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Data collection strategy

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FCA Resilience.io
Decision-Making Model:

Resource Economic Human Ecosystem
Modeling Platform Prototype

Data Collection Strategy

Draft - Version

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1. Overview

This document describes the data collection strategy for the Ghana Water and Sanitation, and Hygiene (WASH) application of the resource-economic human ecosystem model under development. The prototype model is developed as part of the Department for International Development (DfID) funded Future Cities Africa (FCA) project and is to become a core component of the **resilience.io** platform of the Ecological Sequestration Trust (the Trust). Comments on the document can be sent to Rembrandt Koppelaar (koppelaar@iier.ch) and Stephen Passmore (Stephen.passmore@ecosequestrust.org).

1.1 Purpose of the Data Collection Strategy

The data collection strategy in the FCA project relates to milestone 7 of the decision-making model prototype building component. The strategy describes the approach to collect, clean, and verify the data that is required to populate and test the model for the Ghana WASH application. The prototype will cover the Greater Accra Metropolitan Area (GAMA) districts, their population, sector infrastructure, supply, and demand, will be represented for prototype simulation purposes. The data collection strategy serves to provide a rigorous step-by-step methodology to ensure quality assurance plus traceability of data adjustments, and efficiency plus transparency of the overall data effort. It thereby structures the collection effort of local data to build the first prototype (milestone 10), as per figure 1.1 below

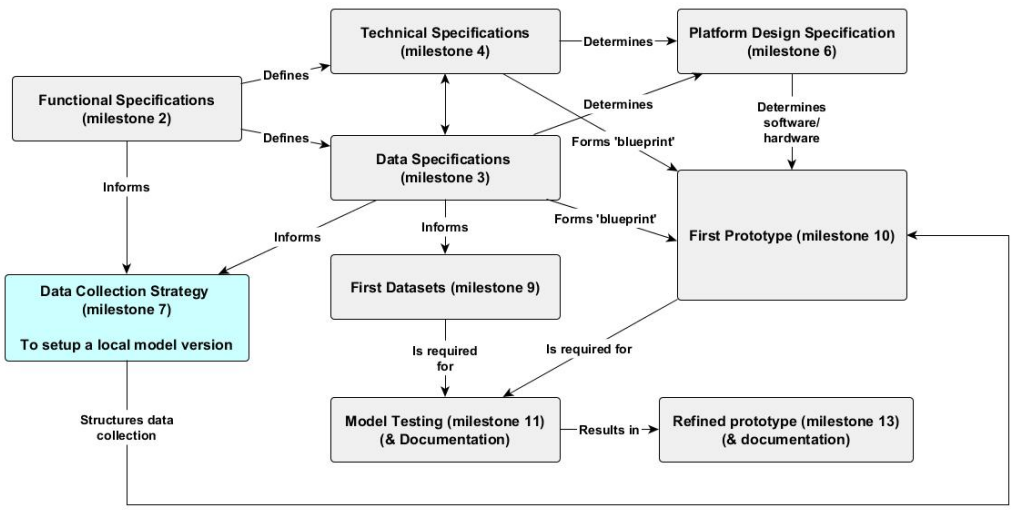


Fig 1.1 – Relationship between data collection strategy and other milestones of the decision-making model development component of the FCA project.

Since the project effort is limited to utilise in the best possible manner existing digital data from local and non-local data providers, and analyse this using desk-based methods, a constraint is posed on the level of detail that can be incorporated in the prototype. For example, water consumption data might not be publicly digitally available at district levels, and in the absence of local data collection, instead needs to be inferred from aggregate figures using a combination of population distribution and socio-economic rulesets.

In relation to this constraint the second purpose, as part of the data collection process, is to evaluate what data exists, what gaps there are, and at what level of spatial and temporal granularity. This in the context of constructing a spatial-temporal model of the GAMA, and in particular the WASH sector.

1.2 Greater Accra Metropolitan Area spatial setting

The aim is to develop the prototype WASH application at a spatial scale which is both relevant as well as feasible in terms of data availability. The preliminary choice at present, given data availability as described in section 2, is to develop the prototype at the level of MMDAs within the Greater Accra Metropolitan Area.

In its totality the Greater Accra Region covers the following 16 MMDAs:

- The 2 Metropolitan Assemblies within Greater Accra (Accra and Tema)
- The 10 Municipal Assemblies within Greater Accra (Adente, Ashaiman, Ga East, Ga West, Ga Central, Ga South, La Dade-Kotopon, La-Nkwantanag-Madina, Ledzokuku-Krowor, and Ningo-Prampram)
- The 4 District Assemblies within Greater Accra (Ada West, Ada East, Shai Osudoku, Kpone-katamanso)

These areas relate to the District boundaries in Greater Accra as per the June 2012 change in district boundary subdivisions. The selected boundaries of GAMA within the 16 MMDAs of Greater Accra are at present discussed by the FCA in-country team via its focus groups, and their decision will be adopted for the GAMA WASH application.

Any further sub-delineation to sub-district level such as neighbourhoods will need to be assessed on the basis of feasibility. Main constraints relate to availability of data to adequately cover additional spatial detail.

1.3 Data collection strategy that describes complete economy

The prototype effort is developed for the specific WASH sector as locally selected by stakeholders in GAMA. The FCA funded effort covers phase 1a of model development, as described in the functional specifications milestones. After demonstration of functionality and further expansion under 1b, a full economy model is to be built in phase 2 which covers all sectors (see figure 1.2).

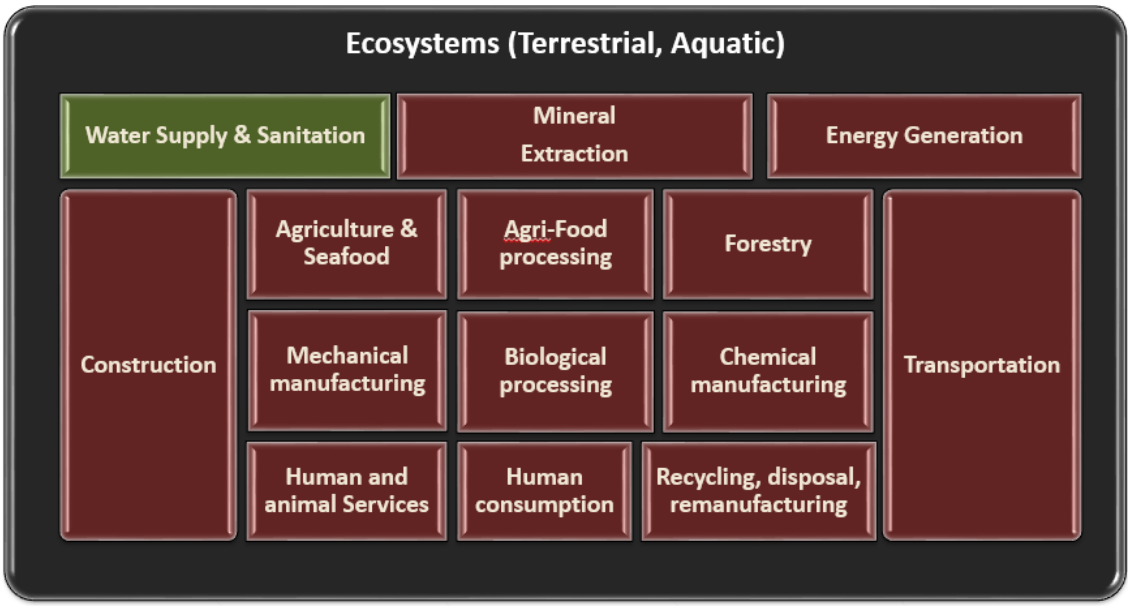


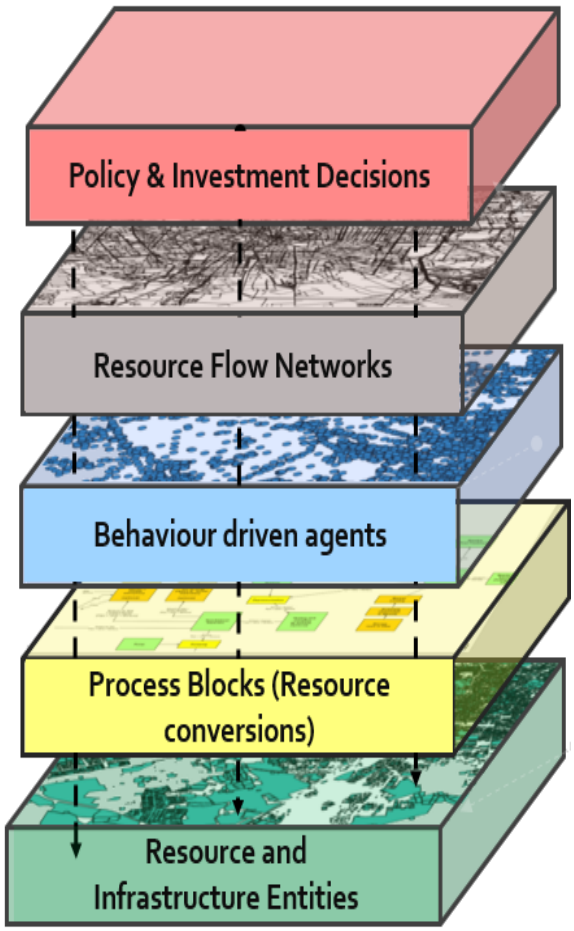
Figure 1.2 – Overview of sectors for a complete economy model

The data collection strategy in this document has been built also with this view in mind, by providing for generic procedures that can be applied to any of these sectors and data-set types. The main sector difference between sectors lies in the datasets which are collected themselves, in terms of the type of technology, distribution infrastructure, and production facilities that are utilised. For example, in case of the WASH sector data is required for existing source-water collection and treatment plants in the GAMA, whilst an application for the energy generation sector would necessitate collecting data on existing power plants. Thereby each sector necessitates tweaking the existing "checklist" to include sector specific distribution and production infrastructures. In all other cases the datasets are similar, since population, household data, and economy wide values do not change regardless of the type of sector.

2. Prototype Sector Application Data Overview

The prototype serves to recreate in simplified form the spatial and temporal dynamics of a city and its hinterland, in this specific application focusing on the WASH sector and its water and sanitation dynamics in the ten GAMA administrative districts.

The model prototype, as described in the functional specifications, consists out of the following five flexible components:



- **Policy and Investment Decisions,** user set decisions around regulatory/distributive policies, spatial planning and investment/procurement
- **Resource Flow Networks,** the pipelines, grids, and networks for distribution within the spatial landscape.
- **Behaviour driven agents,** the model representation of companies and people living in the region as a set of 'agents' with decision algorithms.
- **Process blocks,** the resource conversions datasets which describe material, energy, labour input-output relationships in production.
- **Resource and infrastructure entities,** the mapped areas/point sources where production and conversion takes place, such as built infrastructure such as power plants, agricultural fields,

Figure 2.1 – Overview of model components and relationship to dataset types

To be able to build these components for the WASH sector application there are four types of datasets that need to be collected, cleaned, and verified for use in the sector application:

- **Geospatial data**, so as to represent the GAMA administrative districts and land use at course granularity. This forms the base map to be able to attach other datasets to in space, including the representation of resource flow networks, agents in terms of population, and resource and infrastructure entities.
- **Population and household data**, so as to represent the population within the districts and their socio-economic activity, demographic, and employment characteristics. These datasets are used to populate the agents, such as the number of people and households as attached to a GAMA district, their socio-economic characteristics, and distribution of water source types available and used by the households.
- **Sector (eco)nomic flow data**, so as to represents any data value related to a flow, including the physical quantities or flows in terms of demand, supply, as well as financial flows and quality characteristics. For example, the water consumed of households in GAMA districts, or total raw water produced at GAMA level. The (eco)nomic flow datasets serve to inform the physical quantities for process block development, to create a model initialization, to assess water demands, to inform cost/pricing, and to aid in the establishment of particular model relationships (e.g. the relation between water consumption and socio-economic characteristics of households). Also if sufficient historic data is available it can be used to compare model results with actual historic values.
- **Sector infrastructure data**, so as to represent the point source infrastructure and distribution networks to represent the WASH sector supply operation in the model. For example, the listing, spatial point, and characteristics, of waste water treatment plants in the GAMA. The datasets are used to create resource and infrastructure entities as well as resource flow networks in the model.

After verification the datasets are integrated during a harmonization step. For example, if individual household consumption data is available and total GAMA aggregate net water produced (net of losses), then from these datasets water consumption for individual districts can be generated. This in case water consumption data at this level of detail is absent. Each such step is carried out and documented in the spreadsheet during harmonization.

2.1 Data Checklist and Gaps - Ghana WASH Sector

As part of the data collection strategy a rapid data screening was carried out to generate a first overview of publicly available datasets and their level of granularity. The screening was structured on the basis of assessing datasets available from the websites of 17 relevant local organisations to the WASH sector identified in the Ghana in-country workshop, as summarised in appendix A. The screening was complemented by a literature data search using academic and non-academic databases and specific sets of keywords, as summarised in table 2.1.

Table 2.1 – Overview of complementary data searches conducted for the rapid data assessment

Data Search Engine	Keywords used	No. of Search Results	No. of abstracts scanned	No. of relevant documents retained
University of Ghana Digital Collections	"Water" or "Sanitation"	718	718	4
Google Scholar	"Accra" AND "Water" AND "Sanitation" since 2008	7770	540	24
Google Scholar	"Ghana" AND "Water" AND "Sanitation" since 2008	22,400	120	4
Google	"Accra" AND "Water" AND "pipe" AND "network" AND filetype:pdf	7030	80	6
Google	"Accra" AND "Water" AND "supply" AND "m3" OR "liter" AND filetype:pdf	53,200	110	12
Google	"Kpong" OR "Weija" AND "Waterworks" AND filetype:pdf	391	391	2
Scopus	"Accra" AND "Water" OR ACCRA AND "Sanitation" since 2008	178	178	10
Web of Science	"Accra" AND "Water" OR ACCRA AND "Sanitation" since 2008	131	131	3

The combined analysis led to a total of 152 documents deemed relevant, as listed in Appendix B, which have been screened for contained datasets. The detailed meta-data of the 200+ datasets uncovered from this rapid screening can be found in the spreadsheet accompanying this report, under the tab "data screening".

In parallel a data checklist was made to assess what datasets are available and at what spatial level. The checklist was filled for purposes of a data gap analysis, which can be found in table 2.2 below on the next page, and in the spreadsheet under the tab "Gap analysis". The checklist was filled in with a cross X where systematic data is available, and with a + / - where only small samples could be found.

In the table 2.2 the years are indicated for each data category for which data was found to be available. These are not directly related to the years for which data is collected. The aim of the data collection exercise is firstly, to provide a baseline WASH dataset for GAMA that can be used as the model starting period to run the model. The year with the most complete data points is 2010 when the last population and household census was carried out (e.g. datasets on population and households and their characteristics, and access to water and sanitation services and their types). Secondly, if sufficiently comprehensive historic data is available to create a time-series dataset which can then be used to validate model output. The population and household census of 2000 also provides for significant overall aggregate WASH statistics at the district level (at the level of five districts in Greater Accra given the legal district boundaries). And hence the data collection effort will subsequently focus on collecting data from the 2000 to present period. Thirdly, to provide for background studies that can help in establishing the model and interpreting model results particular to WASH.

Table 2.2 – Summary overview of dataset availability from rapid data screening assessment. A cross X stands for systematic data availability, whilst a + / - indicates only small samples could be found which are not representative.

Dataset	Unit	Period	Spatial area						References
			Ghana	GAMA	GAMA MMDAS	Neighbo rhoods	EAs*	Spatial points	
Boundary and land use data									
Boundaries of city-region and hinterland administrative units	Polygons	n.a.	X	X	+ / -	+ / - (AMA)			[66], [76], [133], [142]
Surface area of city-region and hinterland administrative units	Surface area	n.a.	X	X	X				[30]
Land use data residential / commercial / industrial / agriculture	Polygons	n.a.	X						
Water bodies area	Polygons	n.a.	X	X	X				OpenStreetMap / Bing / GoogleMap
Population									
Population numbers	number	1960, 1970, 1984, 2000, 2010	X	X	X	+ / - (26 slums)			[27], [30], [89], [105], [150]
Population deaths	number	2000, 2010	+ / -	+ / -					[30]
Population births	number	2000, 2010	X	X	X				[30]
Fertility rate	rate	2000, 2010	X	X					[30], [89]
Immigration by numbers	number	2010	+ / -	+ / -					[27], [30], [105]
Emigration by numbers	number	2010	+ / -	+ / -					[27], [30], [105]
Households									
Household numbers	number	1970, 1984, 2000, 2010	X	X	X				[27], [30]
Household numbers by family types	number	2000, 2010	X	X	X				[27], [30]
Household numbers by age of household	number	2000, 2010	X	X	X				[27], [30]

head									
Number of houses	number	2010	X	X	X				[27], [30]
Number of households per house	number	2010	X	X	X				[27], [30]
Activities									
Population activities by minute	minutes	2009, 2012	X	X					[103], [104]
Population activities by minute by age	minutes	2009, 2012	X	X					[98], [103]
Employment									
Workforce numbers	number	2010, 2012	X	X	X				[30], [50], [51], [52], [53], [55], [98]
Workforce numbers by age	number	2010, 2012	X	X	X				
Employment numbers	number	2010, 2012	X	X	X				
Employment by age	number	2010, 2012	X	X	X				
Employment occupations by number	number	2010, 2012	X	X	X				
Employment by sector	number	2010, 2012	X	X	X				
Unemployment numbers	number	2010, 2012	X	X	X				
Unemployment by age	number	2010, 2012	X	X	X				
Education									
Educational enrolment of population by type	number	2007 to 2010	X	X	X				[30], [54]
Educational enrolment of population by type and age category	number	2007 to 2010	X	X	X				[30], [54]
Educational attainment of population for highest diploma	number	2010, 2012	X	X	X				[30], [49]
Education attainment by age category for highest diploma	number								
Educational attainment by occupation and gender for highest diploma	number	2010, 2012	X	X	X				[30], [49]. [102]
Income and expenditures									
Household income / expenditure	GHc	2007, 2012	X	X					[100], [102]
Household expenditure on water	GHc								
Household expenditure on sanitation	GHc								
Cost of sanitation services	GHc / service	2002, 2004, 2012, 2013		X	+ / -	+ / -			[39], [44], [113], [114]
Cost of water supply services	GHc / liter	2007		X	+ / -	+ / -			[14], [20], [39], [42], [99], [101], [113], [116], [114], [121]

Size of economic activity									
Economic activity in GDP	GHc	2006 to 2014	X						[151]
Sector activity as share of GDP	GHc	2006 to 2014	+ / -						[151]
Water production and consumption									
Household access percentage to water by source type	Percentage	2010, 2012, 2013	X	X	X	+ / - (old fadama, nima)			[1], [10], [20], [30], [83], [104]
Population/Household use types of water	Percentage	2010, 2012	X	X	X				[30], [104]
Water consumption from treated water	volume	1986 to 2010	X	X	+ / -				[1], [20], [60], [141], [163]
Production of treated water	volume	1986 to 2010	X	X					[1], [4], [24], [141]
Water lost due to leakage and theft	volume	1986 to 2010	X						[1], [4], [13], [101], [141]
Water repackaging into distributed sources (tanker, satches, bottles)	volume								
Water Reliability									
Water rationing schedule	days	2009, 2010, 2011		X	X				[1], [13], [127], [131]
Water quality									
Reservoir water quality measurements (raw water)	concentrations	2005		+ / -					[5], [21]
Treated water quality measurements (after treatment)	concentrations	2008, 2009		+ / -	+ / -				[67]
Piped water quality measurements	concentrations	2008, 2009, 2012		+ / -	+ / -				[67], [102]
Tanker water quality measurements	concentrations	2011			+ / -				[60]
Satchel water quality measurements	concentrations	Various 2007, 2012		+ / -	+ / -				[7], [111], [127], [129]
Bottled water quality measurements	concentrations	2012			+ / -				[111]
Locally stored water quality measurements	concentrations	2012			+ / -				[6], [83]
Ground water quality measurements	concentrations	2007, 2012		+ / -	+ / -				[15], [97]
Surface water quality measurements other	concentrations	2008, 2012, 2013		+ / -	+ / -				[11], [62], [68], [112]

Source water supply infrastructure									
Source water treatment facilities	spatial points	2013		X				X	[20]
Source water treatment facilities capacity	volume per unit time	1950 to 2010, 2005, 2013		X				X	[13], [20], [119], [141]
Source water treatment facilities avg. production	volume per unit time	2005, 2007, 2013		X				X	[13], [20]
Source water treatment facilities avg. production	Effiency	2005		X				X	[13]
Source water treatment facilities electricity use	kWh	2008		X				X	[134]
Source water treatment facilities technological description	description	2005, 2007		X				X	[9], [13], [121]
Source water treatment facilities workers	number	2005		X					[13]
Bore-hole pumping facilities	spatial points	2010			+ / -				[66]
Bore-hole pumping facilities	Capacity	2012		+ / -					[1]
Bore-hole pumping facilities technological description	description								
Bore-hole pumping facilities electricity use	kWh								
Bore-hole pumping facilities workers	number								
Water supply networks									
Clean water distribution network via pipe	spatial lines				+ / -				[20], [27], [131], [136]
Clean water distribution network via pipe	capacity				+ / -				[131]
Clean water distribution network pipe losses	efficiency or volume	1986 to 2010		X					[1], [4], [13], [101], [141]
Clean water distribution network electricity use	kWh	2008		X				X	[134]
Clean water distribution number of piped connections	number	2005, 2001 to 2006, 2013		X	+ / -				[13], [20], [23], [27], [136]
Waste water collection network drainage/pipes	spatial line	2011				+ / -			[66]
Waste water collection network drainage/pipes	capacity								
Waste water collection network drainage/pipes losses	efficiency or volume								
Tanker water distribution network	spatial points				+ / -				[66]

Tanker water distribution network	volume								
Satchel water distribution network	spatial points	2009		+ / -	+ / -				[66], [127]
Satchel water distribution network	volume	2009		+ / -					[127], [130]
Bottled water distribution network	spatial points				+ / -				[66]
Bottled water distribution network	volume								
Water Storage									
Household/business water storage capacity	volume								
Water tank storage points	spatial points								
Water storage refill rates by tanker	Number per time interval	2011				+ / -			[1]
Rainfall / water bodies									
Water bodies volume	volume								
Rainfall patterns	mm per day	Monthly 1944 - 2013		X					[152]
Sanitation									
Access to toilet facilities by type	Percentage	2010, 2012, (2013)		X	X	+ / -			[6], [30]
Access to toilet facilities by type by socio-economic/income variables	Percentage	2010, 2012, (2013)		X	X	+ / -			[6], [30], [106]
Type of disposal/conversion of liquid wastes	Percentage	2010		X	X				[30]
Bathing facilities, type of , and access to	Percentage	2000, 2010	X	X	X				[30]. [153]
Public toilet facilities	spatial points	2010		X	X	+ / -			[30], [66]
Public toilet facilities	number of users	2010		X	X	+ / -			[30], [66], [83]
Hand washing stations with soap	Percentage access								No visibility
Sewage disposal networks									
Sewage pipe collection/disposal network	spatial lines			+ / -	+ / -				[117], [132]
Sewage pipe collection/disposal network capacity	capacity								
Sewage pipe collection/disposal network use volume	volume								
Sewage pipe network electricity use	kWh								
Sewage pipe network number of connections	number								

Sewage cesspit collection tanker disposal network	storage points	2007, 2008			+ / -				[32], [33]
Sewage cesspit collection tanker disposal network	volume	2013			+ / -				[20], [27], [136]
Sewage cesspit collection technology description	description	2007, 2008		+ / -					[32], [33]
sewage cesspit collection dumping sites	spatial points	2013			+ / -				[20], [27], [136]
Sanitation treatment infrastructure									
sewage treatment facilities	spatial points								
sewage treatment facilities technological description	description	2001, 2006, 2013		X	X				[9], [23], [81], [94], [132], [154], [155]
sewage treatment facilities efficiency	percentage								
sewage treatment facilities capacity	volume	Various, 2012		X	X				[81], [82], [141], [154], [155]
sewage treatment facilities output	volume								
sewage treatment facilities electricity use	kWh								
sewage treatment facilities workers	number								

**EA stands for enumeration areas, the smallest unit used by the Ghana Statistical Service to collect data.*

2.2 Data Gaps Summary

The data gap analysis shows that the majority of WASH data is available for Greater Accra Region MMDAs. Thereby the spatial level of the to be selected GAMA districts is sufficiently covered for creation of a WASH sector prototype. Notwithstanding, a number of datasets are missing - in terms of their availability via internet sources - which would allow for a step-up increase in accuracy of the WASH representation, and also detail of spatial planning insights of policy/technology interventions in the model.

The key datasets - in terms of internet sources – that could not be located at present and plausible sources to retrieve this data are listed in table 2.3 below.

Table 2.3 – Missing datasets from internet sources and organizations at which datasets plausibly exist and can be retrieved

Dataset type	Description	Contact organization for dataset retrieval
Source water pipeline network	Spatial datasets on the location of pipelines, their material type, diameters, and age. And number of connected households.	Ghana Water Company Ltd – GIS team / CERSGIS[1]
Accra and TEMA MDA sewage pipeline networks	Spatial datasets on the location of pipelines, their material type, diameters, and age. And number of connected households.	World Bank (funded construction project of pipelines) / TEMA and AMA metropolitan assemblies
Septic tanks and storage points	Datasets for the number of septic tanks, cesspit storage points, cesspit emptier trucks in use.	Cesspit emptier service companies
Source water consumption for drinking water and non-drinking water[2]	Datasets at district and sub-district level on the amount of water consumed as measure/estimated	Ghana Water Company Ltd.

[1] The Ghana Water Company Limited (GWCL) operates a GIS team that keeps track of for source water pipeline network, in collaboration with CERSGIS, whom can be contacted for source water pipe data.

	from source water piping systems, ideally split by user types (residential, commercial, industrial)	
Non-Revenue water lost from theft, technical losses, accepted Non-Revenue[3]	Dataset describing specifically for GAMA and districts within GAMA on the percentage of Non-Revenue water that is lost from theft, lost due to technical losses, and accepted Non-Revenue.	Ghana Water Company Ltd.
Land use data	Land use data to define areas with agricultural, residential, household, and industrial activities, so as to estimate associated water use differences.	Unknown / CERSGIS[4]
Kpong and Weija water quality data	A historic time-series of physico-chemical and microbiological water quality measurements at Weija and Kpong water treatment works, to enable interpretation of down-stream water quality measurements in existing studies from various sources (e.g. standpipes, bottles, tanker water, satchels). These datasets are available at Ghana Water Company ltd. (GWCL)	Ghana Water Company Ltd.

[2] This data can be generated via harmonization, it will be significantly more accurate if direct spatially disaggregated data-points were available given the large quantity of water losses, including pipeline bursts/leaks and theft, from treatment to final consumption

[3] The data was located via internet sources but only for Ghana as a whole, and not specific to the GAMA area.

[4] In communications with Foster Mensah, Director of CERSGIS, this dataset has not yet been generated.

Water Stations with Soap	Data on the existence and use of water stations with soap at various sanitation facilities at GAMA and at district level.	Unknown at present / to be investigated

As a next step the possibilities to fill identified data gaps will be undertaken as part of the data collection workflow (see next section 3). The approach will be to contact established contacts within individual local organisations, for purposes of assessing if data exists and if it can be shared.

3. Data Collection Workflow

The collection, cleaning, verification, and harmonization of data, for the GAMA in general, and in particular the WASH sector, serves to enable data population of the model prototype application. At the end of the process the results will be available in spreadsheet format, and the reporting documentation thereof, to be delivered as part of milestone FCA decision-making model milestone 9 (first dataset). The datasets can thereby be used both within the model prototype application, as well as WASH sector investigations by other parties.

To obtain this outcomes six phases are executed of which this data collection strategy report and associated spreadsheet is the first. Subsequently, the raw datasets are to be collected following procedures outlined in section 3.1, inclusive of communication to local institutions to examine possibilities to fill data gaps. Both during and after the raw data collection phase, a set of desk based procedures will be carried out as part of phases 3 to 6, in the form of checking data quality, cleaning data, quality verification, and data harmonization, as described in sections 3.2 to 3.5.

The data collection process starts in June 2015 and will including lead to an integrated and cleaned dataset by December 2015. The detailed monthly schedule can be found in table 3.1 below with a monthly outline from May 2015 to April 2016.

Table 3.1 – data collection timeline

		2015								2016			
Phase	**Data Collection Phase / Month**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**
1	**Data collection Strategy**	X											
1	**Data collection spreadsheets**	X											

1	**Rapid data screening**	X									
2	**Data gap analysis**	X						X			
2	**Data communication/outreach**		X	X	X	X					
2	**Existing raw data collection**		X	X	X	X					
3	**Data quality checks**			X	X	X					
4	**Data cleaning**				X	X	X				
5	**Data quality verification**					X	X	X			
6	**Data harmonization**						X	X	X		

In parallel to the data collection process above a number of particular WASH system relationships will be assessed, as to model particular model indicators. In specific, first the relationship between water/sanitation treatment operations and water quality. Second, the relationships between water quality and health. In case sufficiently robust relationships have been established, plus the local data to inform these relationships, such as water quality datasets, then these can be incorporated in the model prototype.

3.1 Raw Data Collection

The structure of the collection process is to first provide for a data inventory through a screening process of existing data. In the screening a summary of the relevant datasets is included as description of the relevant datasets in a source, the level of detail/coverage at spatial, temporal, or categorical levels, and meta-data for the source plus utilised data collection method.[5]

The geographic scope can include data representative for:

- **Ghana**, the entirety of Ghana
- **GAMA**, the Greater Accra Metropolitan Area in its entirety.
- **GAMA metropolitan, municipal, and districts assemblies (MMDAs)** the administrative boundaries of assemblies which cover GAMA.
- **GAMA constituencies, and neighbourhoods**, areas with a specified boundary within an MMDA.
- **Enumeration areas,** the smallest areas used for surveys as defined by the Ghana Statistical Service.
- **Point sources**, point sources such as for WASH treatment infrastructure

[5] An overview using this approach is included in the spreadsheets accompanying the data collection strategy report.

The next step is to extract the data, typically found in a PDF report, into an XLS/CSV format that can be manipulated.[6] In parallel the set of meta-data is to be expanded by further investigation of quality aspects including:

- The methodology used to collect the data (e.g. paper surveys, expert assessment, model generated theoretical value, laboratory value etc.)
- Notation of sample size at the relevant level of granularity (e.g. how many measurements/surveys for district A),
- The age of data in terms of its collection time where documented (in addition to the already collected age of referenced source).

3.2 Data quality checks

After raw datasets have been collected a number of standardised procedures are employed to assess gaps, suspicious values, and inconsistencies. Any data value that is found to fall under one of the check categories will be noted using meta-data colour coding in the raw dataset, whilst retaining the original data values.

Five checks and corresponding colour codes are to be employed for this purpose:

- **Data consistency check,** code purple, are the data values at the component or portion level matching up to a known total or distribution, such as to 100% in case of a percentage distribution, or to the total population level.
- **Missing data values check**, code brown, are data values missing for particular periods within a time-series or for particular categories in cross-sectional data.
- **Duplicate data values check**, code blue, are data values found to be exactly similar across periods for time-series or across categories for cross-sectional data, which indicates plausibility that data was copied over.
- **Discontinuities check**, code yellow, are unusually large jumps observed across periods for time-series or across categories for cross-sectional data, after which they persist after the jump. The discontinuity indicates plausibility of prior or latter measurement errors or a sudden adjustment in measurement methodologies.

[6] The majority of data in Ghana exists in reports, as the Ghana Statistical Service is still in the process of setting up an on-line accessible database service.

- **Outliers check,** code red**,** are data values significantly lower or higher than the average in the time-series or cross-sectional data set. This is structurally tested using a box and whiskers-plot procedure taking the data-point distance from lowest and highest end of the interquartile range.

3.3 Data cleaning

The raw datasets after the data check procedures are copied over to a set of new spreadsheet tabs prior to any cleaning adjustments, so as to ensure that no original data is lost.

The five evaluated data issues are addressed in the cleaning procedure using five corresponding standardised cleaning approaches:

- **Data consistency - rescaling of inconsistent data -** all data values are multiplied or divided by a factor which resolves the lack of scaling consistency. For example, if percentage data values only match up to 95%, all individual values are multiplied by 1.0562 so that the values match up to 100%.
- **Missing data - interpolation -** if one or two values between two existing values of a time-interval are missing, the data can be interpolated using a linear procedure, which is equal to data imputation using a local mean.
- **Missing data, duplicate data - imputation using the mean -** if three or more values in a row of a time-interval are missing, if categorical data is missing, or if data values have simply been duplicated, the data can be established or replaced by taking the mean data value across all time-periods or categories.
- **Discontinuities - evaluation and delta adjustment -** the time-period of discontinuity is first examined as to assess a plausible cause, such as a political, technological, or social event. If no plausible cause can be found the data-series prior the jump is adjusted by using the mean difference between the prior and posterior part of the time-series.
- **Outliers - removal of outliers -** any outliers that falls above or below the 1.5 interquartile range, as identified in the box and whiskers procedure, are to be removed from the dataset. In case this results in data gaps the values are to be imputed by the mean value, as per the data generation procedure above.

3.4 Data quality verification

A few additional quality verification steps are carried out prior to the final harmonization step. These serve as additional final quality checks for entire datasets, so as to assess whether the datasets need further investigation prior to going into harmonization where possible, and in case there is a choice of multiple datasets for the same variables to select the one that is most appropriate.

The following procedures are to be carried out:

- **Order of magnitude analysis,** an evaluation is made based whether the mean, minimum, and maximum value of a dataset, obtained via descriptive analysis, lie within the order of magnitude that the dataset should exhibit. For instance, whether mean per capita water consumption levels lie between 5 and 250 litres per day, given that per capita consumption of Western African countries lies in that range.
- **Multiple dataset similitude comparison,** if multiple large datasets are available from different source origins describing the same variables, an analysis of variance (ANOVA) between two groups is carried out, which serves to assess if the mean value is significantly different from one to the other dataset. Subsequently, if a difference exists the rationale needs to be investigated and the appropriate dataset selected.

3.5 Data harmonization

As a final step prior to using the data in the modelling environment a large number of datasets need to be integrated using complete to approximate rulesets, so as to provide for complete identification of relevant variables. For example, we would like to have a dataset that shows water demands within a district based on the household type including % differentiation by sourcing (e.g. satchels, communal standpipes, bottles, private pipes etc.). However, as a fictitious example it could be that one dataset is available which provides for % sourcing within a district, another shows % household types, and another aggregate water consumption.

In order to provide for the desired dataset these need to be combined using a specified ruleset that creates correspondence between % sourcing and % household types, such as that households of type X normally source their water for 40% from satchels and 60% from standpipes. These rulesets are typically derived from smaller samples of available data such as individual studies. Subsequently, we could integrate the level of water consumption on the basis of a ruleset that defined the average litres of water consumed in a particular household type, which needs to match up with total water demands in that district.

In the data harmonization step the standard procedure is to list the variables of the individual datasets and those of the desired integrated harmonized dataset. Subsequently, to create and list the ruleset used for the harmonization, ideally based on available sample data where possible, and finally to carry out the harmonization step.

4. Dataset Collection Templates

As part of structuring the data collection, cleaning, and verification process a set of pre-formatted spreadsheets has been built in accompaniment to this report. These include particular tabs with pre-defined data entry header plus data entry constraints where applicable for quality purposes. Also included in the spreadsheets is an overview of the procedures outlined in section 3, as separate tabs for each of the workflow steps, inclusive of additional implementation details for the excel environment. An overview of the setup of pre-formatted spreadsheets for each dataset type is provided in the next sections 4.1 to 4.4.

4.1 City-region boundary and land use data tab

The data to define the spatial surface area of the city-region can be collected using three table formats. In the first table 4.1 the areas are denoted based on their name, the surface area size in square kilometres, and the type of area. A total of five area types can be distinguished in relation to the GAMA city-region, as the total country level, the GAMA city-region, districts within the city-region such as the Accra Metropolitan District, neighbourhoods within the districts, and as the smallest area the enumeration area. The latter relate to the finest sampling size used in surveys conducted by the Ghana Statistical Service.

Table 4.1 – Surface of City-Region Areas snapshot from excel spreadsheet

DATASET: SURFACE OF CITY-REGION AREAS				
Area_type	Area_name	Surface_area	Unit	Source_of_data
country	Ghana		km2	
city_region	GAMA		km2	
city_region_district			km2	
city_region_neighbourhood			km2	
city_region_enumeration_area			km2	

In the second table 4.2 spatial points, vertices, which defined the boundary of an area are described, on the basis of latitudinal and longitudinal coordinates, in a simple setup that can easily be converted into GIS shapefile formats.

Table 4.2 – Spatial Outline of City-region Districts snapshot from excel spreadsheet

DATASET: SPATIAL OUTLINE OF CITY-REGION AREAS			
Area_name	Latitude_of_vertex	Longitude_of_vertex	Source_of_data

In the third table 4.3 land use data is described for each area on the basis of a limited number of types, and their four spatial corners as vertices, which define the boundary of a land use area. In this manner four rows are required to describe one land use cell.

Table 4.3 – Land Use Datasets snapshot from excel spreadsheet

DATASET: LAND USE DATASET 1 [for...]					
Area_name	Land_cell_number	Latitude_of_vertex	Longitude_of_vertex	Land_use_type	Source_of_data
				Agriculture	
				Industrial_Commercial	
				Residential	
				Commercial_Residential_mixed	
				Forest	
				Water_body	

4.2 City-region population and household data tab

A set of seven tables is used to collect data describing the city population and households including people's activities, employment, education, and demographics information:

- The total population numbers for particular years in respective areas, such as city-region districts (see table 4.4).
- The employment information of the population is logged for particular years and areas on the basis of their participation to the workforce, and their employment status (see table 4.5).
- The educational activity of the population is entered for particular years including number of people in present educational enrolment (yes/no), and the type of education of enrolment (see table 4.6).
- The educational status of the population is entered on the basis of the highest diploma achieved (see table 4.7).
- The number of households and any information on their characteristics is entered (see table 4.8).
- The time spent on activities by population member characteristic is logged (see table 4.9).
- The number of births in the population per year is entered (see table 4.10), as well as the number of deaths (see table 4.11)
- Any migratory information including emigration and immigration is logged (see table 4.12).

In all cases additional socio-economic data may be available for which additional variables can be added to the respective tables, for which the variable [other_socio_economic_variables] has been included on an a-priori basis.

Table 4.4 – Population in City-Region Areas

DATASET: POPULATION IN CITY-REGION AREAS			
Area_name	Population_number	Year	Source_of_data

Table 4.5 – Population Socio-Economic Employment Data

DATASET: POPULATION SOCIO_ECONOMIC_EMPLOYMENT DATA						
Area_name	Population_number	Member_of_workforce	Employment	Year	[Other_Socio_Economic_Variables]	Source_of_data
		Part_of_workforce	Unemployed			
		Part_of_workforce	Employed			

Table 4.6 – Population Socio-Economic Educational Enrolment Data

DATASET: POPULATION SOCIO_ECONOMIC_EDUCATION_ENROLLMENT DATA						
Area_name	population_number	enrolled_in_education	education_level	Year	[Other_Socio_Economic_Variables]	Source_of_data

Table 4.7 – Population Socio-Economic Educational Diploma Data

DATASET: POPULATION SOCIO_ECONOMIC_EDUCATION_ACHIEVEMENT DATA					
Area_name	population_number	highest_diploma	Year	[Other_Socio_Economic_Variables]	Source_of_data

Table 4.8 – Household Data

DATASET: HOUSEHOLD DATA					
Area_name	number_of_households	number_of_people_per_household	type_of_household	Year	[Other_Socio_Economic_Variables]

Table 4.9 – Activity Time Duration of Population

DATASET: ACTIVITY TIME DURATION OF POPULATION					
Age	Gender	Area_name	Activity	Time_spent_per_day_in_minutes	[Other_Socio_Economic_Variables]

Table 4.10 – Population Births

DATASET: POPULATION BIRTHS			
Area_name	Number_of_births	Year	Source_of_data

Table 4.11 – Population Deaths

DATASET: POPULATION DEATHS			
Area_name	Number_of_deaths	Year	Source_of_data

Table 4.12 – Population Migration

DATASET: POPULATION MIGRATION				
Area_name	Population_number	Year	Migration	Source_of_data
			Emmigration	
			Immigration	

DATASET: POPULATION INCOME FLOW DATA						
Area_name	Occupation_level	Population_hourly_income	Currency	Year	[Other_Socio-economic_variables]	Source_of_data

Table 4.13 – Population Income Data

4.3 City-region WASH sector flow data

The sector flows are captured on the basis of physical flows occurring per unit time in relation to the area of occurrence, and where applicable also any related infrastructure if mapped. Additional data points, as per the snapshot table 4.14 from the accompanying spreadsheet, include the amount of the flow and the time period for which it was valid.

Table 4.14 – Water and Sanitation Sector Flow Data

DATASET: WASH SECTOR FLOW DATA							
Area_name	Infrastructure_name	Flow_name	Amount	Unit	Time_period	Duration	Source_of_data
	Plant_x	Water_input_consumption	10000	m3	2009	Year	
	not_applicable				02/2009	Month	
					01/02/2009	Day	

In addition to flow data also service access is captured, on the basis of which service type and the source type within the service, such as stand-pipe sourcing within water services. The percentage of sourcing for the area, as captured from table 4.15, is included for the particular time-period of data measurement, plus other socio-economic variables of relevance where available.

Table 4.15 – Population Access to Sector Services

DATASET: SERVICE ACCESS						
Area_name	Service_type	Service_source_type	Percentage_source_of_service	Year	[Other_Socio-economic_variables]	Source_of_data

Also in particular case of the WASH sector quality characteristics of water are captured, as per table 4.16, as measured at different points in the chain from water in the environment, water treatment, and consumption chain. The data can be used to assess energy and material input requirements for water treatment plants, necessary for the removal of physical, chemical, and microbiological impurities. It also can potentially be used to include implications of water quality on health, if meaningful relationships between water quality and health can be established.

DATASET: WATER QUALITY DATA								
Point of measurement	Geospatial area / point	Quality characteristic	Concentration value	Unit	Year	Month	[Other variables]	Source_of_data

T*able 4.16 – Population Access to Sector Services*

4.4 WASH infrastructure data

Two types of infrastructure are captured where available, in the processing points and their technologies, such as water treatment plants, and the distribution infrastructure to transport physical flows from one point in the city-region to another.

Two tables have been prepared for this purpose. In table 4.17, as captured from the accompanying spreadsheet, the processing technologies are captured from their given name, technology type operational status and year, capacity, and location based on the latitudinal and longitudinal point. In the second table 4.18 distribution infrastructure is captured in a similar fashion, including details of a starting and ending point on the basis of a line segment.

Table 4.17 – Technology Infrastructure

DATASET: TECHNOLOGY INFRASTRUCTURE									
Area_name	Infrastructure_name	Infrastructure_technology_type	Operational	Capacity	Capacity_unit	Year	Latitude	Longitude	Source_of_data
			yes/no						

Table 4.18 – Distribution Infrastructure

DATASET: DISTRIBUTION INFRASTRUCTURE									
Area_name	Distribution_technology_type	Capacity	Capacity_unit	Year	Start_Latitude	Start_Longitude	End_Latitude	End_Longitude	Source_of_data

Appendix A – WASH Sector Data Sources

No.	Institution
1	CERGIS – Centre for remote sensing and geographic information services
2	LUPMP – Land Use Planning and Management Project - Town and Country Planning dept.
3	ILGS – Institute of Local Government Studies Geospatial
4	Land Commission
5	Ghana statistics office / Ghana statistical service
6	National Population Council
7	District Citizen services MMDs
8	Ghana water network partnership
9	Water research institute
10	Water resources commission
11	Environmental Protection Agency
12	Ghana standards office
13	Water Aid
14	African institute of water and waste management
15	Ghana water company
16	Coalition of water NGO's
17	WB – World Bank Ghana sanitation project
18	International Water Management Institute (IWMI)
19	Community Water and Sanitation Agency

Appendix B – References

1. Abbey, F. M. Assessing existing water demand and supply patterns and reuse options as additional sources of water in the Greater Accra Metropolitan Area (GAMA). (University of Ghana, 2013).

2. Abraham, E. M., Rooijen, D. Van, Cofie, O. & Raschid-sally, L. *Planning urban water - dependent livelihood opportunities for the poor in Accra*. *Water Supply* (2007).

3. Ackah, M. *et al.* Uptake of heavy metals by some edible vegetables irrigated using wastewater: A preliminary study in Accra, Ghana. *Environ. Monit. Assess.* **186,** 621–634 (2014).

4. Addai, E. *et al. Water and Sanitation Sector Performance Report*. (2010).

5. Addico, G., Hardege, J., Komarek, J., Babica, P. & de Graft-Johnson, K. Cyanobacteria species identified in the Weija and Kpong reservoirs, Ghana, and their implications for drinking water quality with respect to microcystin. *African J. Mar. Sci.* **28,** 451–456 (2006).

6. Addo, H. O., Addo, K. K. & Langbong, B. Sanitation and its impact on the bacteriological quality of water: a study in three communities in Ghana. *Afrıcal J. Food, Agric. Nutr. Dev.* **13,** 8258–8272 (2013).

7. Addo, K., Mensah, G., Bekoe, M., Bonsu, C. & Akyeh, M. Bacteriological quality of sachet water produced and sold in Teshie-Nungua suburbs of Accra, Ghana. *African J. Food, Agric. Nutr. Dev.* **9,** (2009).

8. Addo, L. Y. Institutional Analysis of Urban Water Supply in Ghana: The case of Accra Metropolitan Assembly. (Aalborg University, 2010).

9. Adu-ahyiah, M. & Anku, R. E. *Small Scale Wastewater Treatment in Ghana (a Scenerio)*. (2007).

10. Afrane, S. K. & Poku, B. A.-. Expanding the Frontiers of Microfinance in the Service of the Poor: Experiment with Water and Sanitation. *Int. J. Acad. Res. Bus. Soc. Sci.* **3,** 129–141 (2013).

11. Aglanu, L. M. & Appiah, D. O. The Korle Lagoon in Distress : The Stress of Urban Solid Waste on Water Bodies in Accra, Ghana. *Int. J. Innov. Appl. Stud.* **7,** 717–728 (2014).

12. Akormedi, M. K. Working conditions of electronic waste workers at Agbobloshie, Accra. (University of Ghana, 2012).

13. Al-Hassan, K. Y. Water Demand Management of Domestic Water in the Accra, Tema Metropolitan Area (ATMA), Ghana. (Unesco-IHE, 2007).

14. Amankwaa, E. F., Owusu, A. B., Owusu, G. & Eshun, F. Accra ' s Poverty Trap: Analysing Water Provision in Urban Ghana. *J. Soc. Sci. Policy Implic.* **2,** 69–89 (2014).

15. Amfo Otu, R., Omari, S. & Boakye Dede, E. Assessment of Physico-chemical Quality of Groundwater Sources in Ga East Municipality of Ghana. *Environ. Nat. Resour. Res.* **2,** 19–24 (2012).

16. Amisigo, B. a, Mccluskey, A. & Swanson, R. *WIDER Working Paper 2014 / 033 Modeling impact of climate change on water resources and agriculture demand in the Volta Basin and other basin systems in Ghana*. (2014).

17. Amoako, C. & Frimpong Boamah, E. The three-dimensional causes of flooding in Accra, Ghana. *Int. J. Urban Sustain. Dev.* **7,** 109–129 (2014).

18. Annepu, R. & Themelis, N. J. *Analysis of Waste Management in Accra, Ghana and Recommendations for further Improvements Earth Engineering Center , Columbia University*. (2013).

19. Arthur, R., Baidoo, M. F., Brew-Hammond, A. & Bensah, E. C. Biogas generation from sewage in four public universities in Ghana: A solution to potential health risk. *Biomass and Bioenergy* **35,** 3086–3093 (2011).

20. Aryee, A. *et al. GA Central Municipal Assembly WASH Masterplan*. (2014).

21. Asante, K., Quarcoopome, T. & Amevenku, F. Water Quality of the Weija Reservoir after 28 Years of Impoundment. *West African J. Appl. Ecol.* **13,** (2008).

22. Assembly, A. M. *The composite budget of the Accra Metropolitan Assembly for the 2012 fiscal year*. (2012).

23. Awuah, E. & Abrokwa, K. a. Performance evaluation of the UASB sewage treatment plant at James Town (Mudor), Accra. *33rd WEDC Int. Conf. Accra, Ghana* 22–26 (2008).

24. Awuah, E. & Assan, D. State of Water Supply in Accra. in *SWITCH Accra visioning and scenario planning workshop August 23rd to 24th* 5 (SWITCH, 2007).

25. Awuah, E., Nyarko, K. B. & Owuso, P. A. Water and Sanitation in Ghana. *Desalination* **252,** 43–50 (2010).

26. Awuah, E., Donkor, E. & Sanjok, E. K. M. Access to sanitation and safe water: Management of Sewerage System Case Study in Tema. in *33rd WEDC International Conference, Accra, Ghana* 1–7 (2008).

27. Awusabo-Asare, K., Nsowah-Nuamah, N., Anaman, K. A., Gaisie, S. K. & Dovide, Delali, B. *2010 Population & Housing Census: National Analytical Report*. (2013).

28. Bahri, A., Drechsel, P. & Brissaud, F. *Water reuse in Africa : challenges and opportunities*. (2010).

29. Bank, T. W. *GH-GAMA Sanitation and Water Project (P119063)*. (2015).

30. Bentsi-Enchill, N., Cudjoe, S. N., Sepah, E., Anarfi, J. K. & Gaisie, S. K. *2010 Population & Housing Census: Regional Analytical Report Greater Accra Region*. (2013).

31. Bohman, A. Framing the Water and Sanitation Challenge A history of urban water supply and sanitation in Ghana 1909-2005. (Umea University, 2010).

32. Boot, N. L. D. The use of transfer stations for faecal sludge management in Accra, Ghana. *Waterlines* **27,** 71–81 (2008).

33. Boot, N. L. D. & Scott, R. E. Faecal sludge in Accra, Ghana: Problems of urban provision. *Water Sci. Technol.* **60,** 623–631 (2009).

34. Butterworth, E. J. *et al.* Costs and benefits of multiple uses of water: a case from Ethiopia in Multiple-Use Water Services. in *Proceedings of an international symposium held in Addis Adaba, Ethiopia* 152 (MUSGROUP, 2008).

35. Cofie, O., Olugbenga, A. & Amoah, P. Introducing Urine as an Alternative Fertiliser Source for Urban Agriculture: Case Studies from Nigeria and Ghana. *Urban Agriculture Magazine* 49–50 (2010).

36. Council, N. P. *National Population Council Fact Sheet No. IV: Population, Water and Sanitation*. (2006).

37. Cowater International. *Findings and Recommendations for the Assessment of Sanitation and Water Needs in Low Income Urban Communities & Development of Participatory Strategy of Sanitation and Water Services in the Greater Accra Metropolitan Area (Ghana), June 2013: Volume 2*. **2,** (2013).

38. Diener, S. *et al.* A value proposition: Resource recovery from faecal sludge - Can it be the driver for improved sanitation? *Resour. Conserv. Recycl.* **88,** 32–38 (2014).

39. Doris, F. A. Water and Sanitation Challenges of Slum Dwellers in Ghana : The Case of Nima Women. *Int. J. Innov. Res. Dev.* **3,** 468–471 (2014).

40. Dotsi, E. *et al. Report of Cholera Outbreak Investigation, Greater Accra Region, June-August 2014*. (2014).

41. Drechsel, P. & Keraita, B. *Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risk Mitigation*. (IWMI, 2014).

42. Dwumfour-asare, B., Nyarko, K. B. & Quaye, S. A. The cost of urban water service delivery in Ghana : the case of the Kumasi and Accra-Tema water systems. *Ghanaian J. Econ.* **2,** 119–134 (2014).

43. Eckart, J. *et al. The Future of Water in African Cities: Why Waste Water?* (2011).

44. Eleke-aboagye, P. Q., Ekow, S., Ackon, D., Sewerage, A. & Project, I. Assessment of Sewerage Tariff in Accra. *J. Econ. Sustain. Dev.* **4,** 20–54 (2013).

45. Frazier, T. J. Powering Accra : Projecting Electricity Demand for Ghana‘ s Capital City. (University of Bonn, 2010).

46. Frimpong, J. A. Housing and Household Characteristics and Payment for Solid Waste Disposal in the Greater Accra Region, Ghana. (University of Ghana, 2005).

47. Fuest, V., Ampomah, B., Haffner, S. A. & Tweneboah, E. *Mapping the water sector of Ghana: an inventory of institutions and actors*. (2005). at <http://www.ircwash.org/sites/default/files/Fuest-2005-Mapping.pdf>

48. Ghana Statisical Service (GSS), Ghana Health Service (GHS) & ICF Macro. *Ghana Demographic and Health Survey 2008*. (Ghana Statistical Service, 2009).

49. Ghana statistical Service. *Level of education of population 3 years and older by region , district and sex , 2010.* (2012).

50. Ghana Statistical Service. *Employment status of employed persons 15-64 years by region and district , 2010.* (2012).

51. Ghana Statistical Service. *Economic activity status of persons 15-64 years by region , district and sex , 2010.* (2012).

52. Ghana Statistical Service. *Occupation of employed persons 15-64 years by region and district , 2010.* (2012).

53. Ghana Statistical Service. *Employment sector of employed persons 15-64 years by region and district, 2010.* (2012).

54. Ghana Statistical Service. *Enrolment in primary school by region and sex, 2007-2010.* (2012).

55. Ghana Statistical Service. *Economic activity status of persons 15 years and older by region, district and sex , 2010.* (2012).

56. Ghana Statistical Service (GSS). *Ghana's Economic Performance 2009 in figures*. (2009).

57. Ghana Statistical Service (GSS). *Ghana's Economic Performance 2010 in figures*. (2011). at <http://www.statsghana.gov.gh/docfiles/news/gh_eco_performance_2010_in_figures.pdf>

58. Gibson, K. E., Opryszko, M. C., Schissler, J. T., Guo, Y. & Schwab, K. J. Evaluation of human enteric viruses in surface water and drinking water resources in southern Ghana. *Am. J. Trop. Med. Hyg.* **84,** 20–29 (2011).

59. Grieco, M. Living infrastructure: Replacing children's labour as a source of sanitation services in Ghana. *Desalination* **248,** 485–493 (2009).

60. Gyamfi, E. T. *et al.* Chemical analysis of potable water samples from selected suburbs of Accra, Ghana. in *Proceedings of the International Academy of Ecology and Environmental Sciences* **2,** 118–127 (IAEES, 2012).

61. Heijnen, M. *et al.* Shared sanitation versus individual household latrines: A systematic review of health outcomes. *PLoS One* **9,** (2014).

62. Himans, I. P. Assessment of marine debris and water quality along the Accra-Tema Coastline of Ghana. (University of Ghana, 2013).

63. International, C. *Findings and Recommendations for the Assessment of Sanitation and Water Needs in Low Income Urban Communities & Development of Participatory Strategy of Sanitation and Water Services in the Greater Accra Metropolitan Area (Ghana), June 2013: Volume 1*. **1,** (2013).

64. Isabella, L. Analysis of the Public Health Risks of the Urban Water System in Accra by Microbial Risk Assessment. (Unesco-IHE, 2011).

65. Jensen, O. K. *et al. GA West Municipal Assembly WASH Masterplan*. (2014).

66. Kang, S., Pescina, J. U. C., Quashigah, P. J. & Kumashie, I. *Nima Land use Mapping Project Report and Map Set*. (2010).

67. Karikari, a. Y. & Ampofo, J. a. Chlorine treatment effectiveness and physico-chemical and bacteriological characteristics of treated water supplies in distribution networks of Accra-Tema Metropolis, Ghana. *Appl. Water Sci.* **3,** 535–543 (2013).

68. Karikari, A., Asante, K. & Biney, C. Water quality characteristics at the estuary of Korle Lagoon in Ghana. *West African J. Appl. Ecol.* **10,** (2009).

69. Karley, N. K. Flooding and Physical Planning in Urban Areas in West Africa: situational analysis of Accra,Ghana. *Theor. Empir. Res. Urban Manag.* **4,** 25–41 (2009).

70. Keraita, B. & Amoah, P. *Fecal exposure pathways in Accra : A literature review with specific focus on IWMI ' s work on wastewater irrigated agriculture*. (2011).

71. Konan, R. E. Assessing the Viability of a ' Water Shop Franchise Business ' To Supply Safe and Affordable Water To Selected Locations Within the Accra Metropolis , Ga East & Ga West Districts. (Ashesi University College, 2011).

72. Kortatsi, B. K. & Jorgensen, N. O. The origin of high salinity waters in the accra plains groundwaters. in *First International Conference on Saltwater Intrusion and Coastal Aquifers - Monitoring, Modeling and Management. Essaouira, Morroco* 10

73. Kuma, J. S. & Ashley, D. N. Runoff estimates into the Weija reservoir and its implications for water supply to Accra, Ghana. *J. Urban Environ. Eng.* **2,** 33–40 (2008).

74. Labite, H. *et al.* Quantitative microbial risk analysis to evaluate health effects of interventions in the urban water system of Accra, Ghana. *J. Water Health* **8,** 417–430 (2010).

75. Lente, I., Brimah, A. K., Atiemo, S., Studies, S. & Commission, E. Heavy Metal Pollution of Vegetable Crops Irrigated with Wastewater in Accra , Ghana. **22,** 41–58 (2014).

76. Lippit, C. D., Stow, D. A., Toure, S. & Vejraska, M. in *Spatial Inequalities: health, Poverty, and Place in Accra* (eds. Weeks, J. R. & Hill, A. G.) **110,** 57–71 (2013).

77. Lydecker, M. & Drechsel, P. Urban agriculture and sanitation services in Accra, Ghana: the overlooked contribution. *Int. J. Agric. Sustain.* **8,** 94–103 (2010).

78. Machdar, E., van der Steen, N. P., Raschid-Sally, L. & Lens, P. N. L. Application of Quantitative Microbial Risk Assessment to analyze the public health risk from poor drinking water quality in a low income area in Accra, Ghana. *Sci. Total Environ.* **449,** 134–142 (2013).

79. McGarvey, S. T. *et al.* Community and household determinants of water quality in coastal Ghana. *J. Water Sanit. Heal.* **6,** 339–349 (2008).

80. Melara Arguello, J. E., Grant, R., Oteng-Ababio, M. & Ayele, B. M. Downgrading - An overlooked reality in African cities: Reflections from an indigenous neighborhood of Accra, Ghana. *Appl. Geogr.* **36,** 23–30 (2013).

81. Melendez, P. Abengoa inaugurates the first desalination plant in West Africa at Accra, Ghana. (2015).

82. Ministry of Foreign Affairs. The Sludge Treatment Project at 'Lavender Hill', Accra Ghana. 1–22 (2015).

83. Monney, I., Buamah, R., Odai, S., Awuah, E. & Nyenje, P. M. Evaluating Access to Potable Water and Basic Sanitation in Ghana's Largest Urban Slum Community: Old Fadama, Accra. *J. Environ. Earth Sci.* **3,** 72–80 (2013).

84. Monney, I., Odai, S. N., Buamah, R., Awuah, E. & Nyenje, P. M. Environmental impacts of wastewater from urban slums : case study - Old Fadama, Accra. *Int. J. Dev. Sustain.* **2,** 711–728 (2013).

85. Montangero, A. & Strauss, M. *Feacal Sludge Treatment*. (2002).

86. Munumi, A. Flooding and diarrhoeal disease incidence in urban poor communities in Accra, Ghana: Investigating the effects of risk perception measures. (University of Ghana, 2013).

87. Namara, R. E. *et al. Typology of Irrigation Systems in Ghana*. *IWMI working Paper* (IWMI, 2010).

88. Nartey, V. K., Hayford, E. K. & Ametsi, S. K. Assessment of the Impact of Solid Waste Dumpsites on Some Surface Water Systems in the Accra Metropolitan Area, Ghana. *J. Water Resour. Prot.* **04,** 605–615 (2012).

89. National Population Council. *National Population Council. Fact Sheet No. III Population of Ghana: Demographic and Socio-Economic Indicators by District*. (2005).

90. National Population Council. *National Population Council Fact Sheet no. 1 Population of Ghana: National Trends*. (2004).

91. Network, S. W. *Ghana Market Assessment: Market-based Provision of Water at the Community Level Executive Summary*. (2013).

92. Nikiema, J., Cofie, O. & Impraim, R. *Technological Options for Safe Resource Recovery from Fecal Sludge*.

93. Nordic Development Fund. *Ghana Greater Accra Anaerobic Digesters Project: Appraisal Report*. (2011).

94. Norström, A. *Water and sanitation in Ghana – Focus on Adenta Municipal District in the Greater Accra Region.* (2009).

95. Nsenkyire, E. O. *Ghana National Climate Change Policy*. (2013).

96. Nyame, F. K., Tigme, J., Kutu, J. M. & Armah, T. K. Environmental Implications of the Discharge of Municipal Landfill Leachate into the Densu River and Surrounding Ramsar Wetland in the Accra Metropolis, Ghana. *J. Water Resour. Prot.* **04,** 622–633 (2012).

97. Nyarko, A. A. Assessment of Groundwater quality and urban water provision: a case study of Taifa Township in the GA-East district of the Greater Accra Region, Ghana. (Kwame Nkrumah University of Science and Technology, 2008).

98. Nyarko, E. P. *Ghana Living Standards Survey Round 6 (GLSS 6): Labour Force Report*. (2014).

99. Nyarko, K. B. Cost of delivering water services in rural areas and small towns in Ghana. in *IRC Symposium 2010: Pumps, Pipes and Promises* (IRC, 2010).

100. Nyarko, K. B., Odai, S. N., Owusu, P. a & Quartey, E. K. Access to Sanitation and Safe Water: Water supply coping strategies in Accra. in *33rd WEDC International Conference, Accra, Ghana* 416–420 (WEDC, 2008).

101. Nyarko, K. B. Drinking water sector in Ghana: drivers for performance. (Technical University of Delft, 2007). at <http://www.worldcat.org/title/drinking-water-sector-in-ghana-drivers-for-performance/oclc/166381275?referer=br&ht=edition>

102. Nyarko, P. *Ghana Living Standards Survey Round 6 (GLSS 6)*. (2014).

103. Nyarko, P. *How Ghanaian Women and Men Spend their Time: Ghana Time-Use Survey 2009*. (2009).

104. Nyarko, P. E. *Ghana Living Standards Survey Round 6 (GLSS 6): Community facilities*. (2014).

105. Nyarko, P. *2010 Population and Housing Census: Summary Report of Final Results*. (2012). doi:10.1371/journal.pone.0104053

106. Nyarko, P. *et al. Ghana Living Standards Survey Round 6 (GLSS 6): Poverty Profile in Ghana 2005-2013*. (2014).

107. Obuobie, E. *et al. Irrigated Urban Vegetable Production in Ghana : Characteristics , Benefits and Risks*. (IWMI/RUAF/CPWF, 2006).

108. Odunuga, K. Analysis of domestic water use for commercial activities among the poor in Alajo and Sabon Zongo Communities of Accra, Ghana. (University of Manitoba, 2010).

109. Oduro-Appiah, K., Aidoo, D. O. & Graham, S. Fee-based solid waste collection in eneconomically developing countries: The case of Accra metropolis. *Int. J. Dev. Sustain.* **2,** 629–639 (2013).

110. Ohene-Budu, H. Managing rural water systems for sustainable livelihood in Ghana: The case of GA EAST Municipal Assembly. (University of Ghana, 2013).

111. Osei, A. S., Newman, M. J., Mingle, J. a a, Ayeh-Kumi, P. F. & Kwasi, M. O. Microbiological quality of packaged water sold in Accra, Ghana. *Food Control* **31,** 172–175 (2013).

112. Osei, J. *et al.* The Impact of Oblogo Landfill Site in Accra-Ghana on the Surrounding Environment. *Res. J. Environ. Earth Sci.* **3,** 633–636 (2011).

113. Osumanu, I. K. Private sector participation in urban water and sanitation provision in Ghana: Experiences from the Tamale Metropolitan Area (TMA). *Environ. Manage.* **42,** 102–110 (2008).

114. Osumanu, K., Abdul-Rahim, L. & Songsore, J. *Urban water and sanitation in Ghana: How local action is making a difference*. *Water and Sanitation* (2010). at <http://pubs.iied.org/pdfs/10586IIED.pdf>

115. Owusu, P. a., Odai, S. N., Annor, F. O. & Adjei, K. a. Reservoir storage for managing floods in urban areas: a case study of Dzorwulu basin in Accra. *Hydrol. Process.* **27,** 1615–1625 (2013).

116. Peloso, M. & Morinville, C. 'Chasing for water': Everyday practices of water access in Peri-Urban Ashaiman, Ghana. *Water Altern.* **7,** 121–139 (2014).

117. Public Utilities Project Department. *International Bank for Reconstruction and Development International Development Association: Appraisal of the Accra-Tema Water Supply and Sewerage Project*. (1969). at <http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2002/07/12/000094946_02040904023182/Rendered/PDF/multi0page.pdf>

118. Quarcoo, A., Adotey, G. & Ayittey, K. Heavy metal levels in fish caught and processed at Lavender – Hill, Accra. *Int. J. Environ. Sci.* **5,** 776–782 (2015).

119. Rachmadyanto, H. UNESCO-IHE INSTITUTE FOR WATER EDUCATION Mapping pro-poor water supply services in Accra City, Ghana. (UNESCO-IHE, 2010).

120. Rain, D., Engstrom, R., Ludlow, C. & Antos, S. *Accra Ghana: A city vulnerable to flooding and drought-induced migration*. *Global report on human settlements 2011* (2011).

121. Sahl, M. & Westerblom, J. A proposal for improving the water supply in South Teshie, Ghana: Applying Sea Water Reverse Osmosis. (Royal Institute of Technology, Stockholm Sweden, 2008).

122. Santah, C. Patterns of Human excreta disposal in Ayikuma, Shai-Osudoku District. (University of Ghana, 2013).

123. Seidu, R. *et al.* Quantification of the health risk associated with wastewater reuse in Accra, Ghana: A contribution toward local guidelines. *J. Water Health* **6,** 461–471 (2008).

124. Shahrizal, M. & Razak, A. Application of QMRA for analyzing public health risk from drinking water supply in a low income area in Accra, Ghana. (UNESCO-IHE, 2011).

125. Sharpe, N. S. Develpment of a Novel Plan for Emptying Pit Latrines in Urban Slums. (University of Cambridge, 2010).

126. Siita, H., Mills, J. E., Musah, I., Nashiru, A. & Watts, R. *Financing of the water , sanitation and hygiene sector in Ghana*. (2012).

127. Stoler, J. Spatial Patterns of Water Insecurity in a Developing City: Lessons from Accra, Ghana. (University of California Santa Barbara, 2012).

128. Stoler, J. *et al.* When urban taps run dry: Satchet water consumption and health effects in low income neigborhoods of Accra, Ghana. *J. Heal. Place* **18,** 250–262 (2013).

129. Stoler, J., Tutu, R. a., Ahmed, H., Frimpong, L. A. & Bello, M. Sachet water quality and brand reputation in two low-income urban communities in Greater Accra, Ghana. *Am. J. Trop. Med. Hyg.* **90,** 272–278 (2014).

130. Stoler, J., Tutu, R. a. & Winslow, K. Piped water flows but sachet consumption grows: The paradoxical drinking water landscape of an urban slum in Ashaiman, Ghana. *Habitat Int.* **47,** 52–60 (2015).

131. Stoler, J., Weeks, J. R. & Appiah Otoo, R. Drinking Water in Transition: A Multilevel Cross-sectional Analysis of Sachet Water Consumption in Accra. *PLoS One* **8,** (2013).

132. Stoll, N. Potential Costs and Revenues of Ecological Sanitation in Accra (Ghana). (University of Hamburg, 2008).

133. Stow, D. a. *et al.* Urban Vegetation Cover and Vegetation Change in Accra, Ghana: Connection to Housing Quality. *Prof. Geogr.* 120718104048000 (2012). doi:10.1080/00330124.2012.697856

134. TERI. Presentation from the 2009 World Water Week in Stockholm: Energy Audit Findings at Water Utilities. 25 (2009).

135. The World Bank. *Project Appraisal Document for the Greater Accra Metropolitan Area Sanitation and Water Project*. (2013).

136. Thompson, A. *et al. GA South Municipal Assembly WASH Masterplan*. (2014).

137. Thurman, K. G. Land Use Regulations and Urban Planning Initiatives in Accra , Ghana. 1–35 (2010).

138. Tilley, E., Peters, S., Henseler, M., Gudel, K. & Lehnhard, Y. *Sandec Training Tool 1.0 - Module 4: Sanitation Systems & Technologies*. (2008).

139. Unknown. *Urbanization and changing land access and rights in ghana's largest metropolis, accra and kumasi*. (2007).

140. Uusitalo, K. An Evaluation of Urban Water Systems using Environmental Sustainability Indicators: A case study in Adenta, Ghana. (Chalmers University of Technology, 2002).

141. Van Rooijen, D. J. Implications of Urban Development for Water Demand , Wastewater Generation and Reuse in Water-Stressed Cities: Case studies from South Asia and sub-Saharan Africa. (Lougborough University, 2011).

142. Vanderpuije, A. O. *et al. Participatory Slum Upgrading and Prevention: Millenium City of Accra, Ghana*. (2011).

143. Verhagen, J. & Carrasco, M. *Non-sewered Sanitation Services Full-Chain Sanitation Services that Last: Non-Sewered Sanitation Services*. (2013).

144. Verhagen, J., Darteh, B., Osei-Tutu, H., Adank, M. & Sharp, P. *A Learning Platform to address Urban Water Management in the City of Accra . An assessment of the SWITCH project in Accra 2010*. (2010).

145. Vliet, B., Spaargaren, G. & Oosterveer, P. *Social Perspectives on the Sanitation Challenge*. (Springer, 2010).

146. Water Resources Commission. *National Integrated Water Resources Management (IWRM) PLAN*. (2012).

147. Water Resources Commission. *Schedule of Proposed Water Use Charges*. (2001).

148. Weeks, J. R. *et al.* Connecting the Dots Between Health, Poverty and Place in Accra, Ghana. *Ann. Assoc. Am. Geogr.* **102,** 932–941 (2012).

149. Weeks, J. R., Hill, A. G. & Stoler, J. *Spatial Inequalities: Health, Poverty, and Place in Accra, Ghana*. **110,** (Springer, 2013).

150. People's Dialogue on Human Settlements. Information about slum. (2014) Available http://www.pdfghana.org/page.php?page=402&section=50&typ=1

151. Economics Statistics Directorate, Revised Gross Domestic Product 2014. Ghana Statistical Service. 10 pages (2015).

152. CIMMS Rainwatch, 2015. Ghana Monthly Rainfall Data. Cooperative Institute for Mesoscale Metereological Studies (2015). Available http://www.cimms.ou.edu/rainwatch/#

153. Twum-Baah, K.A., Kumekpor, T.K.N. Addae-Mensah, I. Appiah, R., Tawiah, E.O., Wadieh, B., 2005. *2000 population and housing census: Greater Accra Region. Analysis of District Data and implications for Planning*. Ghana Statistical Service.

154. WaterBioTech, 2012. Report on the general obstacles potentially hindering any innovative Biotechnological Wastewater Treatments implementation in the targeted countries. Biotechnology for Africa's Sustainable Water Supply. Deliverable D1.3. [online]. Available at: www.waterbiotech.eu

155. Murray, A., Drechsel,p., 2011. *Why do some wastewater treatment facilities work when the majority fail? Case study from the sanitation sector in Ghana.* Practical Action Publishing 2011.