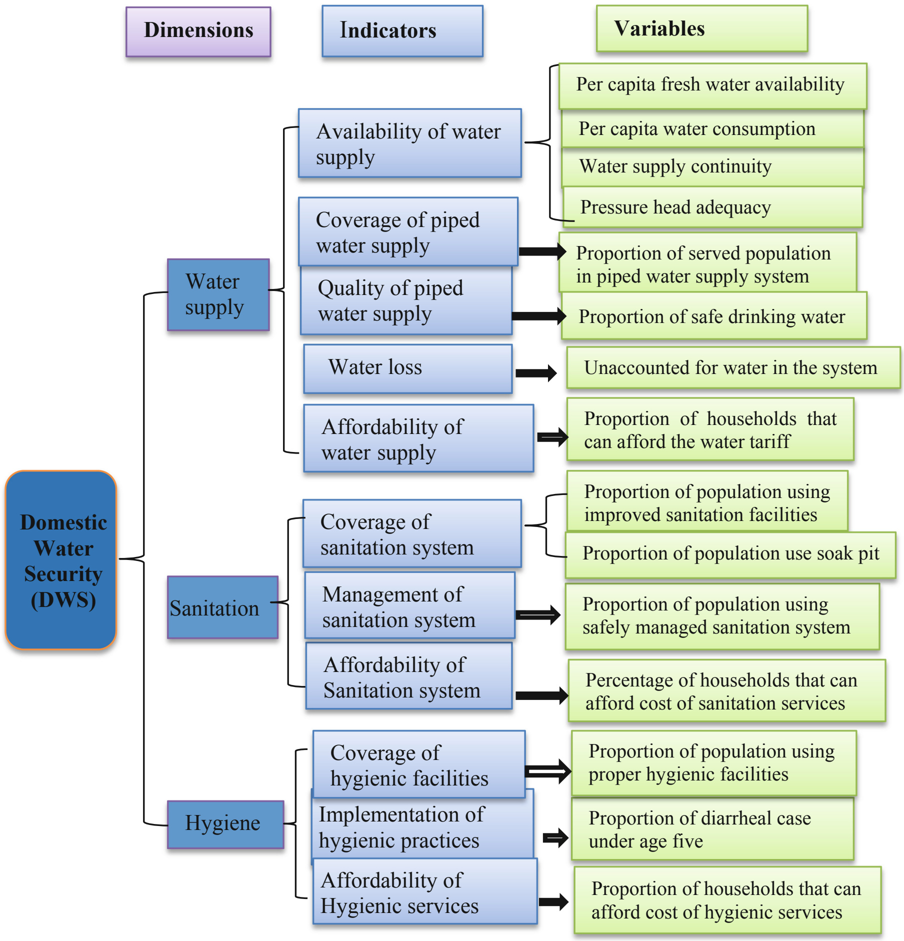

Fig. 1. Developed domestic water security framework

2.2 Representation and Interpretation of the Domestic Water Security Index

In this study, 1 to 5 scale which are <1 very low, 1 to 2 low, 2 to 3 medium, 3 to 4 high and 4 to 5 very high domestic water security was adopted. The very low domestic water security means that the city of the study area is incapable of meeting the basic water supply requirements of its citizens, whereas very high-water security is defined as the city is a model for domestic water secured society.

2.3 Scaling and Bench Marks of Water Security Variables

Developing domestic water security index means expressing it in terms of number or specific value. It is also helpful for the stakeholders to understand the status of the security in easy and understandable way. Growth and Transformation Plan II, SDG and Asian

Water Development Outlook 2013 documents were mostly applied as a benchmark for the assessment of scales of variables. Therefore, to calculate the index, different variables with various measuring units have to be normalized to common scale with interpretation. In this study the value of each variable is classified into a 1 to 5 scale as shown in Table 1.

Table 1. Representation of variable scores in relation to the 1–5 scale adopted

Dimensions	Variables	Unit	Scale					Sources
			1	2	3	4	5	
Water supply	1. Water supply Availability							
	1.1. Per capita water consumption	L/c/d	>25 & <130	[25–40)	[40–60)	[60–80)	[80–130]	[12]
	1.2. Water supply continuity	hr	[0–8)	[8–16)	[16–20)	[20–24)	24	[12]
	1.3. Pressure head adequacy	mH_2O	[0–5)	[5–14)	[14–21)	[21–28)	[28–40]	[13]
	1.4. Per capita water availability	m^3/c/yr	[0–500)	[500–800)	[800–1000)	[1000–1700)	≥1700	[14]
	2. Piped water supply coverage	%	[0–50)	[50–60)	[60–80)	[80–100)	100	[12]
	3. Water quality index	WQI	>100	(75–100]	(50–75]	[20–25]	≤25	[14]
	4. Water loss	%	>35	(30–35]	(25–30]	[20–25]	[0–20)	[12]
	5. Affordability	%	≥5	[4–5)	[3–4)	[2–3)	<2	[12, 16]
Sanitation	1. Sanitation coverage	%	[0–60)	[60–70)	[70–80)	[80–90)	[90–100]	[17, 18]
	1.1. Latrine coverage							
	1.2. Coverage of grey water soak pit							
	2. Management of sanitation							
	3. Affordability	%	≥5	[4–5)	[3–4)	[2–3)	<2	[12, 16]
Hygiene	Coverage hand wash facilities	%	[0–60)	[60–70)	[70–80)	[80–90)	[90–100]	[3, 5]
	Implementation of hygienic practices (Diarrheal prevalence)	No.	>760	(500–760]	(200–500]	(100–200]	[0–100]	
	Affordability	%	≥5	[4–5)	[3–4)	[2–3)	<2	[3, 8]

In the calculation of the index, Analytical Hierarchy Process (AHP) approach was employed to set weightage of dimensions. AHP is an effective method for decision analysis and calculation of weighting factors based on multiple criteria to solve computing dimensions. Eleven group of WaSH experts from different organizations were requested to prioritize domestic water security dimensions, indicators and variables in questionnaire form, from 1 to 9 scale of preference and analyzed by saaty scale AHP method. Table 2 shows the result of weights of domestic water security dimensions, indicators and variables.

Table 2. Weight of dimensions, indicators and variables

Domestic water security index					
Dimensions	Wt. (%)	Indicators	Wt. (%)	Variables	Wt (%)
Water supply	62.1	Availability	35	Per capita water consmp.	38.8
				Supply continuity	32.3
				Pressure head adequacy	28.9
		Quality	31.1	Water quality index	100
		Coverage	21.1	Proportion of people use piped water supply	100
		Affordability	6.5	Proportion of water tariff from total expenditure	100
		Loss	6.3	Water loss in the system	100
Sanitation	23.6	Management	43.4	Sanitation management	100
		Coverage	56.6	Improved sanitation facility	75.9
				Grey water soak pit	24.1
Hygiene	14.3	Coverage of hygienic facilities	50.7	Coverage of hand wash facilities	100
		Implementation of hygienic practice	49.3	Prevalence of diarrhea under age five children	100

Domestic water security index was then estimated by analyzing each variable weighted to the respective indicators, each indicator weighted to the respective dimensions and finally the weighted arithmetic sum of three dimensions gave domestic water security index. The procedure in calculating domestic water security index can be generally described as,

$$\text{Variable (Vi)} = \frac{\sum \text{Wvi} * \text{Svi}}{\sum \text{Wv}} \tag{1}$$

$$\text{Indicator (Ii)} = \frac{\sum \text{Vi} * \text{WIi}}{\sum \text{WI}} \tag{2}$$

$$DWSI = \frac{\sum Ii \, * \, Wdi}{\sum Wd} \tag{3}$$

Where: Wvi - weight of variable, Svi - score of variables, WIi - weight of indicator, Wd - weight of dimension and DWSI - domestic water security index.

3 Result and Discussion

First, how the developed framework was applied in Bahir Dar is described and at the end we indicated the overall index. In order to get the index of overall water security, the values of variables, indicators, and dimensions were aggregated. The unequal weight methods (Table 3) to all variables, indicators, and dimensions were applied based on the expert's judgment by using analytical hierarchy process.

3.1 Application of the Developed Framework for Bahir Dar City

Water Supply

According to the data obtained from (Bahir Dar town water and sanitation services office, Bahir Dar health center, Bahir Dar Municipality/Mayor office and Central Statistical Authority), the analyzed and scored results has shown on Table 3. Water tariff affordability (scoring 5) has very high value, which means that current water tariff is affordable and cheap. Whereas, water quality, water supply coverage, water supply continuity and coverage of improved sanitation facilities scored 3.9, 4.0, 3.2 and 4.0 respectively, of which all fall on high domestic water security status. The respective per capita water consumption (scoring 3) and the pressure head adequacy (scoring 1.9)

Table 3. Result of scored variables

Variables	Variable code	Unit	Result	Score
Water supply coverage (% of people)	WSC	%	82.5	4.0
Unaccounted for water in the system	UFW	%	45.5	1.0
Per capita water consumption	PWC	L/c/d	50.6	3.0
Supply continuity	SC	hrs./day	18.2	3.2
Pressure head adequacy	PHA	mH_2O	7.98	1.9
Water tariff affordability	WTA	%	1.43	5.0
Water quality index	WQI	Value	40.5	3.9
Improved sanitation coverage	ISC	%	87.7	4.0
Grey water soak pit coverage	GSC	%	57.4	1.0
Proportion of safely managed sanitation	SMS	%	27.0	1.0
Coverage of hand wash facilities	HWF	%	48.5	1.0
Prevalence of diarrhea under age 5	PDU	%	21.8	1.0

show a medium and low domestic water security status. The rest variables having scored values of 1.0 show a very low domestic water security status, which imply that water is used indiscriminately without proper planning and management.

Arithmetic weighted water quality index (AWQI) has done by using selected water quality parameters (pH, turbidity, nitrate, total hardness, E. coli and temperature). Water quality index result in distribution system shows highly satisfactory, but in two of the nine sub- cities Shimbit and Gish Abay, there is still a problem of chlorine dosing, emerging of E. coli and turbidity problem, especially in summer season. The probable reason of this water quality problem for coliform bacteria existence is lack of enough and continuous chlorination and for turbidity there is contamination of the1 water sources by surface water flooding, contamination by storm water from urban areas or may be absorption of mud or soil particles during pumping [19]. Based on the water quality indices and the respective scale values for each sub cities, all sub cities have good water quality status (scoring 4) except Shimbit and Gish Abay (scoring 3), which are under a category of poor water quality.

Improved sanitation coverage isn't in better level as the result shows 12.3% open defecation practices in the city in contrary to the SDG 6.2, which states that there should not be open defecation practices in the city. Water supply coverage (82.5%), is on higher domestic water security status. It showed an improvement from coverage of water supply (55.3%) in 2013 [2]. Average piped water supply coverage of urban cities of Ethiopia (89.7%) in 2015 [20]. But as per Ethiopia Growth and Transformation Plan (GTP-2) and SDG goal, drinking water supply coverage must be 100% with the entire population. Per capita water consumption resulted 50.6 l/c/day falls on medium status which is a satisfactory but still it needs improvement. It does not even meet the GTP-2 plan of minimum per capita water consumption (80 l/c/d) for category two which Bahir Dar City falls in.

Water supply continuity also shows water is available at an average of 18.2 h/day. According to Desalegn [21], 41.6% of the population got water greater than 19 h. where as 17% got water less than 6 h. Though the continuity shows better improvement by meeting the GTP-2 (16 h./day) towards water supply continuity, SDG goal dictates that the community should get water at any time when they need 24 h. to achieve water security. In the study area, water supply continuity differs from one sub city to another. From the average domestic water supply continuity results during the data collection time, people in Gish Abay sub-city get the highest i.e. 21.4 h. water supply time with a scale of 4 whereas in Belay Zeleke sub-city, people get the lowest supplying time of 16.5 h. scaled 2.78 (Fig. 2).

Based on the result of pressure gauge measurements at the customers tap, the pressure head sufficiency shows a low range, which means that there are major gaps on pressure sufficiency and need attention to increase the pressure head. According to some literatures and water supply system design guideline, the minimum water pressure head at ground floor is 5 m, and therefore the average pressure head on tap for the city is 7.98 m, which a little bit higher than the minimum range. Since the city plans for house building is given as ground plus one and above, these pressure head will not be enough. The maximum tap water pressure head is shown in 'Shum Abo' sub city with a value of

9.7 m and scale of 2 whereas the minimum tap water pressure head in 'Gish Abay' with the value of 6.4 m scaled 1.5.

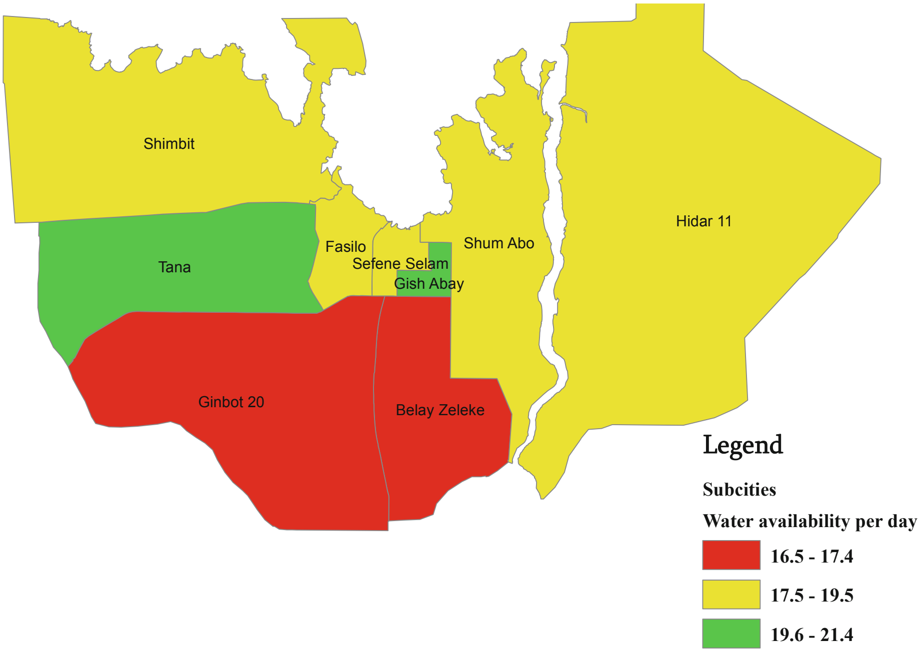

Fig. 2. Average daily domestic water supply availability in hours in each sub-city

Based on the analysis of the collected data, water loss in the system was 45.5% which falls under very low range, which imply incapable of meeting those criterions. High degree of water loss in the system might be due to metering inaccuracies, unbilled metered consumption, unbilled unmetered consumption. In addition, leakage from corroded, old, defective and broken pipes, on service connections up to point of customer metering, due to high pressure, caused by connecting distribution pipes on pressure lines and leakage and overflow at service reservoirs and collection chambers might also be the reasons [21]. This needs strong commitment of the water utility to reduce the high degree of water loss that helps to increase the duration of water availability and coverage in the city which is lagging behind.

Sanitation and Hygiene

Based on the analysis of the collected data, grey water soak pit coverage was 57.4%. The respective proportion of safely managed faecal sludge and coverage of hand wash facilities in the city was 27% and 48.5%. Prevalence of diarrhea under age five was 21.8%. All the above variables fall under very low range, which imply incapable of meeting those criterions. This result clearly indicates that huge proportion of the wastewater generated in the city is discharged in to the local area to the source, neighborhood and within the city (Fig. 3) which might potentially create public health problems. Moreover, the water sources in and around the city like Abay River and Lake Tana will be unsecured due to the discharging of huge volume of untreated wastewater. As per the interview with water quality experts in the city water utility, more than three deep wells within the boundary of the city, which were source of water for the city population, were abandoned due to contamination. High level of diarrhea in the city might be due to contamination of water in the distribution system by the improper discharged wastewater in the city through leaks and weak pipe joints. As per transient weak in some locations in the city, aged water supply lines are installed across and along storm drains where sanitary sewage is stored and flowing through over the pipe line.

From the result of sheet flow diagram (Fig. 3), the fecal sludge (FS) that emptied and transported to the dump site were not treated, rather discharged to the local and nearby environment. Only 27% of the faecal sludge generated is safely managed which is mainly due to faecal sludge contained within the toilet and not emptied from the toilets and the toilets are away from water sources like hand dug wells. There is still practice of open defecation in the city. When toilets got filled, 46% of the community neither safely buried nor emptied, just over flow to the nearby locality and ends up to water bodies including groundwater source. The faecal sludge not contained is the main contributor for unsafely managed faecal sludge in the city and is the main challenge in the sanitation service chain. The faecal sludge contained and emptied but not delivered to treatment plant rather discharged into the city which has 15% proportion to unsafely managed faecal sludge. The proportion of faecal sludge discharged in to the environment within the boundary of the city administration (unsafely managed faecal sludge) is 73% (Fig. 3). This might have significant influence on the security of domestic water in the city.

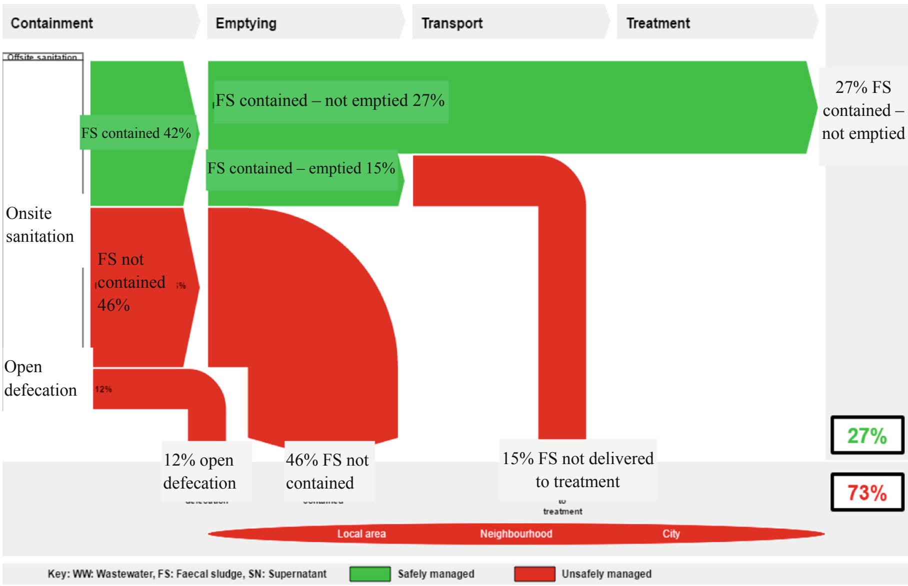

Fig. 3. Existing faecal sludge management situation in the city

The result of coverage of grey water soak pit also shows almost half part of the community does not use it, rather simply pour the grey water into the nearby drainage ditches. On the other hand, both indicators of hygiene have major gaps because of poor coverage of hygienic facilities which are provision of hand wash facilities near to their toilet and implementation of personal hygiene practices. Diarrhea is one of the common indicators that is caused by poor water related hygienic practice. Although all human beings at any age can be affected by diarrhea, its acute effect is usually seen on children under age five. In this study the prevalence of diarrhea in Bahir Dar city on children under age five was estimated as 21.8%, which is very severe that the city health office with other stakeholders need to give strong attention to minimize it.

3.2 Estimation of Water Security Index for Bahir Dar City

The AHP analysis shows that experts give the highest weighting factor to water supply dimension (62.1%), followed by to sanitation dimension (23.6%) and hygiene dimension (14.3%). It results a domestic water security index of medium level (2.8) (Table 4), which implies that the city has a satisfactory system and environment for facilitating domestic water security and still a cause of concern on sanitation (2.29) and hygiene (1.0).

Table 4. Scored result of driver, pressure, state, impact and response by Analytical hierarchy process

Variables	Score	Wt	Indicators	Score	Wt	Dim.	Score	Wt	DWSI
Per capita consumption	3.00	0.39	Water supply availability	2.73	0.35	Water supply	3.41	0.62	**2.8**
Water supply continuity	3.19	0.32							
Pressure adequacy	1.86	0.29							
			Water quality	3.94	0.31				
			Piped water supply coverage	4.00	0.21				
			Water supply affordability	5.00	0.07				
			Water supply loss	1.00	0.06				
Coverage of improved latrine facility	4.00	0.76	Sanitation facilities coverage	3.28	0.57	Sanitation	2.29	0.24	
Coverage of grey water soak pit	1.00	0.24							
			Management of sanitation system	1.00	0.43				
			Coverage of hygienic facilities	1.00	0.51	Hygiene	1.00	0.14	
			Implementation of hygienic practice	1.00	0.49				

4 Conclusion

The developed conceptual domestic water security assessment framework uses an indicator-based approach to carry out an assessment on water supply, sanitation, and hygiene dimensions in Bahir Dar City. The assessment framework would therefore help to identify major challenges of a city in terms of water supply, sanitation, and hygiene situations that are location specific. The developed framework was applied in Bahir Dar City and the result shows considerable difference in domestic water security in different sub-cities in the city. Based on DPSIR result using AHP approach, the water supply dimension is better developed across the city; however, the sanitation dimension shows medium results and hygiene shows poor results. This indicates that the town administration should give the priority to sanitation particularly on the management of wastewater generated but not contained at the point of generation and on the promotion of hygienic practices to enhance the water security level in the city. Generally, the developed framework is applicable, and can be applied to other cities and towns in the country.

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