A Water and Sanitation Ontology for Global City Indicators (ISO 37120)

Robson Navalta and Mark S. Fox
robson.navalta@mail.utoronto.ca; msf@eil.utoronto.ca

Enterprise Integration Laboratory, University of Toronto
5 King's College Road, Toronto ON, M5S 3G8

EIL Working Paper, First Published: 9 October 2019

1. Introduction

To compare and ultimately improve any type of performance, it must be measured and benchmarked. Measuring against defined metrics and indicators are a means of carrying out this activity. Although measuring city performance is no exception to this rule there are issues that make it difficult to do so. These issues are rooted in inconsistency, with cities evaluating their performance using differing metrics amongst each other resulting in poor performance comparisons.

In an effort to standardize the measurement of the performance of city services and quality of life, ISO 37120 "Sustainable Development of Communities – Indicators for City Services and Quality of Life" was published in 2014. Within the standard is a collection of over 100 city indicators spread across 17 different themes each with their own definition and methodology.

The goal of the PolisGnosis project (Fox, 2015) is to develop theories to perform automated longitudinal analysis (how and why a city's indicators change over a period of time) and transversal analysis (how and why indicators differ across cities) in order to identify root causes of differences in city performance. The objective of the first phase of the project is to develop ontologies that represent the ISO 37120 indicator definitions and their supporting data and have them published on the Semantic Web.

The focus of this paper is to identify the requirements to create an ontology that represents the definitions of the indicators in the Water and Sanitation theme as well as its supporting data. To begin the development of the ontology, a set of competency questions are formulated which the ontology must be capable of answering. Next, a literature review of applicable knowledge standards and ontologies is conducted. A GCI Water and Sanitation ontology is then defined along with the specific ISO 37120 Water and Sanitation themed indicator ontologies. Lastly, the ontologies are evaluated on the basis of their capability to answer the competency questions formulated earlier.

2. Indicators and their competency requirements

In this section, the requirements for each Water and Sanitation indicator are provided as defined in ISO 37120. For each indicator, a Competency Questions (CQ) are formulated using the ontology engineering methodology defined by Gruninger & Fox (1995). These competency questions represent the knowledge requirements for an ontology and the formulation of these competency questions are a means of identifying said requirements. Competency questions are organized into four categories:

- **Factual (F):** Questions that ask what the value of some property is.
- **Consistency – Definitional (CD):** Questions that determine whether the instantiation of an indicator by a city is consistent with the ISO 37120 definition.
- **Consistency – Internal (CI):** Questions that determine whether parts of the instantiation are consistent with each other.
- **Deduced (D):** A value or relationship that can be deduced from the instantiation.

Common to all indicators are competency questions that are meta-data related. The following are examples of such competency questions:

1. (F) What are the units of measure for the numerical value?
2. (F) When was the numerical value measured?
3. (F) Who or what agency measured the numerical value?
4. (F) What process was used to measure the value?
5. (CD) Is the indicator's supporting data consistent with the ISO 37120 definition?

21.1 Percentage of city population with potable water supply service (core indicator)

Requirements:

"The percentage of city population with potable water supply service shall be calculated as the total number of people with potable water supply service (numerator) divided by total city population (denominator). The result shall then be multiplied by 100 and expressed as a percentage of city population serviced by a potable water supply service.

The total number of people with potable water supply service shall be calculated as the total number of households in the city connected to a potable water supply service multiplied by the current average household size for the city.

Potable water shall refer to water that is treated or confirmed safe for human consumption. A potable water supply service shall refer to a service that delivers potable water through a pipe or similar duct that is connected to a network, the supply of which is relatively continuous given that it includes a deposit built for its storage. If a house or group of houses has a 'mother' pipe connected either provisionally or permanently; it shall be considered to have access to potable water.

A house shall not be considered to have access to potable water when an individual or group is served by a conduit system built with for example wood, bamboo, or rubber hose, connected directly to a river, well, or to another house."

Data Source:

"*Information should be obtained from the local operator(s) of water supply systems."*

Competency Questions:

1. (F) What city is the indicator measuring?
2. (F) What is the total number of people with potable water supply service?
3. (F) What is the total number of households in the city connected to a potable water supply service?
4. (F) What is the city's average household size for the year the indicator was reported?
5. (F) What type of connection is delivering a potable water supply service to a specific household?
6. (D) Is the potable water supply service to a specific household continuous?
7. (F) What is the source of the potable water supply for a specific household?
8. (F) Which storage deposit is supplying potable water to the network that a household is connected to?
9. (F) Which water service provider is delivering the potable water supply service to a specific household?

21.2 Percentage of city population with sustainable access to an improved water source (core indicator)

Requirements:

"*The percentage of city population with sustainable access to an improved water source shall be calculated as the total population with access to an improved water source (numerator) divided by the total city population. The result shall then be multiplied by 100 and expressed as a percentage.*

An improved water source shall refer to piped water, public tap, borehole or pump, protected well, protected spring or rainwater.

The percentage of city population with sustainable access to an improved water source represents the percentage of the population with reasonable access to an adequate supply of safe water in their dwelling or within convenient distance of their dwelling. Reasonable access to water is defined as availability of at least 20 litres of water per person a day from a source within one kilometer of the dwelling."

Competency Questions:

1. (F) What is the total population with access to an improved water source?
2. (F) What is the total population of the city for the year the indicator was reported?
3. (F) What is the type of improved water source that a person has access to?
4. (F) How far is the nearest improved water source to a specific household?
5. (F) How much water is available to a person in a specific household?

21.3 Percentage of population with access to improved sanitation (core indicator)

Requirements:

"*The percentage of population with access to improved sanitation shall be calculated as the total number of people using improved sanitation facilities (numerator) divided by the total city population (denominator). The result shall then be multiplied by 100 and expressed as a percentage.*

Access to improved sanitation facilities shall refer to the percentage of the city population with at least adequate access to excreta disposal facilities that can effectively prevent human, animal and insect contact with excreta. Improved facilities range from simple, but protected pit latrines to flush toilets with a sewerage connection. To be effective, facilities must be correctly constructed and properly maintained.

Improved sanitation facilities shall include:

- *Flush or pour-flush to piped sewer system, septic tank or pit latrine,*
- *Ventilated improved pit latrine,*
- *Pit latrine with slab and*
- *Composting toilet*

NOTE: Sanitation facilities are not considered improved when shared with other households, or open to public use.

Unimproved sanitation shall include:

- *Flush or pour-flush to elsewhere,*
- *Pit latrine without slab or open pit,*
- *Bucket, hanging toilet or hanging latrine and*
- *No facilities or bush or field (open defecation)"*

Competency Questions:

1. (F) What is the total number of people using improved sanitation facilities?
2. (F) What type of sanitation facility does a person have access to?
3. (CD) Is a household sharing a specific sanitation facility with another household?

4. (CD) Is a specific sanitation facility open to public use?
5. (F) What standard does the sanitation facility adhere to?
6. (F) Who certified the sanitation facility and when?
7. (D) On what basis does maintenance occur? On-demand or scheduled?
8. (F) If maintenance is scheduled, on what frequency is it maintained?

21.4 Total domestic water consumption per capita (litres/day) (core indicator)

Requirements:

"The total domestic water consumption per capita shall be calculated as the total amount of the city's water consumption in litres per day for domestic use (numerator) divided by the total city population (denominator). The result shall be expressed as the total domestic water consumption per capita in litres per day.

Only water consumed for domestic purpose shall be taken into account. Water for industrial and commercial purposes shall be excluded."

Data Sources:

"This information should be obtained from the main water supply companies, which maintain records on water supplied, delivered, consumed and ultimately paid by the end-users for domestic purposes."

Competency Questions:

1. (F) What is the city's total amount of domestic water consumption per day?
2. (F) How much water was consumed by a specific household?
3. (F) Which water supply company supplied the household?

21.5 Total water consumption per capita (liters/day) (supporting indicator)

Requirements:

"Total water consumption per capita (litres/day) shall be calculated as the total amount of the city's water consumption in litres per day (numerator) divided by the total city population (denominator). The result shall be expressed as the total water consumption per capita in litres/days."

Data sources:

"*This information should be obtained from the main water supply companies, which maintain records on water supplied, delivered, consumed and ultimately paid by the end-users."*

Competency Questions:

1. (F) What is the city's total amount of water consumption per day?
2. (F) How much water was consumed by a specific building?

3. (D) Is a specific building a domestic, industrial or commercial consumer?
4. (F) Which water supply company supplied the building?

21.6 Average annual hours of water service interruption per household (supporting indicator)

Requirements:

"The average annual hours of water service interruption per household shall be calculated by taking the total sum of hours of interruption multiplied by the number of households impacted (numerator), divided by the number of households (denominator). The results shall be expressed as the average annual hours of water service interruption per household.

Incidents of complete shutoff, low flow restriction, boil water advisory, water main flushing, planned and unplanned interruptions shall be counted equally.

This indicator shall exclude:

- *Incidents where there is some reduction to the level of service but where normal activities (shower, washing machine, toilet flushing etc.) are still possible, and*
- *Breaks in house connection branches.*

An 'unplanned interruption' is an interruption caused by a fault in the utility's system. A "planned interruption" is an interruption for which the utility has provided at least 24 h advanced notification (or as otherwise prescribed by regulatory requirements)."

Competency Questions:

1. (F) What is the total sum of hours of water service interruptions?
2. (F) How many households were impacted by a water service interruption?
3. (F) What was the type of water service interruption?
4. (D) Was the water service interruption planned or unplanned?
5. (D) Were water services still accessible?

21.7 Percentage of water loss (unaccounted for water) (supporting indicator)

Requirements:

"The percentage of water loss (unaccounted for water) shall be calculated as the volume of water supplied minus the volume of utilized water (numerator) divided by the total volume of water supplied (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

The percentage of water loss (unaccounted for water) represents the percentage of water that is lost from treated water entering distribution system and that is accounted for and billed by the water provider. This includes actual water losses, e.g. leaking pipes, and billing losses, e.g. delivered through informal or illegal connection."

Data Sources:

"*Data should be obtained from water utilities servicing the city.*"

Competency Questions:

1. (F) What is the total volume of water supplied?
2. (F) What is the volume of water consumed by a specific building?
3. (F) Which water supply company provided the water?

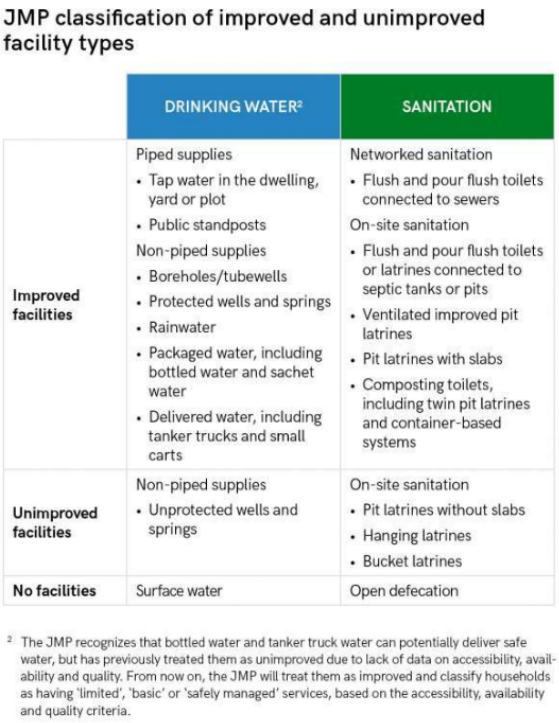
3. Background

In this section, established knowledge standards and ontologies are reviewed. The ontologies that can satisfy the competency questions for the GCI Water and Sanitation ontology are identified for re-use. The ontologies reviewed are placed into two categories: water-related and non water-related.

3.1. Knowledge standards

JMP Facility Type Classification

The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) established a standard set of drinking water and sanitation facility type classes (JMP, 2015) that are captured within indicators 21.2 and 21.3. Note that within the requirements for indicators 21.2 and 21.3, the facility types that fall under the 'No facilities' category are included under the 'Unimproved facilities' category. Figure 1 below depicts the category types.



JMP classification of improved and unimproved facility types

	DRINKING WATER[2]	SANITATION
Improved facilities	Piped supplies • Tap water in the dwelling, yard or plot • Public standposts Non-piped supplies • Boreholes/tubewells • Protected wells and springs • Rainwater • Packaged water, including bottled water and sachet water • Delivered water, including tanker trucks and small carts	Networked sanitation • Flush and pour flush toilets connected to sewers On-site sanitation • Flush and pour flush toilets or latrines connected to septic tanks or pits • Ventilated improved pit latrines • Pit latrines with slabs • Composting toilets, including twin pit latrines and container-based systems
Unimproved facilities	Non-piped supplies • Unprotected wells and springs	On-site sanitation • Pit latrines without slabs • Hanging latrines • Bucket latrines
No facilities	Surface water	Open defecation

[2] The JMP recognizes that bottled water and tanker truck water can potentially deliver safe water, but has previously treated them as unimproved due to lack of data on accessibility, availability and quality. From now on, the JMP will treat them as improved and classify households as having 'limited', 'basic' or 'safely managed' services, based on the accessibility, availability and quality criteria.

Figure 1 - JMP Classification of Facility Types

3.2. Water Related Ontologies

Smart City Artifacts – Water Ontology

The Smart City Artifacts Water ontology was one of the ontologies developed to create the Semantic Water Quality Portal (SWQP). SWQP aims to connect water data to ultimately identify polluted water sources and facilities in geographic areas that are of interest. The water ontology itself contains four classes related to water quality concepts: BodyOfWater, Facility, Measurement, and MeasurementSite. As such, the Smart Artifacts Water Ontology provides more micro level concepts that are not specified by our CQs. The concept of potable water is enough to convey the notion of water quality in the context of answering our competency questions. Its OWL file can be found here:

http://ci.emse.fr/opensensingcity/ns/sca/project_19/

Environment Ontology (ENVO)

The ENVO ontology (Buttigieg, et al., 2016) contains the concept of water and further classification concepts of water such as acidic water and fresh water. The concept conveyed by the environment ontology is in the context of an environmental material composed of its chemical constituents. It does not contain the concept of potable water or drinking water. Not suitable for our use case.

Preferred Name	water
Definitions	An oxygen hydride consisting of an oxygen atom that is covalently bonded to two hydrogen atoms.
ID	http://purl.obolibrary.org/obo/CHEBI_15377
definition	An oxygen hydride consisting of an oxygen atom that is covalently bonded to two hydrogen atoms.
label	water
prefixIRI	CHEBI:15377
prefLabel	water
subClassOf	oxygen hydride inorganic hydroxy compound molecular entity mononuclear parent hydride

Figure 2 - Water as conceptualized by ENVO

hydrOntology

hydrOntology (Vilches-Blazquez, et al., 2009) is an ontology focused on defining concepts related to hydrographical features such as rivers, reservoirs, and lakes. The ontology was developed using knowledge models such as the IGN-E, the Alexandria Digital Library, the UNESCO Thesaurus and many more. ISO 37120 was not one of the knowledge standards considered. hydrOntology evolved into a global hydrographical domain ontology and as such lacks concepts related to water as a resource and within the context of city infrastructure, which is what is required to answer our competency questions.

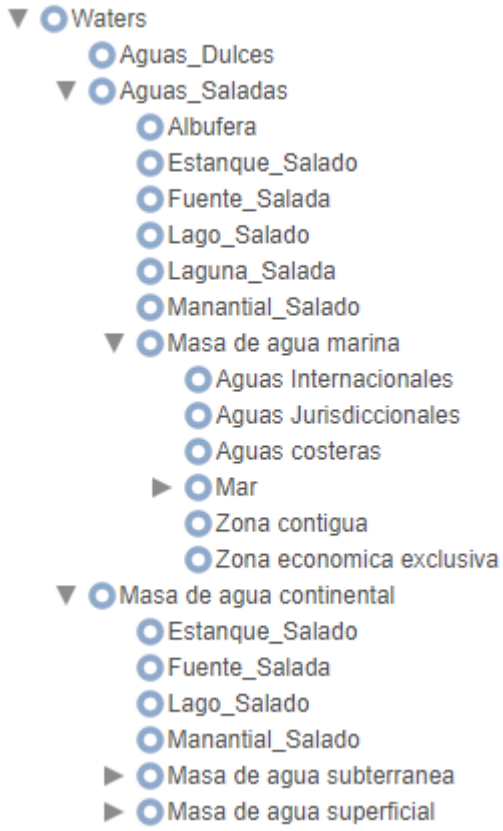


Figure 3 – Water related class and subclasses represented in hydrOntology

WatERP Ontology

The WatERP (Varas, 2015) ontology was developed with the purpose of representing the water distribution supply chain and resource management. It merges different hydrological management perspectives (operational, financial, and planning) to form a holistic one. The concepts represented within the ontology can be divided into five categories:

- Matching between supply and Demand
  Observation & Measurement
- Decision procedures
- Water Management Flows
- Economic Management Flows

Figure 4 below depicts an overview of the general schema of the WatERP ontology.

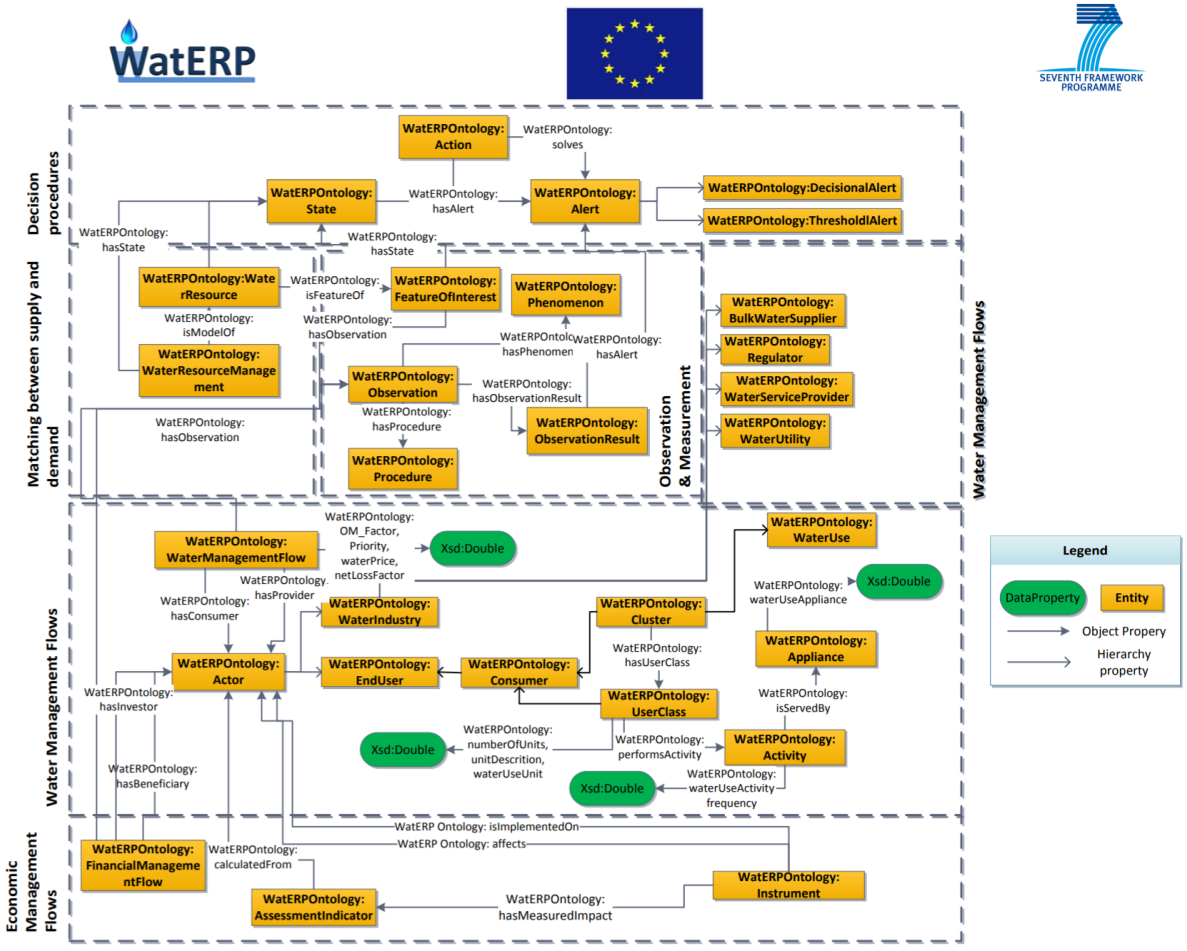


Figure 4 - Overview of concepts found in the WatERP ontology

Of all the concepts depicted in the WatERP ontology, those that fall under the "Matching between water supply and demand" category are the closest representation of the concepts that are required to answer our competency questions. For example, the 'Transport' concept represents a water management resource that is capable of moving water from one point to another. However, these concepts are higher level abstractions that are not specific enough to satisfy our competency questions. We would need to extend the 'Transport' concept to contain subclasses that convey the notion of pipes with different materials of construction. Figure 5 below depicts a representation of the 'Matching between water supply and demand' category within the WatERP ontology.

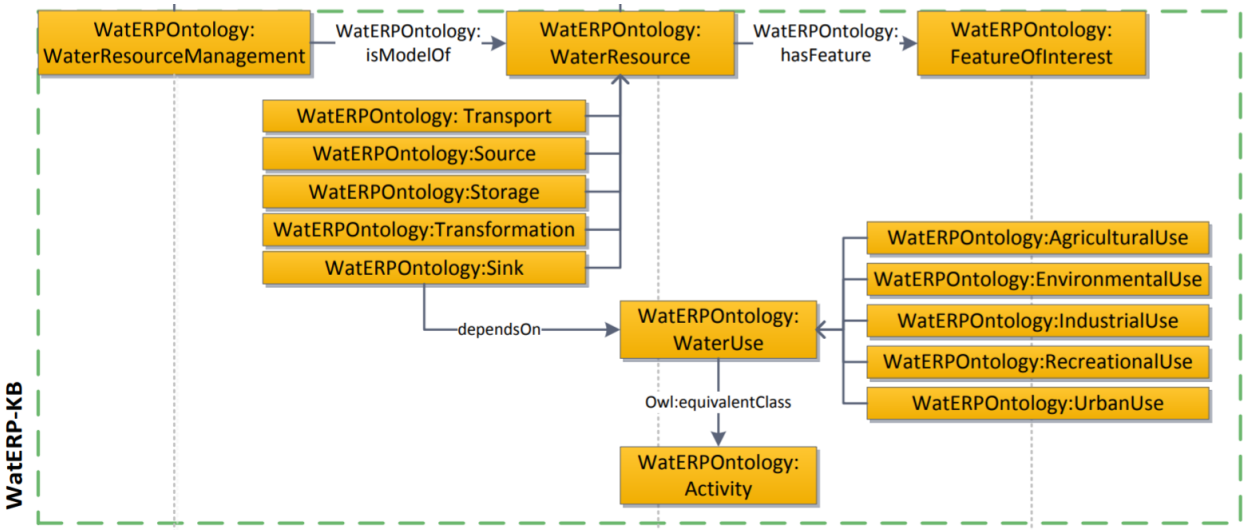


Figure 5 - Concepts found in the "Matching between water supply and demand" category

3.3. Non-Water Related Ontologies

Smart City Artifacts - Infrastructure Product Ontology

The Smart City Artifacts Infrastructure Product ontology provides representations for utility infrastructure products and their attributes. Product concepts are divided into five types:

- Water
- Wastewater
- Gas
- Electricity
- Telecom

Within the water type infrastructure products, the concepts defined are extended to a deeper level that is beyond what is required to answer our competency questions. Concepts such as 'WaterValveType' and 'WaterPlug' are examples of this. The ontology does contain the concepts of metallic and non-metallic piping which could be used to answer competency questions in indicator 21.1; however, the ontology needs to be extended to convey the notion of wood, bamboo, and rubber hosing/piping which are evidently missing. The Smart City Artifacts – Infrastructure Product ontology can be found here:

http://ci.emse.fr/opensensingcity/ns/wp-content/plugins/smartcities/survey_files/vocabs/vocabulary_86

Common Semantic Model (COSMO)

The Common Semantic Model (COSMO) ontology (Cassidy, 2010) is an upper level ontology that was intended to represent general concepts for a broad range of applications. Many of the classes defined within the COSMO ontology were re-used from the OpenCYC and SUMO ontologies. The COSMO ontology contains classes related to facilities, maintenance, and construction which can be re-used to

satisfy some sanitation related knowledge requirements in a GCI Water and Sanitation ontology. To fill in the requirement gaps, sanitation specific concepts need to be defined and extensions need to be made to link these concepts to each other.

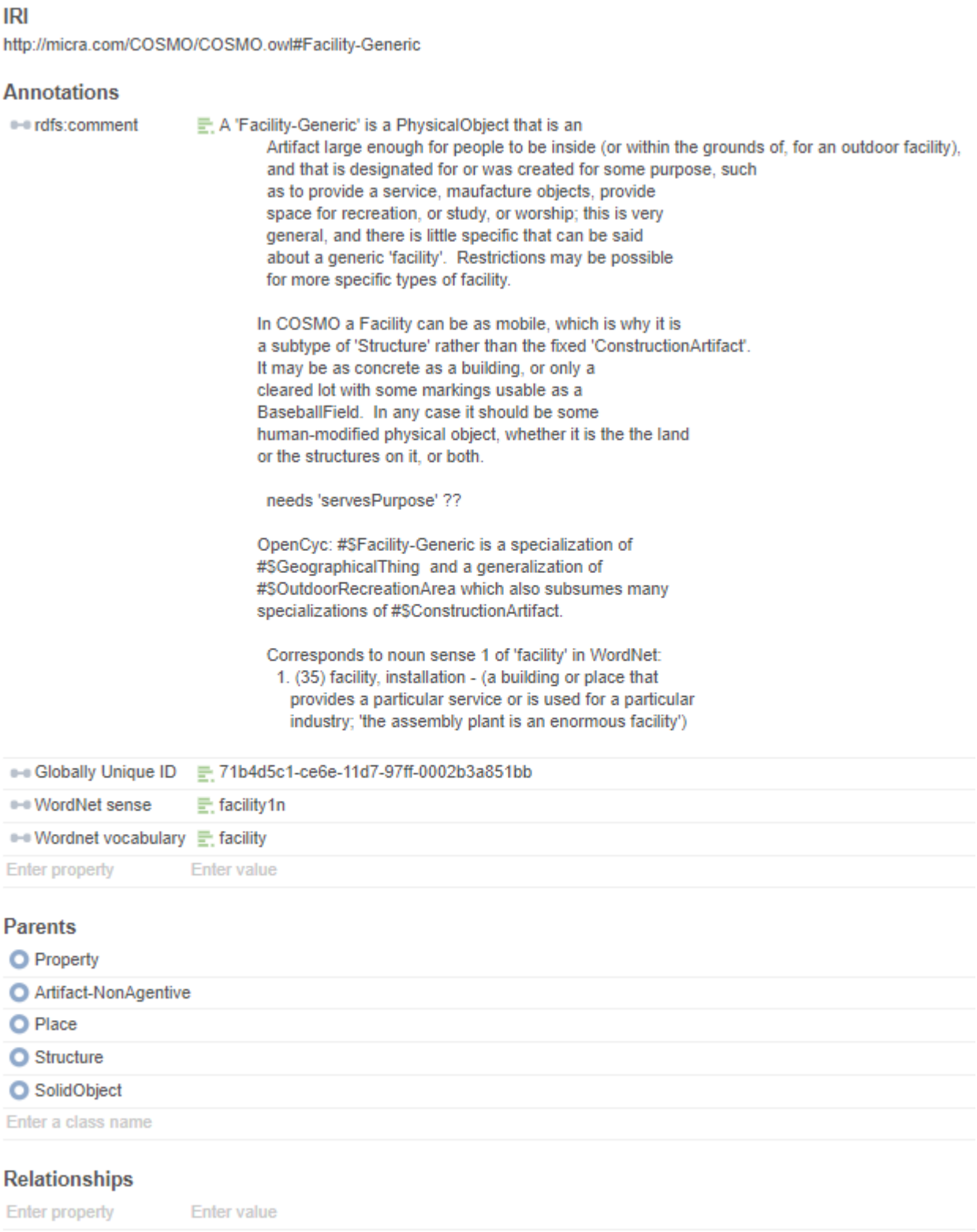


Figure 6 - A "Generic Facility" as defined by the COSMO ontology

GCI Service Ontology

A majority of the knowledge requirements for a GCI Water and Sanitation ontology are inherently a need to represent water services. As such, it is appropriate to review service type ontologies. Figure 7 below depicts classes and properties defined within the Service ontology (Voß, 2013).

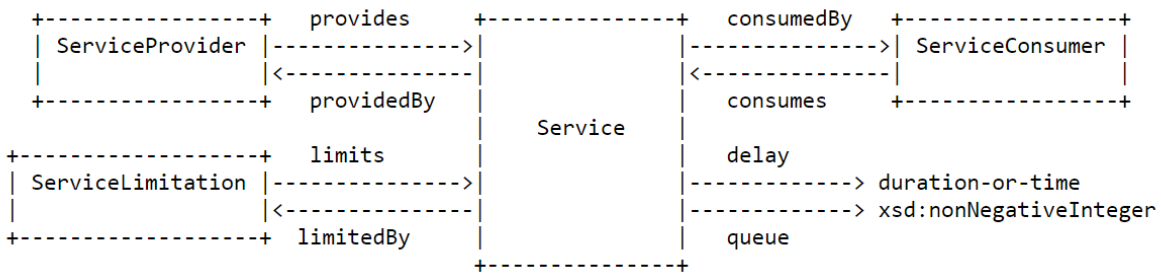


Figure 7 - Classes and properties of the service ontology

The GCI Telecommunications and Innovation (Forde & Fox, 2015) ontology contains the GCI Service sub-ontology that integrates and extends the Service ontology. The GCI Service sub-ontology extends the Service ontology by introducing the concept of 'APurchase' and to convey the notion of a transaction that allows service provision/consumption at a given price. The GCI Energy (Komisar & Fox, 2017) ontology extends the GCI Service ontology even further by defining an ElectricalService ontology to capture electricity related concepts needed to answer its competency questions.

Much like the GCI Energy ontology, the water and sanitation ontology will require a 'WaterService' ontology to capture water related concepts needed to answer our competency questions. The ElectricalService ontology provides a framework that can be mirrored almost completely. Its only shortcoming is that it does not capture the concept of planned/unplanned service interruptions and delivery of services that is required to answer the competency questions in indicator 21.6 and 21.1, respectively.

GCI Building Occupancy Ontology

Indicators 21.4 and 21.5 differentiate between domestic, industrial and commercial buildings. Therefore there is a need to review ontologies that represent these concepts. The GCI Building Occupancy ontology (Komisar and Fox 2017) satisfies this need by defining the building concepts needed to answer our competency questions and additionally a 'PublicBuilding' concept. It also addresses the fact that building occupancy can be heterogeneous with respect to the nature of its use (residential + commercial) and defines concepts such as 'Residential_FloorArea' to capture region specific definitions of a domestic/residential building.

3.4. Global City Indicator Foundation Ontology

To develop the GCI Water and Sanitation ontology, we build it on top of the GCI Foundation (Fox, 2013) ontology. As its name suggests, this ontology serves as a foundation for our ontology by providing concepts that are necessary to represent metadata for all indicator themes. The GCI

foundation ontology integrates and extends the following ontologies which are also depicted in the figure below:

- Statistics (Pattuelli, 2009)
- Trust (Huang & Fox, 2006)
- Placenames (www.geonames.org)
- Measurement (Rijgersberg et al., 2011)
- Provenance (Lebo et al., 2013)
- Validity (Fox & Huang, 2005)
- Time (Hobbs & Pan, 2006)

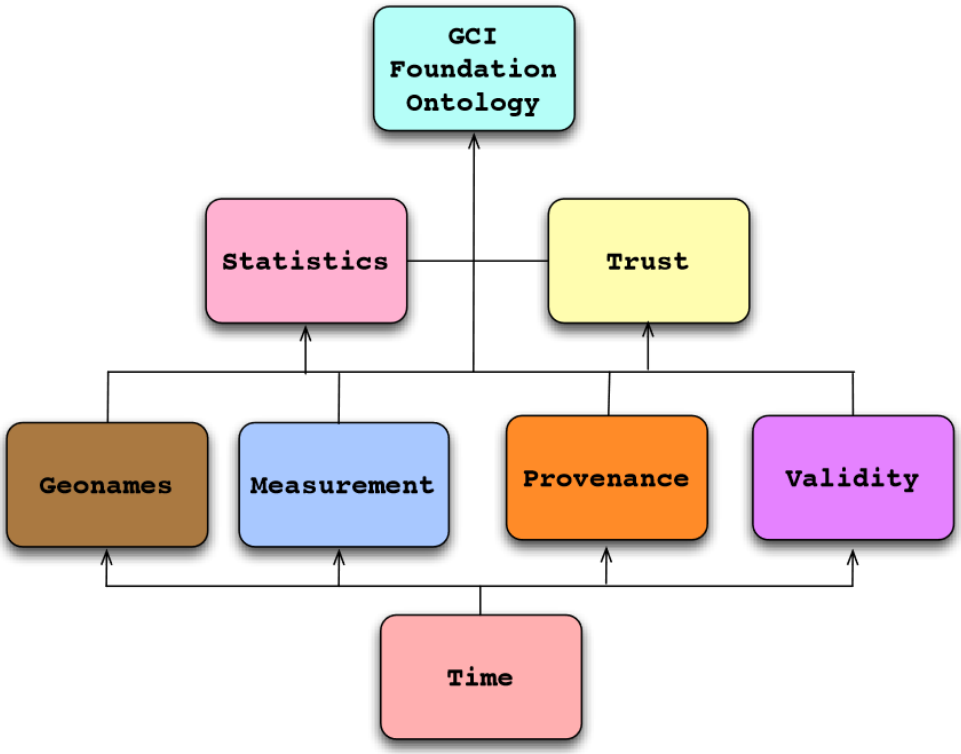


Figure 8 - GCI Foundation Ontology

4. Architecture of the Global City Indicator Ontology

At the top level of the architecture is the ISO37120 ontology which defines all of the global city indicators and contains the IRIs for each one. For example, the IRI for indicator 21.4 "Total domestic water consumption per capita" is as follows: http://ontology.eil.utoronto.ca/ISO37120.owl#21.4

For each set of ISO 37120 theme indicators, a separate OWL file exists that contains the definition of each indicator for that specific theme. For the Water and Sanitation theme, its OWL file contains all seven indicator definitions specific to Water and Sanitation.

Below the ISO37120 ontology are the theme specific GCI ontologies. Within the theme specific GCI ontologies are the sub-ontologies required to develop their respective indicator definitions. For example, to define the ISO 37120 Water and Sanitation theme indicators, concepts such as water services and sanitation facilities need to be represented and are captured within the GCI Water and Sanitation ontology.

The GCI Foundation ontology serves as the base for all of the ISO 37120 and GCI theme ontologies and contains more generic concepts related to populations, units, meta-data, etc.

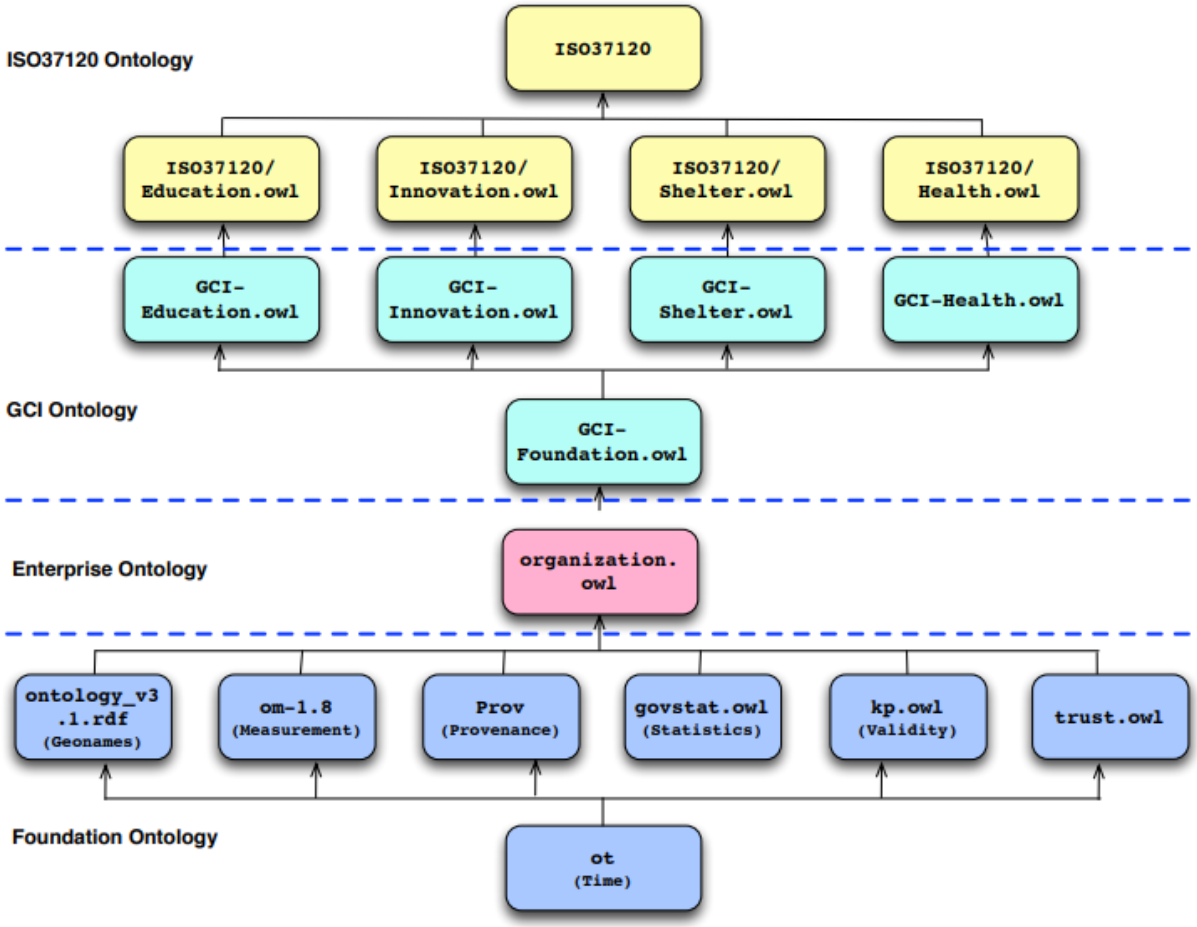


Figure 9 - GCI Ontology Architecture

5. GCI Water and Sanitation Ontology

5.1 GCI Service Ontology

Conceptually water is treated as a service within the ISO 37120 Water and Sanitation theme, therefore the ontology for the theme should be developed on top of a service ontology. An ontology that captures concepts of consumption, provision, delivery, transportation, and interruption of a service will need to be defined.

Below are some of the competency questions related to service:

1. (F) What is the total number of households in the city connected to a potable water supply service?
2. (F) What is the source of the potable water supply for a specific household?
3. (F) How far is the nearest improved water source to a specific household?
4. (F) How much water is available to a person in a specific household?
5. (F) What is the city's total amount of domestic water consumption per day?
6. (F) How much water was consumed by a specific building?
7. (F) How many households were impacted by a water service interruption?
8. (D) Were water services still accessible?
9. (F) What is the total volume of water supplied?

The underlying service ontology is the GCI Service ontology which is an extension of the Document Service ontology (Voß, 2013), GCI Innovation ontology (Forde & Fox, 2015), and GCI Energy ontology (Komisar & Fox, 2017). Classes and properties that are re-used from the GCI Service ontology contain the prefix "gcise" and those that do not contain a prefix denote concepts that are additions. The extensions introduced in this paper include concepts related to distance of a service source, delivery of services as well as water service related subclasses of established service classes.

Service Entities

As defined in the GCI Energy ontology, "ServiceConsumer" and "ServiceProvider" are classes that represent entities that participate in the act of service consumption and provision, respectively. The "ServiceConsumerGroup" class represents entities that take part in the act of consumption and are defined by groups such as residential households or commercial organizations as opposed to individuals.

Class	**Property**	**Value Restriction**
gcise:ServiceConsumer	owl:subclassOf	so:ServiceConsumer
	owl:subclassOf	org:agent
	gcise:experience ServiceInterruptions	only gcise:ServiceInterruption
	so:consumes	min 1 gcise:Service
	gcise:connectedThrough	gcise:ServiceAccount
	gcise:authorizedBy	min 1 gcise:ServiceProvider
gcise:Service ConsumerGroup	gcise:consist_of	min 1 gcise:ServiceConsumer
	gcise:experience ServiceInterruption	only gcise:ServiceInterruption
	gcise:authorizedBy	min 1 gcise:ServiceProvider
	so:consumers	min 1 gcise:Service
	gcise:using	min 1 gcise:ServiceAccount
	gcise:legallyAuthorizedBy	min 1 gcii:Apurchase
	gcise:represents_a	some (org:Division or gcis:Household or

		org:Organization)
gcise:ServiceProvider	owl:subclassOf	so:ServiceProvider
	owl:subclassOf	org:Organization
	gcise:authorizes	min 1 gcise:ServiceAccount
	so:provides	min 1 gcise:Service
	ic:hasAddress	some ic:Address

Service Accounts

As defined in the GCI Energy ontology, a transaction must occur before the consumption and provision of services are allowed. The "APurchase" class from the GCI Innovation ontology conveys this concept. This class is a subclass of schema.org's "Offers" class which is defined as "the transfer of some rights to an item or to provide a service" and extends this definition to occur between a "ServiceProvider" and a "ServiceConsumer".

Class	Property	Value Restriction
gcii:Apurchase	owl:subclassOf	sch:Offer
	gcii:consumedBy	some so:ServiceConsumer
	gcii:providedBy	exactly 1 so:ServiceProvider
	gcii:servicetype	exactly 1 so:Service
	gcii: 'price currency'	some xsd:decimal
	gcii:certification_Date	exactly 1 xsd:dateTime
	gcii:expiry_Date	exactly 1 xsd:dateTime

The "ServiceAccount" class is a subclass of the "APurchase" and extends the class to include information related to consumption and provision measures, account ownership and active/inactive statuses.

Class	Property	Value Restriction
gcise:ServiceAccount	owl:subclassOf	gcii:APurchase
	gcise:accountActive	exactly 1 xsd:boolean
	gcise:authorizedBy	exactly 1 gcise:ServiceProvider
	gcise:providedBy	exactly 1 gcise:ServiceProvider
	gcise:hasServiceAddress	min 1 ic:Address
	gcise:hasServiceArea	only gcise:ServiceAreaMeasure
	gcise:hasServiceType	only gcise:Service
	gcise:consumedBy	min 1 gcise:ServiceConsumer
	gcise:owned_by	min 1 foaf:Agent
	gcise:hasConsumption	min 1 gci:GCI_quantity
	gcise:has ServiceInterruption	only gcise:ServiceInterruption

Service Consumption

"ServiceConsumptionQuantity" is imported from the GCI Service ontology to measure the amount of services that are by being consumed by all instances of "ServiceConsumer" and

"ServiceConsumerGroup" classes. The "om:value" property represents the numerical value of service consumption.

Class	Property	Value Restriction
gcise:Service ConsumptionQuantity	owl:subclassOf	gci:GCI_quantity
	om:value	only (om:Measure and om:unit_of_measure)
	gcise:forService	only gcise:Service
		min 1 gcise:Service
	gcii:consumedBy	only (so:ServiceConsumer or so:ServiceConsumerGroup)
gcise:service ConsumptionVar	rdf:type	gs:Variable
	gs:has_Name	value "hasConsumption"

Service Production

The "ServiceProduction" class is imported from the GCI Service ontology and includes an object property "deliveredBy" which is introduced as an extension to convey the notion of the transportation of services between providers and consumers.

Class	Property	Value Restriction
gcise:ServiceProduction	gcise:forService	some gcise:Service
	deliveredBy	some ServiceDelivery
	gcise:quantity OfProduction	some gcise:ServiceProductionQuantity
gcise:ServiceProduction Quantity	owl:subclassOf	gci:GCI_quantity
	om:value	only (om:Measure and om:unit_of_measure)
	gcise:forService	only gcise:Service
gcise:serviceProductionVar	rdf:type	gs:Variable
	gs:has_Name	value gcise:quantityOfProduction

Service Source Distance

The GCI Service ontology needs to be extended to capture the distance of services sources as it is represented within the ISO 37120 Water and Sanitation theme. The "ServiceSourceDistance" and "ServiceSourceDistanceQuantity" classes are introduced below to satisfy this requirement.

Class	Property	Value Restriction
ServiceSourceDistance	owl:subclassOf	sch:Distance
	gcise:forService	some gcise:Service
	toServiceSource	some gcise:ServiceProduction
	quantityOf SourceDistance	some ServiceSourceDistanceQuantity
ServiceSourceDistance Quantity	owl:subclassOf	gci:GCI_quantity
	om:unit_of_measure	om:kilometer
	om:value	only (om:Measure and

		om:unit_of_measure.om:kilometer)
serviceSourceDistanceVar	rdf:type	gs:Variable
	gs:has_Name	value “quantityOfSourceDistance”

Service Interruption

Indicator 21.6 requires the “ServiceInterruption” class to construct its ontology and as such is re-used from the GCI Service ontology. The property “serviceWasAccessible” was added to identify access to service during interruptions. “causedBySystemFault” and “advancedNoticeOf” was added to differentiate between planned and unplanned interruptions within the ISO 37120 Water and Sanitation theme.

Class	**Property**	**Value Restriction**
gcise:ServiceInterruption	owl:subclassOf	Iode:Event
	causedBySystemFault	only xsd:Boolean
	ot:HasDurationDescription	exactly 1 ot:DurationDescription
	gcise:impactAccount	only gcise:ServiceAccount
	gcise:num_accounts	exactly 1 xsd:nonNegativeInteger
	gcise:impactProvider	only gcise:ServiceProvider
	serviceWasAccessible	only xsd:Boolean
	advancedNoticeOf	only ot:DurationDescription
gcise:Service InterruptionMeasure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:interruption
gcise:serviceInterruptionVar	rdf:type	gs:Variable
	gs:has_Name	value "num_accounts"
gcise:Service DurationMeasure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value om:hour
gcise:serviceDurationVar	rdf:type	gs:Variable
	gs:has_Name	value "HasDurationDescription"

Service Delivery

Indicator 21.1 requires the representation of the delivery of services between a source and consumer. The class “DeliveryMethod” from schema.org is defined as “…a standardization procedure for transferring the product or service to the destination of fulfillment…” The extended “ServiceDelivery” class introduced below is built upon this definition.

ISO 37120 deems defines a water service a potable water supply service if it satisfies the following criteria:

- Is delivered through a pipe or a similar duct
- Has a continuous supply
- Includes a deposit built for its storage

The class “ServiceTransporter” is meant to represent the means of transporting services such as a pipe or duct. The property “composedOfMaterial” is added to the “ServiceTransporter” class to

capture its material of construction. “ServiceStorage” depicts a physical construct that stores a service resource between the source and consumer and is used to represent storage deposits and is linked to the “ServiceDelivery” class by its property “hasStorage”. The property “isContinuous” is added to the “ServiceDelivery” class to convey the notion of a continuous supply of services.

Class	Property	Value Restriction
ServiceDelivery	owl:subclassOf	sch:DeliveryMethod
	gcise:forService	some Service
	hasSource	only gcise:ServiceProduction
	hasStorage	only ServiceStorage
	isTransportedBy	only ServiceTransporter
	gcise:consumedBy	only (gcise:ServiceConsumer or gcise:ServiceConsumerGroup)
	isContinuous	only xsd:Boolean
ServiceTransporter	owl:subclassOf	cosmo:Conveyance
	composedOfMaterial	some cosmo:Construction MaterialType
ServiceStorage	owl:subclassOf	cosmo:StorageConstruct
	gcise:forService	only gcise:Service

With the service ontology and its extensions developed, subclasses specific to water services can be constructed.

Water Service Entities

Litres per day is the specific unit of measure used consistently across the ISO 37120 Water and Sanitation theme definitions and is therefore used as the default unit of measure for all classes of water related measures requiring one.

Class	Property	Value Restriction
WaterService	owl:subclassOf	gcise:Service
WaterConsumer	owl:subclassOf	gcise:ServiceConsumer
	gcii:consumes	some WaterService
WaterConsumerGroup	owl:subclassOf	gcise:ServiceConsumerGroup
	gcii:consumes	some WaterService
WaterServiceAccount	owl:subclassOf	gcise:ServiceAccount
	gcise:hasServiceType	only WaterService
	hasWaterConsumption	only WaterService ConsumptionQuantity
WaterService ConsumptionQuantity	owl:subclassOf	gcise:Service ConsumptionQuantity
	om:value	only (om:Measure and om:unit_of_measure. gci:liter_per_day)
	om:unit_of_measure	gci:liter_per_day
	gcise:forService	only WaterService

waterConsumptionVar	rdf:type	gs:Variable
	gs:has_Name	value "hasWaterConsumption"
WaterServiceProvider	owl:subclassOf	gcise:ServiceProvider
	gcise:distributes	some WaterService

Water Service Delivery

Indicator 21.1 considers a house to have access to potable water if it has a mother pipe that is connected provisionally or permanently. Therefore, the object property "hasMotherPipeConnectionType" was added to the "WaterServiceDelivery" subclass to satisfy requirements for indicator 21.1. Two subclasses of "WaterServiceDelivery" are added "ProvisionalWaterServiceDelivery" and "PermanentWaterServiceDelivery" are introduced and are differentiated by the value of its "hasMotherPipeConnectionType" property.

Class	**Property**	**Value Restriction**
WaterServiceDelivery	owl:subclassOf	ServiceDelivery
	gcise:forService	only WaterService
	hasStorage	only WaterServiceStorage
	hasSource	only WaterServiceSource
	hasConsumer	only (WaterConsumer or Water ConsumerGroup)
	hasMotherPipeConnectionType	only (cosmo:Provisional or cosmo:Permanent)
ProvisionalWaterServiceDelivery	owl:subclassOf	WaterServiceDelivery
	hasMotherPipeConnectionType	only cosmo:Provisional
PermanentWaterServiceDelivery	owl:subclassOf	WaterServiceDelivery
	hasMotherPipeConnectionType	only cosmo:Permanent
WaterServiceTransporter	owl:subclassOf	ServiceTransporter
	gcise:forService	only WaterService
WaterServiceStorage	owl:subclassOf	ServiceStorage
	gcise:forService	only WaterService

Water Service Source

The unit of measure to convey distance within the ISO 37120 Water and Sanitation theme is kilometer; therefore its measure is conveyed as such.

Class	**Property**	**Value Restriction**
WaterServiceSource	owl:subclassOf	gcise:ServiceProduction
	gcise:forService	only WaterService
	gcise:quantityOf Production	WaterServiceProductionQuantity
	quantityOf SourceDistance	WaterServiceSource DistanceQuantity
WaterServiceProductionQuantity	owl:subclassOf	gcise:ServiceProductionQuantity

	om:unit_of_measure	gci:liter_per_day
	om:value	only (om:Measure and om:unit_of_measure. gci:liter_per_day)
	gcise:forService	only WaterService
waterProductionVar	rdf:type	gs:Variable
	gs:has_Name	value “quantityOfProduction”
WaterServiceSourceDistance	owl:subclassOf	sch:Distance
	gcise:forService	only WaterService
	toServiceSource	only WaterServiceSource
WaterServiceSource DistanceQuantity	owl:subclassOf	ServiceSourceDistanceQuantity
	om:unit_of_measure	om:kilometer
	om:value	only (om:Measure and om:unit_of_measure.om:kilometer)
	gcise:forService	only WaterService
waterServiceSourceDistanceVar	rdf:type	gs:Variable
	gs:has_Name	value “quantityOfSourceDistance”

Indicator 21.2 defines water sources as improved or unimproved. Additional improved water sources subclasses are defined to capture the different types outlined within the indicator.

Class	**Property**	**Value Restriction**
ImprovedWaterSource	owl:subclassOf	WaterServiceSource
UnimprovedWaterSource	owl:subclassOf	WaterServiceSource
PipedWater	owl:subclassOf	ImprovedWaterSource
PublicTap	owl:subclassOf	ImprovedWaterSource
Borehole	owl:subclassOf	ImprovedWaterSource
Pump	owl:subclassOf	ImprovedWaterSource
ProtectedWell	owl:subclassOf	ImprovedWaterSource
ProtectedSpring	owl:subclassOf	ImprovedWaterSource
ProtectedRainwater	owl:subclassOf	ImprovedWaterSource

Water Service Interruption

Indicator 21.6 defines additional subclasses of water service interruptions. The “UnplannedWaterServiceInterruption” class is defined by its “causedBySystemFault” property when it is equal to true. The “PlannedWaterServiceInterruption” class is defined by its “advancedNoticeOf” property as per the requirement in indicator 21.6.

Class	**Property**	**Value Restriction**
WaterServiceInterruption	owl:subclassOf	gcise:ServiceInterruption
	forService	only WaterService
WaterServiceDurationMeasure	owl:subclassOf	gcise:ServiceDurationMeasure
	forService	only WaterService

Class	**Property**	**Value Restriction**

CompleteShutoff	owl:subclassOf	WaterServiceInterruption
LowFlowRestriction	owl:subclassOf	WaterServiceInterruption
BoilWaterAdvisory	owl:subclassOf	WaterServiceInterruption
WaterMainFlushing	owl:subclassOf	WaterServiceInterruption
UnplannedWater ServiceInterruption	owl:subclassOf	WaterServiceInterruption
	causedBySystemFault	value xsd:true
PlannedWater ServiceInterruption	owl:subclassOf	WaterServiceInterruption
	advancedNoticeOf	exactly 1 ot:DurationDescription

5.2 GCI Building Occupancy Ontology

Water services can be consumed by buildings alongside the people who occupy them. The ISO 37120 Water and Sanitation theme distinguishes between domestic, commercial, and residential water service consumers. There is a need to capture these concepts in order to develop the GCI Water and Sanitation ontology.

Some of the building occupancy related competency questions include:

1. (F) Which storage deposit is supplying potable water to the network that a household is connected to?
2. (F) How much water was consumed by a specific household?
3. (F) How much water was consumed by a specific building?
4. (D) Is a specific building a domestic, industrial or commercial consumer?
5. (F) Which water supply company supplied the building?

The building occupancy ontology is re-used from the GCI Energy ontology (Komisar & Fox, 2017) and served as an extension of concepts developed within the GCI Shelter ontology (Wang & Fox, 2015) and GCI Innovation ontology (Forde & Fox, 2015). Water service related concepts are combined with the building occupancy concepts outlined below to represent the different types of water service consumers.

Building

As defined in the GCI Energy ontology, the concept of a building is depicted as an enclosed free standing structure that contains rooms and spaces. The “Building” class below, which is imported directly from the GCI Building Occupancy ontology, allows for regionally specific definitions of a “ResidentialBuilding”. The property “hasWaterConsumption” is added to the “Building” class to capture its water consumption.

Class	**Property**	**Value Restriction**
gcibo:Building	owl:subclassOf	db:Building
	ic:hasAddress	exactly 1 ic:Address

	gcibo:hasUnitAddress	exactly 1 gcibo:TenantSpace
	gcibo:hasFloorArea	exactly 1 gcibo:FloorArea_Quantity
	gcibo:hasResFloorArea	exactly 1 gcibo:FloorArea_Quantity
	gcibo:occupied_by	some (gcis:Household or org:Division or org:Organization)
	gcise:has WaterConsumption	gcise:WaterService ConsumptionQuantity
	gcibo:hasTenantSpace	only gcibo:TenantSpace
	gcibo:hasTenancy	only gcibo:Tenant
	org:has_Ownership	exactly 1 org:Ownership
	owned_by	min 1 org:agent
gcibo:ResidentialBuilding	owl:subclassOf	gcibo:Building
	gcibo:hasHouseholds	min 1 gcis:Household
gcibo:CommercialBuilding	owl:subclassOf	gcibo:Building
gcibo:IndustrialBuilding	owl:subclassOf	gcibo:Building

Tenant

As defined in the GCI Energy ontology, building occupancy is not always homogenous in its composition. For example, a building may have commercial businesses that occupy some part of it while the rest of the building is used for residential purposes. By re-using the "Tenant" class from the GCI Building Occupancy ontology, heterogeneous buildings can be captured.

Class	**Property**	**Value Restriction**
gcibo:Tenant	owl:subclassOf	org:Agent
	gcibo:occupies	min 1 gcibo:TenantSpace
	gcibo:represents	only (gcis:Household or org:Division or org:Organization)
gcis:Household	gcis:hasSize	only gcis:Household_size
	gcis:hasMember	only sch:Person
org:Organization	gcis:hasSize	only gcibo:Organization_size
	gcibo:consistsOf	only org:Division
	gcibo:has_Ownership	only gcibo:Ownership
	gcibo:hasLegalName	1 xsd:string
org:Division	gcibo:divisionOf	some org:Organization
	gcis:hasSize	only gcibo:Organization_division_size
gcibo:TenantSpace	gcibo:hasUnitIndicator	some rdfs:Literal
	gcibo:insideBuilding	exactly 1 gcibo:Building
	gcibo:occupied_by	min 1 gcibo:Tenant
	gcise:connected ServiceAccounts	min 1 gcibo:ServiceAccount

Household

The definition of household is directly imported from the GCI Shelter ontology and is used to represent residentially occupied buildings.

Class	Property	Value Restriction
gcis:Household_size	owl:subclassOf	gci:GCI_quantity
	om:value	only gcis:Household_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	prov:wasDerivedFrom	some cyc:census
gcis:Household_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
gcis:Average_household_size	owl:subclassOf	gci:GCI_quantity
	gci:for_city	only gci:City
	om:value	only gcis:Household_size_measure
gcis:Average_household_size_ Measure	owl:subclassOf	gci:GCI_measure
	prov:wasDerivedFrom	some gcis:Household_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string

Organization

For the representation of non-residential buildings, the concepts of an organization and organization division are re-used from the GCI Building Occupancy ontology.

Class	Property	Value Restriction
gcibo:Organization_size	owl:subclassOf	gci:GCI_quantity
	om:value	only gcibo:Organization_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
gcibo:Organization_ size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string
gcibo:Organization_ Division_size	owl:subclassOf	gci:GCI_quantity
	om:value	only gcibo:Organization_ Division_size_measure
	om:unit_of_measure	value gci:population_cardinality_unit
gcibo:Organization_ Division_size_measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value gci:population_cardinality_unit
	om:numeric_value	exactly 1 xsd:string

Floor Area

The classes below allow for the representation of the amount of floor space that is occupied within a building for a given tenant which are also re-used from the GCI Building Occupancy ontology.

Class	Property	Value Restriction
gcibo:FloorArea_Quantity	owl:subclassOf	gci:GCI_quantity
	om:unit_of_measure	value om:metre_sqaure
	om:value	only gcibo:FloorArea_Measure
gcibo:FloorArea_Measure	owl:subclassOf	gci:GCI_measure
	om:unit_of_measure	value om:metre_sqaure
gcibo:floorAreaVar	rdf:type	gs:Variable
	gs:has_Name	"hasFloorArea"

Water Service Consumers and Customer Accounts

By combining the service concepts defined in the previous section with the building occupancy concepts established above, the different types of water service consumer accounts can be represented.

Class	Property	Value Restriction
ResidentialWaterServiceCustomerAccount	owl:subclassOf	WaterServiceAccount
	gcise:owned_by	some ResidentialWaterConsumerHousehold
	gcise:providedBy	exactly 1 WaterServiceProvider
	gcise:has WaterConsumption	gciws:WaterServiceConsumptionQuantity
CommercialWaterServiceCustomerAccount	owl:subclassOf	WaterServiceAccount
	gcise:owned_by	some CommercialWaterConsumerOrganization
	gcise:providedBy	exactly 1 WaterServiceProvider
	gcise:has WaterConsumption	gciws:WaterServiceConsumptionQuantity
IndustrialWaterServiceCustomerAccount	owl:subclassOf	WaterServiceAccount
	gcise:owned_by	some IndustrialWaterConsumerOrganization
	gcise:providedBy	exactly 1 WaterServiceProvider
	gcise:has WaterConsumption	gciws:WaterServiceConsumptionQuantity
ResidentialWaterConsumerHousehold	owl:subclassOf	gcis:Household
	gcise:connectThrough	some ResidentialWaterServiceCustomerAccount
	gcise:consist_of	only ResidentialWaterConsumer
	gcibo:occupies	only gcibo:ResidentialBuilding
ResidentialWaterConsumer	owl:subclassOf	WaterConsumer
	gcise:connectThrough	some ResidentialWaterServiceCustomerAccount

	gcii:consumes	only WaterService
	gcise:authorizedBy	only WaterServiceProvider
CommercialWater ConsumerOrganization	owl:subclassOf	org:Division or org:Organization
	gcise:connectThrough	some CommercialWater ServiceCustomerAccount
	gcibo:occupies	only gcibo:CommercialBuilding
IndustrialWater ConsumerOrganziation	owl:subclassOf	org:Division or org:Organization
	gcise:connectThrough	some IndustrialWater ServiceCustomerAccount
	gcibo:occupies	only gcibo:IndustrialBuilding

5.3 GCI Activity Facility Ontology

The ISO 37120 Water and Sanitation theme treats sanitation as an activity to partake in. Therefore, the service concepts outlined beforehand will not be sufficient in representing sanitation. Within the requirements of the GCI Water and Sanitation ontology the act of sanitation also occurs within some facility that is designed for it. Thus, there is a need to represent facilities designed for some specific activity in the GCI Water and Sanitation ontology.

Competency questions related to facilities include:

1. (F) What is the total number of people using improved sanitation facilities?
2. (F) What type of sanitation facility does a person have access to?
3. (F) What standard does the sanitation facility adhere to?
4. (F) Who certified the sanitation facility and when?
5. (D) On what basis does maintenance occur? On-demand or scheduled?
6. (F) If maintenance is scheduled, on what frequency is it maintained?

The upper level COSMO ontology contains the “Facility-Generic” class that is defined as “…an artifact large enough for people to be inside (or within the grounds of, for an outdoor facility), and that is designated for or was created for some purpose…” For re-use in the Water and Sanitation ontology to be sufficient, classes and properties pertaining to construction standards and maintenance need to be added.

Within the context of the Water and Sanitation ontology, maintenance needs to be represented as an activity in which the act of maintaining some object occurs. The “FacilityMaintenance” class is introduced to capture the concept of the event of maintaining a facility. The object property “hasFrequencyPeriod” is added to the class to represent maintenance activities that are either instantaneous or happen on some scheduled basis. “ScheduledFacilityMaintenance” and “OnDemandFacilityMaintanence” are introduced as subclasses of “FacilityMaintenance” to differentiate their temporal nature.

Facility

Class	Property	Value Restriction
Facility	owl:subclassOf	cosmo:Facility-Generic
	hasFacilityMaintenance	some FacilityMaintenance
	gcise:owned_by	some (gcis:Household or org:Division or org:Organization)
	gcir:hasFloorArea	exactly 1 gcir:FloorArea_Quantity
	certifiedToFacilityStandard	some FacilityStandard
	gcii:certification_Date	exactly 1 xsd:DateTime
	certifiedBy	some cosmo:Authority
	cosmo:hasDesignFunction	only act:Activity
	isOpenToPublic	only xsd:Boolean
FacilityStandard	owl:subclassOf	cosmo:StandardSpec
	forFacility	some Facility
	cosmo:wasCreatedBy	cosmo:Authority
FacilityMaintenance	owl:subclassOf	act:Activity
	cosmo:allowsOrAssists	cosmo:MaintainingAnObject
	forFacility	some Facility
	hasFrequencyPeriod	only (ot:DurationDescription or ot:Instant)
ScheduledFacility Maintenance	owl:subclassOf	FacilityMaintenance
	hasFrequencyPeriod	only ot:DurationDescription
OnDemandFacility Maintenance	owl:subclassOf	FacilityMaintenance
	hasFrequencyPeriod	only ot:Instant

Sanitation

By defining "Sanitation" as a subclass of an activity, the notion of a facility meant for the act of sanitation can be conveyed by the "SanitationFacility" class.

Class	Property	Value Restriction
Sanitation	owl:subclassOf	act:Activity
	owl:subclassOf	cosmo: HumanActivity
	cosmo:hasParticipant	gcis:Person
SanitationFacility	owl:subclassOf	Facility
	cosmo: isOwnedBy	exactly 1 gcis:Household
	cosmo: hasDesignFunction	only Sanitation

Indicator 21.3 further defines subclasses of sanitation facilities which are outlined below.

Class	Property	Value Restriction
ImprovedSanitationFacility	owl:subclassOf	SanitationFacility
	gcise:owned_by	max 1 gcis:Household
UnimprovedSanitationFacility	owl:subclassOf	SanitationFacility
FlushToPipedSewerSystem	owl:subclassOf	ImprovedSanitationFacility
FlushToSepticTank	owl:subclassOf	ImprovedSanitationFacility

FlushToPitLatrine	owl:subclassOf	ImprovedSanitationFacility
VentilatedPitLatrine	owl:subclassOf	ImprovedSanitationFacility
PitLatrineWithslab	owl:subclassOf	ImprovedSanitationFacility
CompostingToilet	owl:subclassOf	ImprovedSanitationFacility
FlushToElsewhere	owl:subclassOf	UnimprovedSanitationFacility
PitLatrineWithoutSlab	owl:subclassOf	UnimprovedSanitationFacility
OpenPit	owl:subclassOf	UnimprovedSanitationFacility
Bucket	owl:subclassOf	UnimprovedSanitationFacility
HangingToilet	owl:subclassOf	UnimprovedSanitationFacility
HangingLatrine	owl:subclassOf	UnimprovedSanitationFacility
Bush	owl:subclassOf	UnimprovedSanitationFacility
Field	owl:subclassOf	UnimprovedSanitationFacility
NoFacilities	owl:subclassOf	UnimprovedSanitationFacility

6. GCI Foundation Ontology Infrastructure

In this section, the basic structure of a ratio indicator as defined in the GCI Foundation ontology (Fox, 2013) is reviewed. The Water and Sanitation indicators are based upon the same design patterns.

The OM measurement ontology (Rijgersberg, 2011) serves as the basis for the GCI Foundation ontology and allows for the representation of the underlying semantics of a number, such as what is being measured and what units of measure were used. This opens up the opportunity to identify inconsistent numerical comparisons and their root causes such as mismatching units of measure.

Figure 10 depicts the three classes of the OM ontology used to represent an indicator and its value. The “Quantity” class represents what is being measured e.g. the distance to a lake. The “Unit of Measure” class defines how the quantity is measured according to some unit e.g. kilometers. The “Measure” class denotes the numerical value of the measurement of some specific “Quantity” class with some specific “Unit of Measure” class. For example, a “percentage of population with potable water supply service” is a subclass of a “gci:GCI_quantity”. Its value is a subclass of a “measure” that is expressed in units of “percent”. These units of “percent” are a type of “unit of measure”. The numerical value expressed is a property of the “population with potable water supply service measure” class

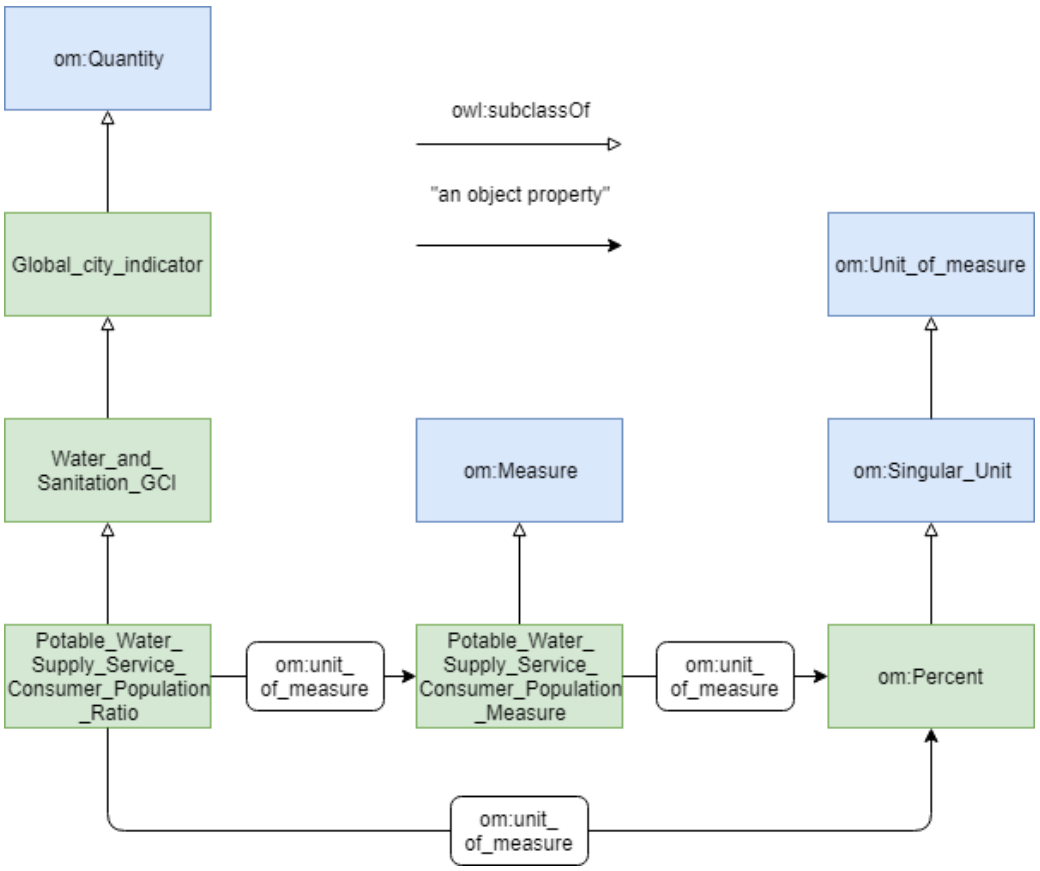


Figure 10 - Potable Water Supply Service Consumer Definition

The percentage of people with potable water supply service is based on the ratio of a population of individuals with potable water supply service to the total population within a city. These numbers can be viewed as a statistical measurement as they are essentially counts of a population that are defined by individuals that satisfy specific criteria for their respective populations. A majority of the indicator require counts of populations of defined members. There are also some indicators that require statistical or mathematical operations such as mean, sum, subtraction, etc. to be performed.

All of the Water and Sanitation indicators are expressed as ratios (Fox, 2013). Therefore, all indicators contain a numerator and denominator that are represented by a “population” class. Each population represents a collection of some defined object such as a consumer or a household that is located in some “City”. “Population size” can be represented as the cardinality of a “population”. For each ratio indicator, its unit of measure is expressed as a “population ratio unit” and is the ratio of cardinalities (“population size”) of two “populations”.

In the case of the percentage of people with potable water supply service, the numerator could be the size of a population defined by a “Person” with potable water supply service that resides in some “City”. The denominator could be the size of a population defined by a “Person” residing in the same “City” as the population defined in the numerator. This ratio indicator structure is used across all indicator ontologies defined in the next section.

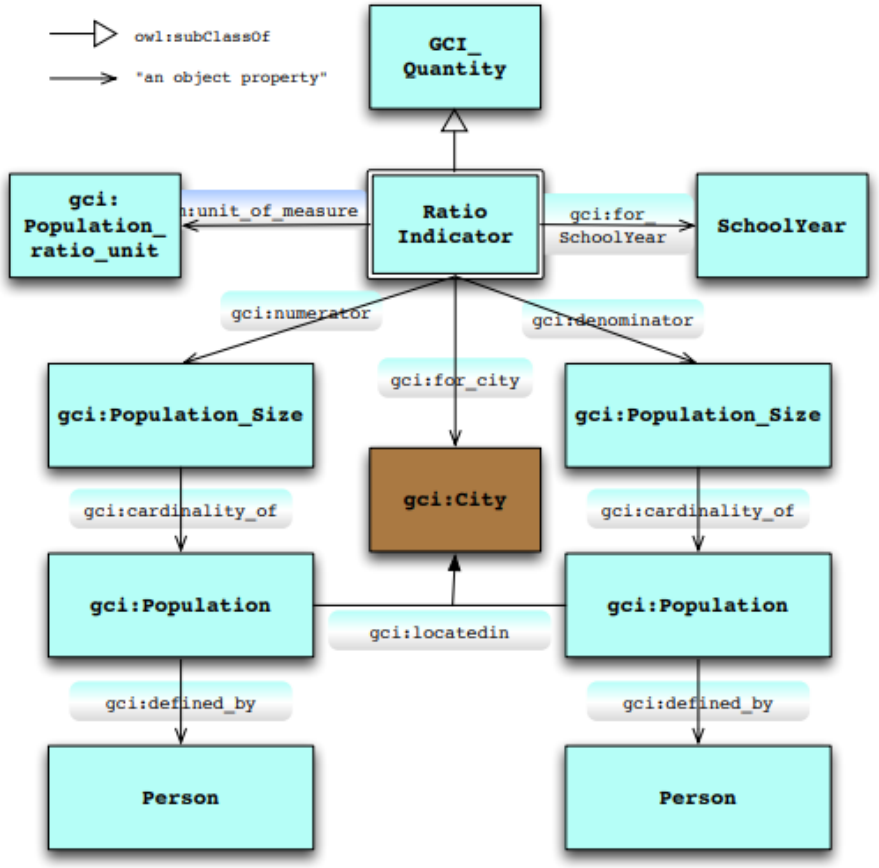


Figure 11 - GCI Foundation Ontology Ratio Indicator Definition

7. ISO 37120 Water and Sanitation Indicators Ontology

In this section, each indicator is defined using the GCI Water and Sanitation ontology defined in section 5. The "gci:City_Population_Size" and "gci:City_Population" classes are common terms that are required for multiple indicator definitions. Their properties are depicted below.

Class	Property	Value Restriction
gci:City_Population_Size	owl:subclassOf	gci:Population_size
	gci:cardinality_of	exactly 1 gci:City_Population
	om:unit_of_measure	value gci:population_cardinality_unit
gci:City_Population	owl:subclassOf	gci:Population
	gci:defined_by	exactly 1 gci:Resident
	function_of	some gcis:Average_household_size
	located_in	exactly 1 gci:city

21.1 Percentage of city population with potable water supply service (core indicator)

This indicator describes the percentage of a city population with potable water supply service. The numerator is "21.1_Population_with_Potable_Water_Supply_Service" and represents the population with potable water supply service. The denominator is the whole population of the city and is represented by the "gci:City_Population_Size" class.

Class	Property	Value Restriction
iso37120:21.1	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	gci:City_Population_Size
	om:numerator	exactly 1 21.1_Population_with_ Potable_Water_Supply_Service
	om:unit_of_measure	only om:percent

The numerator is calculated by multiplying the number of households with potable water supply service by the average household size. The "Average_household_size" class was imported from the GCI Shelter ontology. The quantity calculated determines the total number of people with potable water supply service.

Class	Property	Value Restriction
21.1_Population_with_Potable_ Water_Supply_Service	owl:subclassOf	gci:Product_Quantity
	om:unit_of_ measure	value gci:population_cardinality_unit
	om:term_1	exactly 1 21.1_Population_of_Household_ Accounts_Connected_to_a_ Potable_Water_Supply_Service_Size
	om:term_2	exactly 1 gcis:Average_household_size
	om:value	exactly 1 gci:Population_measure
21.1_Population_of_Household_ Accounts_Connected_to_a_ Potable_Water_Supply_Service_Size	owl:subclassOf	gci:Population_size
	gci:cardinality_ of	only 21.1_Population_of_Household_ Accounts_Connected_to_a_Potabe_ Water_Supply_Service
21.1_Population_of_Household_ Accounts_Connected_to_a_Potable _Water_Supply_Service	owl:subclassOf	gs:Population
	gci:defined_by	only 21.1_Household_Account_ Connected_to_a_Potable_ Water_Supply_Service

For a water service to be consider potable, the indicator requires a water service delivery be continuous and have a deposit for storage. Therefore the value of the object property "isContinuous" is set to true and "hasStorage" is restricted to containing at least 1 WaterServiceStorage for "21.1_Potable_Water_
Supply_Service_Delivery".

Class	Property	Value Restriction
21.1_Household_Account_ Connected_to_a_Potable_ Water_Supply_Service	owl:subclassOf	gciws:ResidentialWater ServiceCustomerAccount
	gcise:hasService Type	some 21.1_Potable_Water_Supply_Service
21.1_Potable_Water_ Supply_Service	owl:subclassOf	gciws:WaterService
	deliveredBy	some 21.1_Potable_Water_Supply _Service_Delivery
21.1_Potable_Water_ Supply_Service_Delivery	owl:subclassOf	gciws:WaterServiceDelivery
	isContinuous	value xsd:true
	hasStorage	min 1 WaterServiceStorage

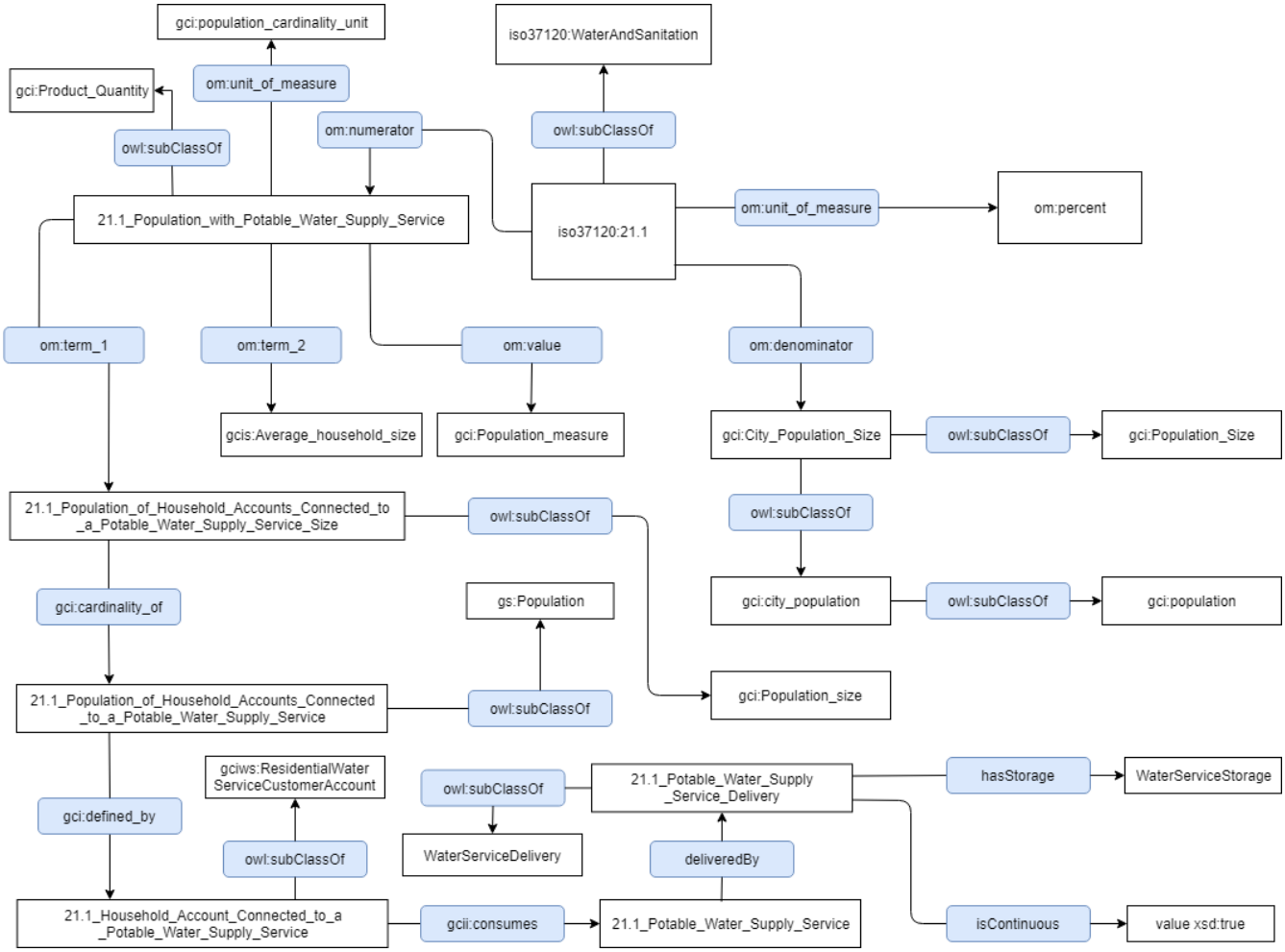


Figure 12 - Definition of ISO 37120 Indicator 21.1

21.2 Percentage of city population with sustainable access to an improved water source (core indicator)

The second indicator describes the percentage of the total population who have sustainable access to an improved water source. The numerator defines said population and is represented by the

gci:cardinality_of "21.2_Population_with_Sustainable_Access_to_an_Improved_Water_Source". gci:City_population_Size is used as the denominator of this indicator and represents the total population of the city.

Class	Property	Value Restriction
iso37120:21.2	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	gci:City_Population_Size
	om:numerator	21.2_Population_with_Sustainable_ Access_to_an_Improved_Water_Source_Size
	om:unit_of_measure	only om:percent

The population with sustainable access to an improved water source is defined by a person who has said access. "21.2_Consumer_with_Sustainable_Access_to_an_Improved_Water_Source" represents these individuals. The definition of a person is subclass of the "ResidentialWaterConsumerHousehold" class.

Class	Property	Value Restriction
21.2_Population_with_ Sustainable_Access_to_an_ Improved_Water_ Source_Size	owl:subclassOf	gci:Population_size
	gci:cardinality_of	21.2_Population_with_Sustainable _Access_to_an_Improved_ Water_Source
21.2_Population_with_ Sustainable_Access_to_an_ Improved_Water_Source	owl:subclassOf	gs:Population
	gci:defined_by	only 21.2_Consumer_with_Sustainable_ Access_to_an_Improved_ Water_Source
21.2_Consumer_with_ Sustainable_Access_to_an_ Improved_Water_Source	owl:subclassOf	ResidentialWaterConsumer
	gcise:hasSource	exactly 1 gciws:ImprovedWaterSource
	gcise:hasWater Consumption	exactly 1 21.2_Improved_Water_Source_with_ Sustainable_Access_Consumption_ Quantity
21.2_Dwelling_with_ Sustainable_Access_to_an_ Improved_Water_Source	owl:subclassOf	gciws:ResidentialWater ConsumerHousehold
	gcis:consist_of	only 21.2_Consumer_with_ Sustainable_Access_to_an_ Improved_Water_Source
	gcise:quantityOf SourceDistance	exactly 1 21.2_Improved_Water_Source_with_ Sustainable_Access_ Distance_Quantity

A source that produces at least 20 litres of water per person a day within one kilometer of the person's dwelling is deemed to have the capacity to provide "reasonable access to an adequate

supply of safe water" according to the indicator requirements. "21.2_Consumer_with_Sustainable_Access_to_an_Improved_Water_Source" requires the object property "quantityOfConsumption" to measure the consumption threshold and "21.2_Dwelling_with_Sustainable_Access_to_an_Improved_Water_Source" requires the property "distanceToSource" to measure the distance threshold to satisfy the indicator requirements.

Class	**Property**	**Value Restriction**
21.2_Improved_Water_Source_with_Sustainable_Access_Consumption_Quantity	owl:subclassOf	gciws:WaterService ConsumptionQuantity
	om:unit_of_measure	gci:liter_per_day
	om:value	only 21.2_Improved_Water_Source_with_Sustainable_Access_Consumption_Measure
21.2_Improved_Water_Source_with_Sustainable_Access_Consumption_Measure	owl:subclassOf	om:Measure
	om:unit_of_measure	gci:liter_per_day
	om:numerical_value	xsd:minInclusive "20"^^xsd:float
21.2_Improved_Water_Source_with_Sustainable_Access_Distance_Quantity	owl:subclassOf	gciws:WaterService SourceDistanceQuantity
	om:unit_of_measure	om:kilometer
	om:value	only 21.2_Improved_Water_Source_with_Sustainable_Access_Distance_Measure
21.2_Improved_Water_Source_with_Sustainable_Access_Distance_Measure	owl:subclassOf	om:Measure
	om:unit_of_measure	om:kilometer
	om:numerical_value	xsd:maxInclusive "1"^^xsd:float

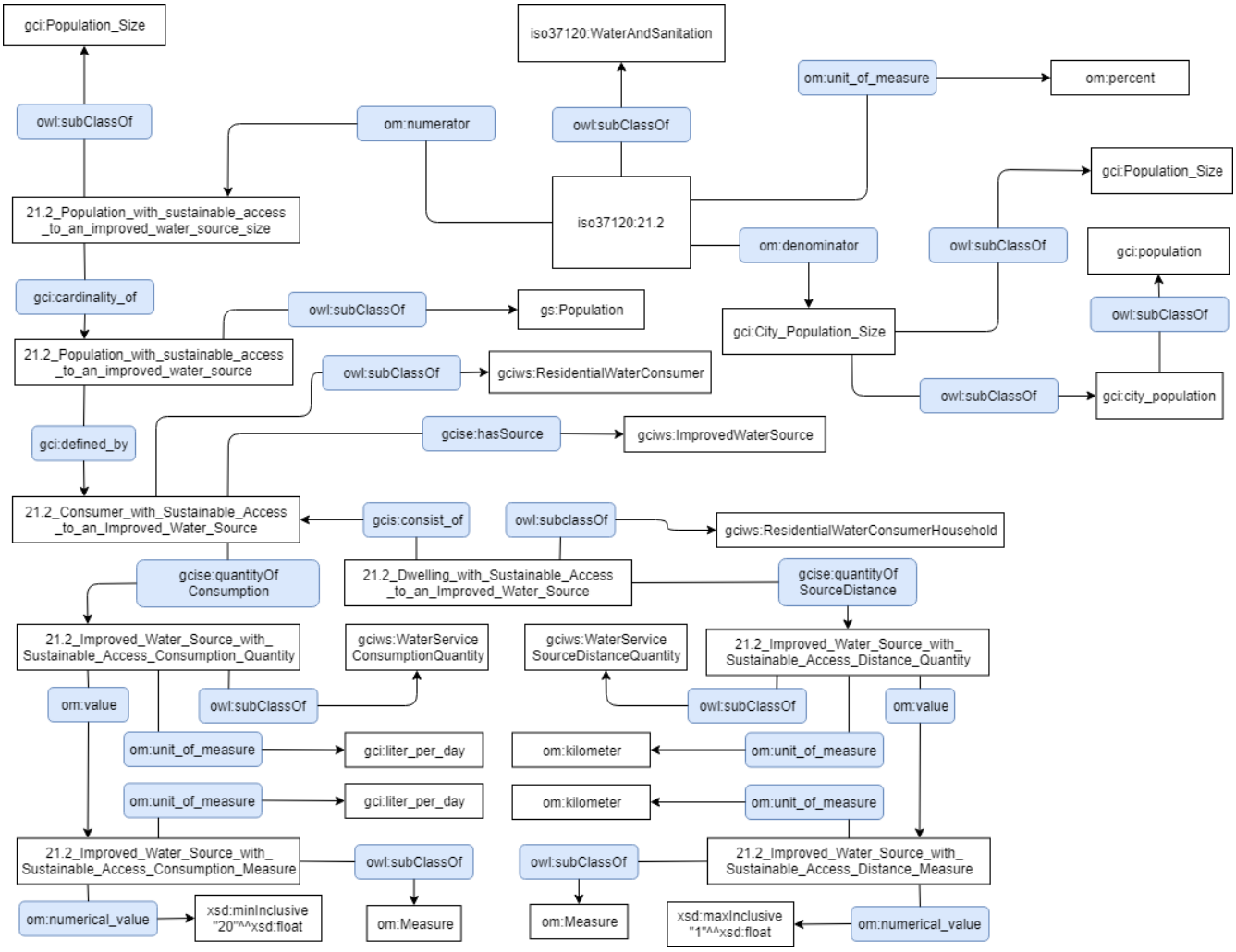


Figure 13 - Definition of ISO 37120 Indicator 21.2

21.3 Percentage of population with access to improved sanitation (core indicator)

The third indicator determines the percentage of a city's population with access to improved sanitation. It is evaluated by determining the ratio of the population with access to improved sanitation to the total city population.

Class	Property	Value Restriction
iso37120:21.3	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	gci:City_Population_Size
	om:numerator	21.3_Population_with_access_to_ improved_sanitation_size
	om:unit_of_measure	only om:percent

The numerator is "21.3_Population_with_access_to_improved_sanitation_size" which is the cardinality of a population defined by a person who has access to an improved sanitation facility.

Class	Property	Value Restriction
21.3_Population_with_access_to_improved_sanitation_size	owl:subclassOf	gci:Population_size
	gci:cardinality_of	21.3_Population_with_access_to_improved_sanitation
21.3_Population_with_access_to_improved_sanitation	owl:subclassOf	gs:Population
	gci:defined_by	only gcis:Person and (hasAccessto. gciws:ImprovedSanitationFacility)

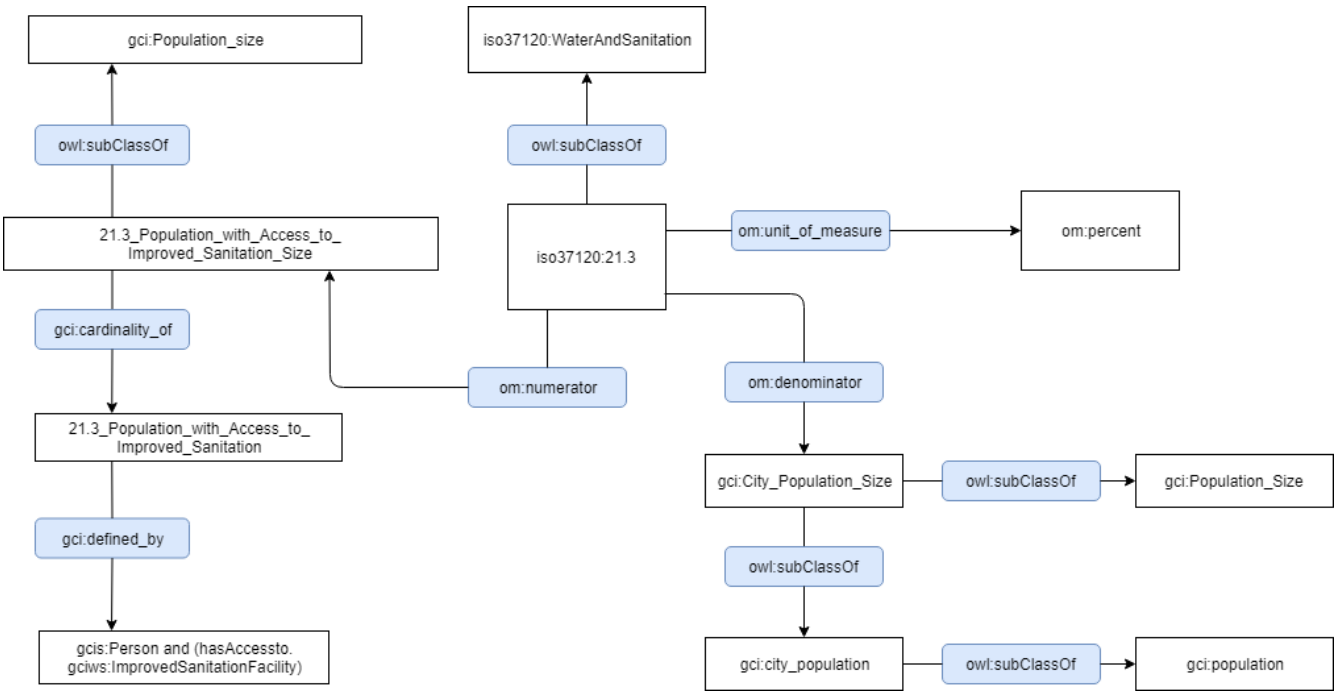


Figure 14 - Definition of ISO 37120 Indicator 21.3

21.4 Total domestic water consumption per capita (litres/day) (core indicator)

The total domestic water consumption per capita represents the total amount of water that a city would consume for domestic use per person and is expressed in litres per day. The denominator for this indicator is “gci:City_Population_Size” which represents the total population of a city. The numerator defines the total domestic consumption term and is represented by “21.4_Total_Domestic_Water_Consumption”.

Class	Property	Value Restriction
iso37120:21.4	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	gci:City_Population_Size
	om:numerator	21.4_Total_Domestic_Water_Consumption
	om:unit_of_measure	gci:liter_per_day

Total domestic water consumption is determined by first identifying a population defined by domestic or residential water service customer accounts. From this population,

"21.4_Total_Domestic_Water_Consumption" sums the value of gcise:hasWaterConsumption from each water service customer account in the population.

Class	Property	Value Restriction
21.4_Total_Domestic_ Water_Consumption	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 21.4_Population_of_ Domestic_Water_Consumption_ Customer_Accounts
	om:value	exactly 1 om:Measure and (om:unit_of_measure.gci:liter_per_day)
	gs:sum_of_var	value gcise:waterConsumptionVar
21.4_Population_of_Domestic_ Water_Consumption_Customer_ Accounts	owl:subclassOf	gs:Population
	gci:defined_by	only gciws:ResidentialWaterService CustomerAccount

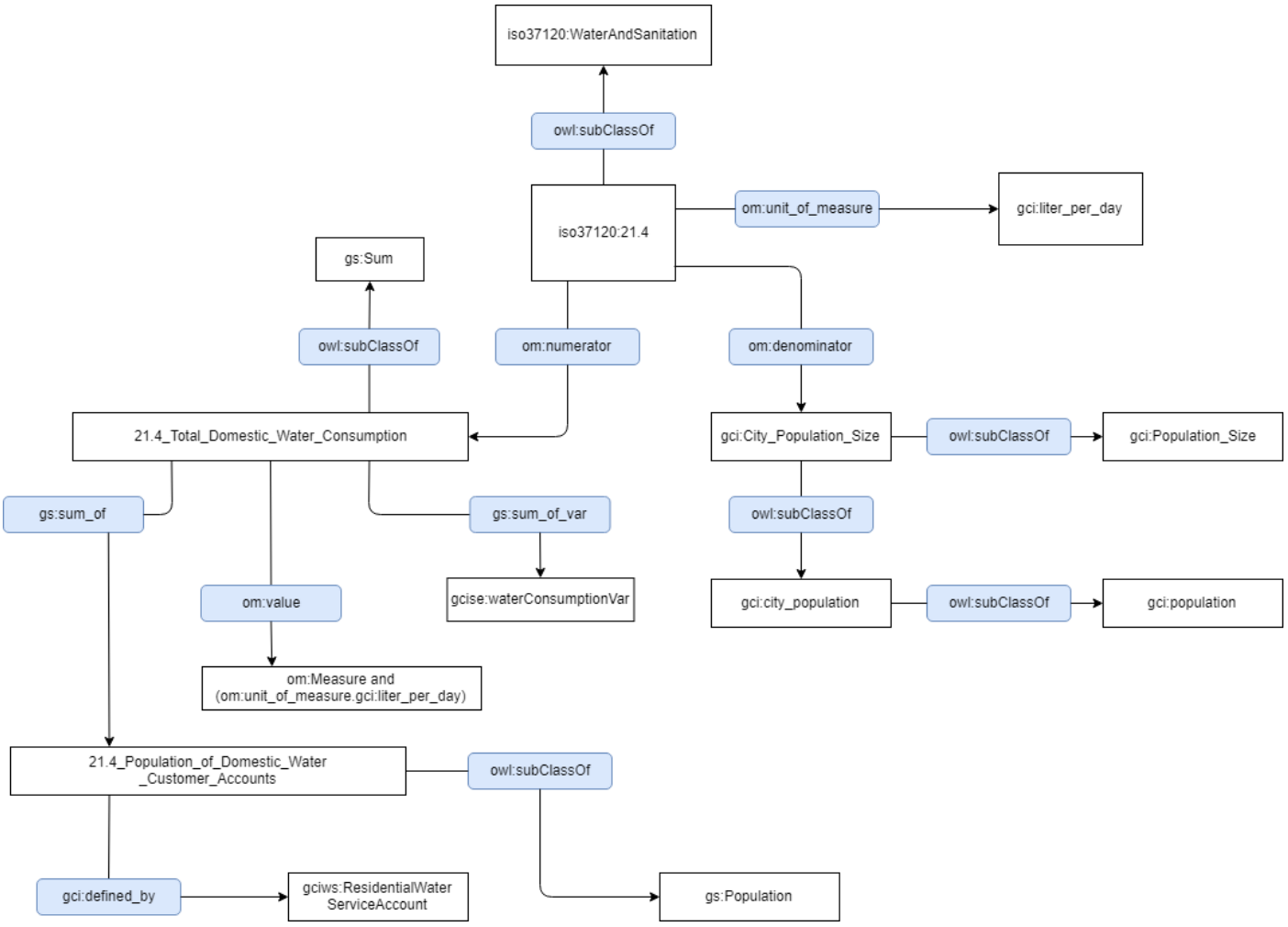


Figure 15 - Definition of ISO 37120 Indicator 21.4

21.5 Total water consumption per capita (litres/day) (core indicator)

The total water consumption per capita represents the total amount of water that a city would consume per person and is expressed in litres per day. The indicator's definition is almost identical to indicator 21.4 with the exception that the defining population encompasses all customer accounts as opposed to just residential accounts.

Class	Property	Value Restriction
iso37120:21.5	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	gci:City_Population_Size
	om:numerator	21.5_Total_Water_Consumption
	om:unit_of_measure	gci:liter_per_day

Class	Property	Value Restriction
21.5_Total_Water_ Consumption	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 21.5_Population_of_Water_ Consumption_Customer_Accounts
	om:value	exactly 1 om:Measure and (om:unit_of_measure.om:liter_per_day)
	gs:sum_of_var	value gcise:waterConsumptionVar
21.5_Population_of_Water_ Consumption_Customer_Accounts	owl:subclassOf	gs:Population
	gci:defined_by	only gciws:WaterServiceAccount

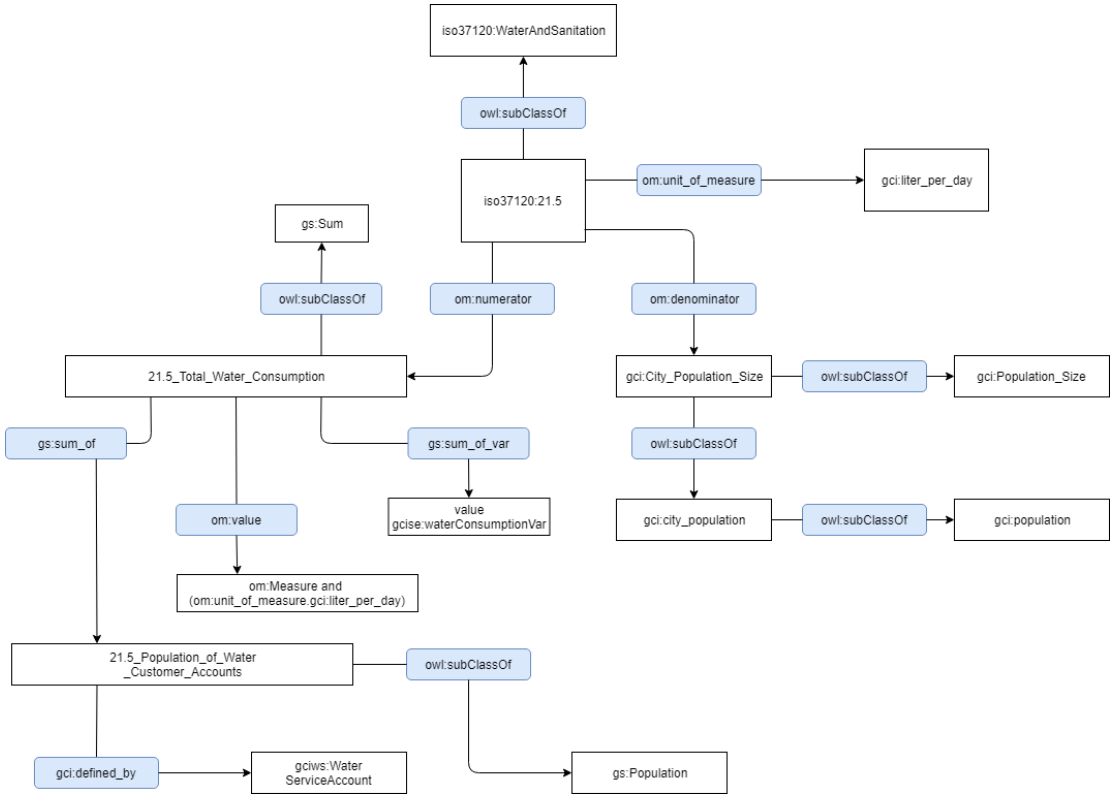


Figure 16 - Definition of ISO 37120 Indicator 21.5

21.6 Average annual hours of water service interruption per household (supporting indicator)

This indicator describes the average annual hours of water service interruption per household and is expressed in hours. The numerator is "21.6_Total_Hours_of_Water_Service_Interruptions_Impacting _Households" which determines the sum of all water service interruption hours which impacted a household. The denominator is "21.6_Population_of_Household_Size".

Class	Property	Value Restriction
iso37120:21.6	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	21.6_Population_of_Household_Size
	om:numerator	21.6_Total_Hours_of_Water_Service_ Interruptions_Impacting_Households
	om:unit_of_measure	om:hour

The numerator is represented by "21.6_Total_Hours_of_Water_Service_Interruptions_Impacting_ Household_Accounts" and is expressed in hours. This indicator only considers water service interruptions where service was not accessible and therefore the value of the "serviceWasAccessible" property of "21.6_Water_Service_Interruptions" is restricted to false.

Class	Property	Value Restriction
21.6_Total_Hours_of_Water_ Service_Interruptions_Impacting _Household_Accounts	owl:subclassOf	gci:GCI_quantity
	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 21.6_Population_of_Impacted _Household_Accounts
	gs:sum_of_var	value gcise:serviceDurationVar
	om:unit_of_measure	om:hour
	om:value	exactly 1 om:Measure and (om:unit_of_measure.om:hour)
21.6_Population_of_Impacted _Household_Accounts	owl:subclassOf	gs:Population
	gci:defined_by	only 21.6_Impacted_Household_Account
21.6_Impacted_Household _Account	owl:subclassOf	gciws:ResidentialWater ServiceCustomerAccount
	gcise:experience ServiceInterruption	only 21.6_Water_Service_ Interruptions
21.6_Water_Service_ Interruptions	owl:subclassOf	gciws:WaterServiceInterruption
	serviceWasAccessible	value xsd:false

The denominator is the cardinality of a city's population of households. This population is defined by "gciws:ResidentialWaterServiceCustomerAccount" which is supposed to represent a single household account.

Class	Property	Value Restriction
21.6_Population_of_Household_Size	owl:subclassOf	gs:Population_size
	gci:cardinality_of	21.6_Population_of_Household_Accounts
21.6_Population_of_Household_Accounts	owl:subclassOf	gs:Population
	gci:defined_by	gciws:ResidentialWaterServiceCustomerAccount

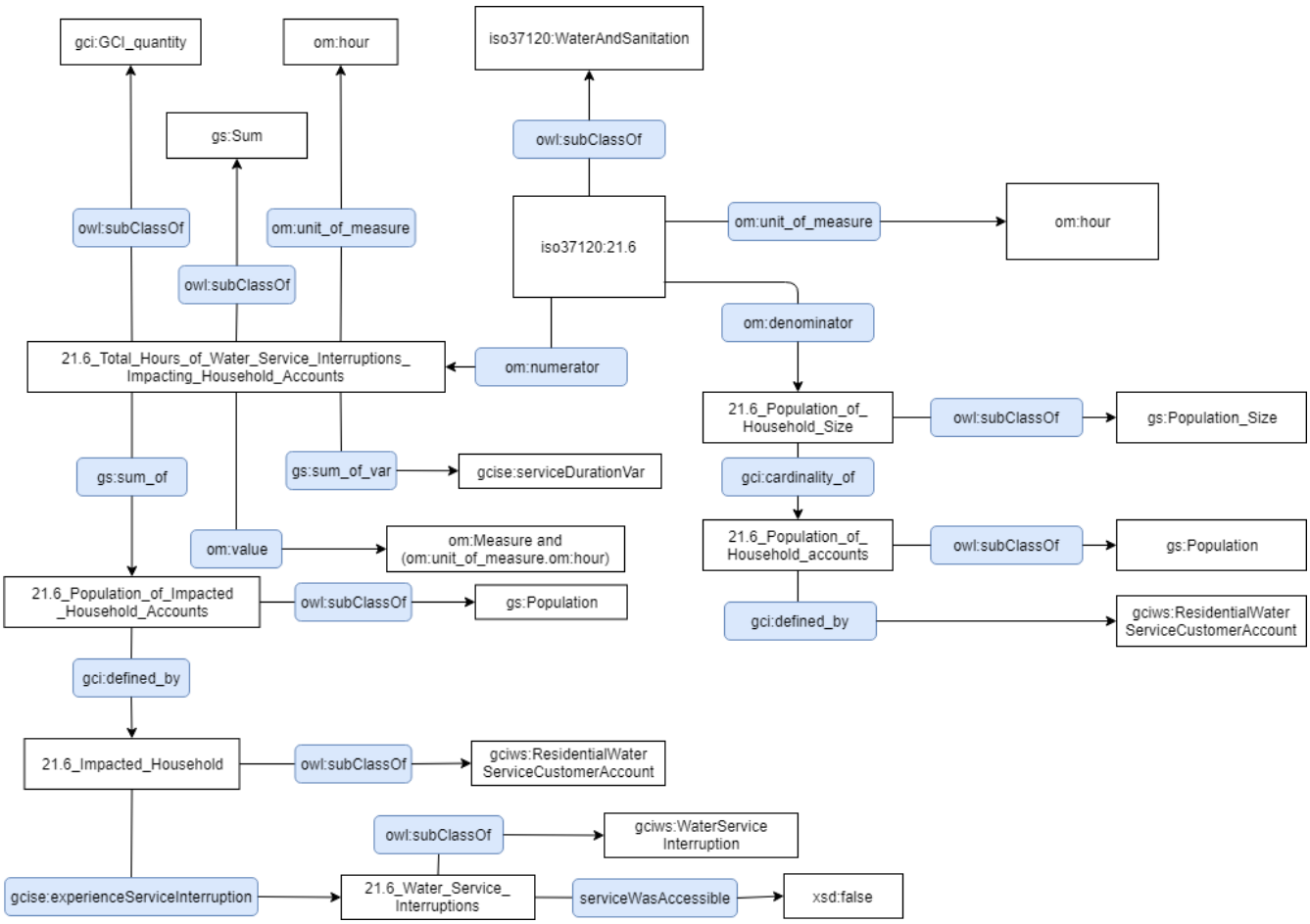


Figure 17 - Definition of ISO 37120 Indicator 21.6

21.7 Percentage of water loss (unaccounted for water) (supporting indicator)

The final indicator measures the percentage of water loss. The indicator is derived by taking the ratio of total water loss to the total volume of water produced.

Class	Property	Value Restriction
iso37120:21.7	owl:subclassOf	iso37120:WaterAndSanitation
	om:denominator	exactly 1 21.7_Total_Volume_of_Water_Produced_Quantity
	om:numerator	exactly 1 21.7_Total_Water_Loss_Quantity
	om:unit_of_measure	only om:percent

The numerator "21.7_Total_Water_Loss_Quantity" is the difference between "21.7_Total_Volume_of_Water_Produced_Quantity" and "21.7_Total_Volume_Consumed_Quantity". "21.7_Total_Volume_of_Water_Produced_Quantity" takes the sum of gcise:QuantityOfProduction from each source in a population of WaterServiceSources. "21.7_Total_Volume_Consumed_Quantity" takes the sum of each gcise:hasWaterConsumption found within a population of water service accounts.

Class	**Property**	**Value Restriction**
21.7_Total_Water_ Loss_Quantity	owl:subclassOf	gci:Difference_Quantity
	om:unit_of_ measure	gci:liter_per_day
	om:term_1	exactly 1 21.7_Total_Volume_of_ Water_Produced_Quantity
	om:term_2	exactly 1 21.7_Total_Volume_of _Water_Consumed_Quantity
21.7_Total_Volume_of_ Water_Consumed_Quantity	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 21.7_Total_Water_ Service_Consumer_Population
	om:value	exactly 1 om:Measure and (om:unit_of_measure.om:liter_per_day)
	gs:sum_of_var	value waterConsumptionVar
21.7_Total_Water_Service_ Consumer_Population	owl:subclassOf	gs:Population
	gci:defined_by	only gciws:WaterServiceAccount

The denominator is the same term "21.7_Total_Volume_of_Water_Produced_Quantity" defined in the numerator.

Class	**Property**	**Value Restriction**
21.7_Total_Volume_of_Water_ Produced_Quantity	owl:subclassOf	gs:Sum
	gs:sum_of	exactly 1 21.7_Total_Water_Service_ Producer_Population
	om:value	exactly 1 om:Measure and (om:unit_of_measure.gci:liter_per_day)
	gs:sum_of_var	value gcise:waterProductionVar
21.7_Total_Water_Service_ Producer_Population	owl:subclassOf	gs:Population
	gci_defined_by	only gciws:WaterServiceSource

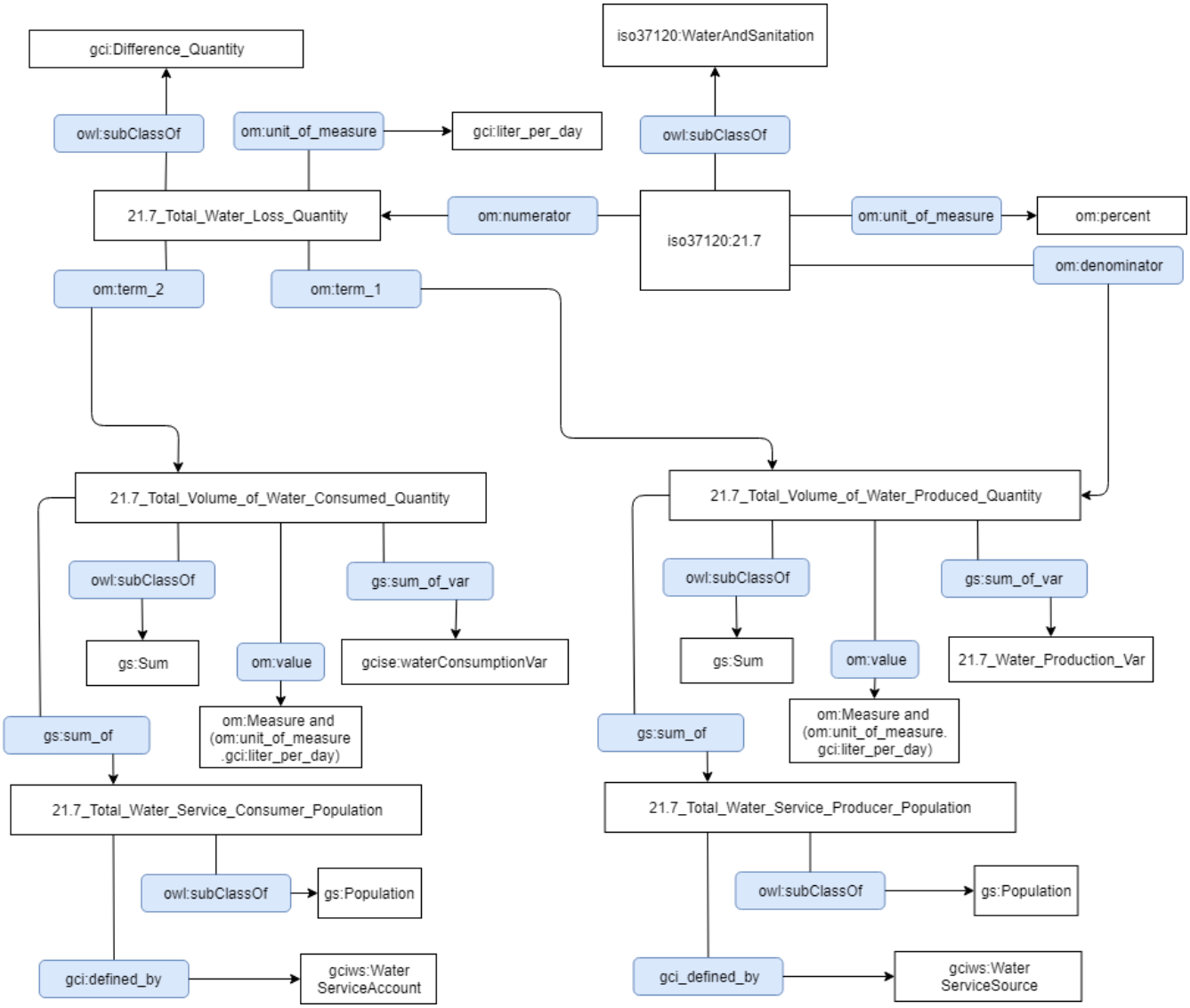


Figure 18 - Definition of ISO 37120 Indicator 21.7

8. Evaluation

In this section, the Water and Sanitation ontology is evaluated by demonstrating that it can answer the competency questions. The table below contains instances for Indicator 21.1 for the city of Toronto. The prefixes listed below are defined in Appendix B.

Instance	Property	Value
gn:6167865	rdfs:label	"Toronto"
	rdfs:type	gs:Feature
	rdfs:type	sc:City
21.1_ex	rdfs:type	iso37120ws:21.1
	gci:numerator	pwss_pop

	gci:denominator	city_pop_size
	gci:for_City	gn:6167865
	om:value	21.1_ex_value
21.1_ex_value	rdf:type	om:Measure
	om:numerical_value	100
	om:unit_of_measure	om:percent
city_pop_size	rdfs:type	gci:City_Population_Size
	gci:cardinality_of	city_pop
	value	city_pop_size_value
city_pop_size_value	rdfs:type	om:Measure
	om:numerical_value	2,771,770
	om:unit_of_measure	gci:population_cardinality_unit
city_pop	rdfs:type	gci:City_Population_Size
	gci:located_in	gn:6167865
	gci:defined_by	resident
resident	rdfs:type	gci:Resident
pwss_pop	rdfs:type	iso37120ws:21.1_Population_with_Potable_Water_Supply_Service
	om:unit_of_measure	gci:population_cardinality_unit
	om:term_1	ha_pwss_pop_size
	om:term_2	avg_h_size
	om:value	pwss_pop_value
pwss_pop_value	rdfs:type	gci:Population_measure
	om:numerical_value	2,771,770
avg_h_size	rdfs:type	gcis:Average_household_size
	om:value	avg_h_size_value
avg_h_size_value	rdfs:type	om:Measure
	om:numerical_value	2.5
ha_pwss_pop_size	rdfs:type	iso37120ws:21.1_Population_of_Household_Accounts_Connected_to_a_Potable_Water_Supply_Service_Size
	gci:cardinality_of	ha_pwss_pop
	om:value	ha_pwss_pop_size_value
ha_pwss_pop_size_value	rdfs:type	gci:Population_measure
	om:unit_of_measure	gci:population_cardinality_unit
	om:numerical_value	1,108,708
ha_pwss_pop	rdfs:type	iso37120ws:21.1_Population_of_Household_Accounts_Connected_to_a_Potable_Water_Supply_Service
	gci:defined_by	ha_pwss_01
ha_pwss_01	rdfs:type	iso37120ws:21.1_Household_Account_Connected_to_a_Potable_Water_Supply_Service
	gcise:hasServiceType	pwss_01
	rdfs:label	"Toronto Household 01"

pwss_01	rdfs:type	iso37120ws:21.1_Potable_Water_Supply_Service
	gciws:deliveredBy	pwssd_01
pwssd_01	rdfs:type	iso37120ws:21.1_Potable_Water_Supply_Service_Delivery
	gciws:hasSource	pwss_source_01
	gciws:hasStorage	pwss_storage_01, pwss_storage_02
	gciws:hasMotherPipeConnectionType	cosmo:Provisional
	gciws:isContinuous	xsd:true
pwss_source_01	rdfs:type	gciws:ImprovedWaterSource
	rdfs:label	"R.C. Harris Water Treatment Plant"
pwss_provider	rdfs:type	gcis:WaterServiceProvider
	rdfs:label	"Toronto Water"
pwss_storage_01	rdfs:type	gciws:WaterServiceStorage
	rdfs:label	"Water Tower 01"
pwss_storage_02	rdfs:type	gciws:WaterServiceStorage
	rdfs:label	"Water Tower 02"

The following depicts how the competency questions for ISO37120:21.1 would be implemented in SPARQL:

1. (F) What city is the indicator measuring?

```
SELECT ?city_name WHERE
{21.1_ex gci:for_City ?city.
?city rdfs:label ?city_name}
```

Answer: “Toronto”

2. (F) What is the total number of people with potable water supply service?

```
SELECT ?num_of_people WHERE
{21.1_ex gci:numerator ?pwss_pop.
?pwss_pop om:value ?pwss_pop_value.
?pwss_pop_value om:numerical_value ?num_of_people}
```

Answer: “2771770” ^^ xsd:integer

3. (F) What is the total number of households in the city connected to a potable water supply service?

```
SELECT ?num_of_hh WHERE
{21.1_ex gci:numerator ?pwss_pop.
?pwss_pop om:term_1 ?ha_pwss_pop_size.
```

?ha_pwss_pop_size om:value ?ha_pwss_pop_size_value.
?ha_pwss_pop_size_value om:numerical_value ?num_of_hh}

Answer: “1108708” ^^ xsd:integer

4. (F) What is the city’s average household size for the year the indicator was reported?

SELECT ?average_hh_size WHERE
{21.1_ex gci:numerator ?pwss_pop.
?pwss_pop om:term_2 ?avg_h_size.
?avg_h_size om:value ?avg_h_size _value.
?avg_h_size _value om:numerical_value ?average_hh_size}

Answer: “2.5” ^^ xsd:float

5. (F) What type of connection is delivering a potable water supply service to a specific household?

SELECT ?connectionType WHERE
{ha_pwss_01 gcise:hasServiceType ?pwss.
?pwss gciws:deliveredBy ?pwssd.
?pwssd gciws:hasMotherPipeConnectionType ?connectionType}

Answer: cosmo:Provisional

6. (D) Is the potable water supply service to a specific household continuous?

SELECT ?continuousService WHERE
{ha_pwss_01 gcise:hasServiceType ?pwss.
?pwss gciws:deliveredBy ?pwssd.
?pwssd gciws:isContinous ?continuousService}

Answer: xsd:True

7. (F) What is the source of the potable water supply for a specific household?

SELECT ?waterSource WHERE
{ha_pwss_01 gcise:hasServiceType ?pwss.
?pwss gciws:deliveredBy ?pwssd.
?pwssd gciws:hasSource ?pwss_source.
?pwss_source rdfs:label ?waterSource}

Answer: “R.C. Harris Water Treatment Plant”

8. (F) Which storage deposit is supplying potable water to the network that a household is connected to?

```
SELECT ?waterStorage WHERE
{?ha_pwss gcise:hasServiceType ?pwss.
?pwss gciws:deliveredBy ?pwssd.
?pwssd gciws:hasStorage ?pwss_storage.
?pwss_storage rdfs:label ?waterStorage.
?ha_pwss rdfs:label ?household.
FILTER regex(?household. “Toronto Household 01”)}
```

Answer: “Water Tower 01”, “Water Tower 02”

9. (F) Which water service provider is delivering the potable water supply service to a specific household?

```
SELECT ?waterServiceProvider WHERE
{ha_pwss_01 gcise:hasServiceType pwss_01.
ha_pwss_01 gcise:providedBy ?pwss_provider.
?pwss_provider rdfs:label ?waterServiceProvider}
```

Answer: “Toronto Water”

9. Conclusions

The goal of this research was to define an ontology that represented the definitions of the indicators of the ISO37120 Water and Sanitation theme as well the supporting data used to derive each indicator’s value. In order to accomplish this, a single generic ontology for water and sanitation knowledge was constructed.

In summary, the following contributions were made:

1) Defines a GCI Water and Sanitation ontology that covers a broader range of concepts related to water as a service and sanitation as a human activity.

2) Defines an ISO 37120 Water and Sanitation indicator ontology is built upon the GCI Foundation and GCI Water and Sanitation ontologies.

3) As a result of the above point, precise definitions of the ISO37120:21 indicators are created within the standards of the Semantic Web.

4) Provides a standard representation for general water and sanitation knowledge related to indicators, regionally specific versions of said knowledge, and the data used to determine the indicator values.

10. Acknowledgements

This research was supported in part by the Natural Science and Engineering Research Council of Canada.

11. References

Buttigieg, P. L., Pafilis, E., Lewis, S. E., Schildhauer, M. P., Walls, R. L., & Mungall, C. J. (2016). The environment ontology in 2016: bridging domains with increased scope, semantic density, and interoperation. *Journal of Biomedical Semantics (7)*, 57. Retrieved from BioPortal.

Cassidy, P. (2010). *COSMO Common Semantic Model.* Retrieved from MICRA Inc.: http://www.micra.com/COSMO/

Forde, A. N., & Fox, M. S. (2015). *A Telecommunication & Innovation Ontology for Global City Indicators (ISO 37120).* Retrieved from Enterprise Integration Laboratory, University of Toronto: http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Innovation-Ontology.pdf

Fox, M. S. (2013). *A Foundation Ontology for Global City Indicators*. Retrieved from Enterprise Integration Laboratory, University of Toronto: http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Ontology-v10.pdf

Fox, M. S. (2015). The PolisGnosis Project: Enabiling the Computational Analysis of City Performance. *Proceedings of the 2017 Industrial and Systems Engineering Conference.*

Gruninger, M., & Fox, M. S. (1995). Methodology for the Design and Evaluation of Ontologies. *IJCAI-95 Proceedings of the Workshop on Basic Ontological Issues in Knowledge.* Montreal, Canada.

JMP. (2015). *Facility types.* Retrieved from https://washdata.org/monitoring/methods/facility-types

Komisar, A., & Fox, M. S. (2017). *An Energy Ontology for Global City Indicators (ISO 37120).* Retrieved from Enterprise Integration Laboratory, University of Toronto: http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Energy-Ontology-May-30-2017.pdf

Rijgersberg, W. M. (2011). How Semantics can Imrpove Engineering Processes: A Case of Units of Measures and Quantities. *Advanced Engineering Informatics, 25*, 276-287.

Smart City Artifacts - Infrastructure Product Ontology. (n.d.). Retrieved from http://ci.emse.fr/opensensingcity/ns/sca/vocabulary_86/

Smart City Artifacts - Water Ontology. (n.d.). Retrieved from http://ci.emse.fr/opensensingcity/ns/sca/project_19/

Varas, G. A. (2015). *Water Enhanced Resource Planning "Where water supply meets demand".* Retrieved from https://cordis.europa.eu/docs/projects/cnect/3/318603/080/deliverables/001-D15ReportoffinaltaxonomyfunctionalmodelandontologyV1.pdf

Vilches-Blazquez, L. M., Ramos, J. A., Lopez-Pellicer, F. J., Corcho, O., Nogueras-Iso, J., & . (2009). An approach to comparing different ontologies in the context of hydrographical information. *Information Gusion and Geographic Information Systems 2009*, (pp. 193-207). St. Petersburg, Russia.

Voß, J. (2013). *The Service Ontology.* Retrieved from http://dini-ag-kim.github.io/serviceontology/service.html

Wang, Y., & Fox, M. S. (2015). *A Shelter Ontology for Global City Indicators.* Retrieved from http://eil.mie.utoronto.ca/wp-content/uploads/2015/06/GCI-Shelter-Ontology.pdf

12. Appendix A – Key Ontologies

The Global City Indicator Foundation ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Founation-v2.owl.

The Global City Indicator Water and Sanitation ontology can be found in:
http://ontology.eil.utoronto.ca/GCI/WaterAndSanitation/GCI-WaterAndSanitation.owl.

URIs for all of the ISO37120 indicators can be found in:
http://ontology.eil.utoronto.ca/ISO37120.owl.

Definitions of the ISO37120 Water and Sanitation indicators, using the GCI Foundation and Water and Sanitation ontologies can be found in:
http://ontology.eil.utoronto.ca/GCI/ISO37120/WaterAndSanitation.owl.

Representation of the City of Toronto 2013 ISO 37120 Water and Sanitation values can be found in:
http://ontology.eil.utoronto.ca/ISO37120/Toronto/2013/ISO37120_21_2013_TO.owl

13. Appendix B – Ontology Prefixes

Prefix	Ontology	URL
act	Activity Ontology	http://ontology.eil.utoronto.ca/tove/activity.owl#Activity
cosmo	Common Semantic Model	http://micra.com/COSMO/COSMO.owl
foaf	FOAF	http://xmlns.com/foaf
gci	GCI Foundation	http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation-v2.owl
gcibo	GCI Building Occupancy	http://ontology.eil.utoronto.ca/GCI/BuildingOccupancy/GCI-BuildingOccupancy.owl
gcii	GCI Innovation	http://ontology.eil.utoronto.ca/GCI/Innovation/GCI-Innovation.owl
gcis	GCI Shelter	http://ontology.eil.utoronto.ca/GCI/Shelters/GCI-Shelters.owl
gcise	GCI Service	http://ontology.eil.utoronto.ca/GCI/Energy/GCI-Service.owl
gciws	GCI Water and Sanitation	http://ontology.eil.utoronto.ca/GCI/WaterAndSanitation/GCI-WaterAndSanitation.owl
gn	Geonames	http://sws.geonames.org/
gs	GovStat	http://ontology.eil.utoronto.ca/govstat.owl
ic	Icontact (international address ontology)	http://ontology.eil.utoronto.ca/icontact.owl
iso37120	ISO 37120 IRI	http://ontology.eil.utoronto.ca/ISO37120.owl
iso37120ws	ISO 37120 Water and Sanitation	http://ontology.eil.utoronto.ca/GCI/ISO37120/WaterAndSanitation.owl
iso37120s	ISO 37120 Shelter	http://ontology.eil.utoronto.ca/GCI/ISO37120/Shelters.owl
lode	LODE Events	http://linkedevents.org/ontology/
om	Measurement Ontology	http://www.wurvoc.org/vocabularies/om-1.8
org	TOVE Organization	http://ontology.eil.utoronto.ca/organization.owl
ot	Owl Time	http://www.w3.org/2006/time
prov	Prov	http://www.w3.org/ns/prov
sch	Schema.org	http://schema.org/
so	Service	http://purl.org/ontology/service