Baseline carbon emission assessment in water utilities in Jordan using ECAM tool

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ABSTRACT

This study presents a baseline assessment of carbon emissions in water utilities in Madaba, Jordan. The Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM) is applied in the present study in order to reduce indirect and direct emissions. Input data for the assessment included inter alia, population, water volumes, energy consumption, and type of wastewater treatment. The methodology focuses on the greenhouse gas (GHG) emissions and energy use that is directly associated with the utility operations covering the whole water cycle. The ECAM's Quick Assessment revealed that 89.7% of the energy is consumed in abstraction and distribution systems of water supply, whereas wastewater collection, treatment, and discharge consumed only 10.3% in Madaba. The detailed ECAM tool assessment results showed that total GHG emissions from the entire water and wastewater system in Madaba are approximately 28.122 million kg CO_2/year. The water supply is the major contributor to GHG accounting for 62.4%, while 37.6% of GHG emissions result from sewage treatment, and are associated with treatment process requirements considered in this work, in addition to sludge transport from septic tanks to the wastewater treatment plant. The findings of this work can help the utility to undertake energy efficiency and GHG reduction measures.

Key words | carbon emission, ECAM, Jordan, WaCCliM, water and wastewater utility, water-energy-GHGs

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INTRODUCTION

Water (drinking water and wastewater) systems are contributing to greenhouse gas (GHG) emissions and climate change since they are considered as major users of energy. Energy can be intensively consumed in every step of water management (Shrestha *et al.* 2011). It is predicted that climate change will only continue to have numerous adverse

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effects on freshwater resources, rendering many available water supplies far less reliable (NRDC 2010; Al-Weshah et al. 2016). GHG emissions are important, but given limited resources, water utilities need to lead by example and mitigate GHG emissions by balancing against climate adaptation, where climate-related issues can be weighed against other issues the utility needs to address.

In the Middle East and North Africa (MENA) region and in Jordan, climate change causes less frequent rainfall and reduced total annual precipitation (by more than 50 mm per year over the past half-century in Amman) (MWI 2016a). The number of heat extremes and days with extremely high temperatures has increased (UNDP 2014; Abdulla 2015; Rahman et al. 2015). Several studies have indicated that Jordan is ranked second in the world in water scarcity (MWI 2016b; Al-Awad et al. 2018; Saidan et al. 2018; Al-Addous et al. 2019; Jabr et al. 2019). The country is classified as being a semi-arid to arid region with an annual rainfall of less than 200 mm over 92% of the land (Saidan et al. 2015). The situation is further exacerbated by the influx of refugees from neighboring countries during recent years (Saidan et al. 2017a, 2017b; Al-Hamamre et al. 2017; Alrabie & Saidan 2018; Hindiyeh et al. 2018; Khasawneh et al. 2019; Saidan 2019; Aldayyat et al. 2019). With a population that is expected to double by 2050, there is a dire need to increase water availability. Energy is required to: abstract and pump water from groundwater aquifers; transport water from remotely located water sources via pumping stations; pump water through the distribution water network; and treat wastewater and meet stringent regulatory levels for reuse purposes (i.e., irrigation, industrial, etc.) (Gleick 1994; Morrison et al. 2009; Shrestha et al. 2012). In Jordan, the electricity consumed by water pumping has been in the range of 14–15% of the total for the country (Saidan 2012; MEMR 2016). Consequently, the consumption of energy in these water utilities is drastically contributing to carbon emissions expressed as carbon dioxide equivalents (CO_{2e}) (Strutt et al. 2008; Shrestha et al. 2011). Most importantly, water utilities produce a significant amount of methane and nitrous oxide. Reducing these emissions is one of the principal challenges in climate change mitigation issues (Gupta & Singh 2012; Santos et al. 2015). This is mainly due to the high global warming potential of nitrous oxide and methane, 298 and 34, respectively, compared to that of carbon dioxide (IPCC 2013).

Several studies have reported the estimation of carbon emissions and inventory in water systems and proposed measures to mitigate the climate change and achieve reduction targets (Larsen & Hertwich 2010; Novotny et al. 2010; Feng et al. 2011; Frijns 2011). The Water and Wastewater Utilities for Climate Mitigation (WaCCliM) Project was initiated in 2014 and is carried out by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) acting on behalf of the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) as part of the International Climate Initiative. WaCCliM is implemented in partnership with the International Water Association (IWA). The aim of the project includes helping water utilities in Mexico, Peru, and Thailand to assess and reduce their GHG emissions (Rojo et al. 2015). As part of the project the Energy Performance and Carbon Emissions Assessment and Monitoring Tool (ECAM) has been recently developed for evaluating water utility GHG emissions and energy use (http://wacclim.org/).

The methodology of the ECAM tool considers the overall performance as well as the performance of each of the six stages of the urban water cycle (i.e., drinking water abstraction, drinking water treatment, drinking water distribution, wastewater collection, wastewater treatment, wastewater discharge). The tool also assesses the quality of service, because a reduction in GHG emissions can only be considered if it does not compromise the quality of the service provided. The service levels and energy performance are calculated mainly based on IWA's Performance Indicators (PI) publications for water supply (Alegre et al. 2006) and wastewater (Matos et al. 2003). The energy requirements are translated into GHG emissions using the country's electricity mix (Brander et al. 2011). The other emissions of nitrous oxide (N_2O) and methane (CH_4) during operations are assessed consistently with the methodology of the Intergovernmental Panel on Climate Change (IPCC 2006). The WaCCliM Project was expanded to Jordan in 2016 with the aim to reduce the carbon emissions of the water supply and wastewater systems in Madaba governorate. A study was conducted using the ECAM tool to estimate the GHG emissions for the Madaba Water Utility and identify opportunities for mitigating emissions. This is the first study reporting a detailed assessment of the GHG emissions of a water utility in Jordan, for the whole urban water cycle.

MATERIALS AND METHODS

Study area

Madaba Governorate lies in the middle of Jordan and is situated 35 km southwest of Amman. It has an area of about 1,000 km^2 and a population of 190,000 inhabitants (Aboelnga *et al.* 2018). It is divided into two directorates, Madaba directorate with 498.30 km^2 and Dhiban directorate with 543.60 km^2. The topography of Madaba influences the water supply system, as shown in Figure 1. The altitude is between 854 m at Ma'in and −425 m at the Dead Sea. However, high densities of consumers are located at a moderate altitude of 750 to 800 meters above sea level. Residential water subscribers represent 93% of total subscribers and consumed 88% of water sold with an average sales price of one cubic meter 0.575 JOD (0.81 USD) in 2016. The numbers of Madaba subscribers are rising by about 5.5% each year. Madaba directorate has 27,213 subscribers while Dhiban has 5,479 subscribers. Water consumption for both directorates amounted to about 5.0 million m^3 in 2016. The Heedan wells represent the major sources for water supply of Madaba governorate with a capacity of 2,100 m^3/hr. About 9 million m^3 were supplied to the whole governorate through the main transmission line at Wala–Libb in 2014.

Figure 2 shows the Madaba water supply system starting with the Heedan wells. The transmission line from Wala to Libb pumping station which is in steel, DN 800, was built in 1991 and is 2.8 km long with no branches. The drinking water is transported from about 440 m above sea level at Wala to 670 m at Libb. The pipeline from Libb pumping station to Muntazah pumping station is at an altitude of 866 m above sea level. The main pipes were laid in 1991; they are 38 km long with several branches. Dhiban

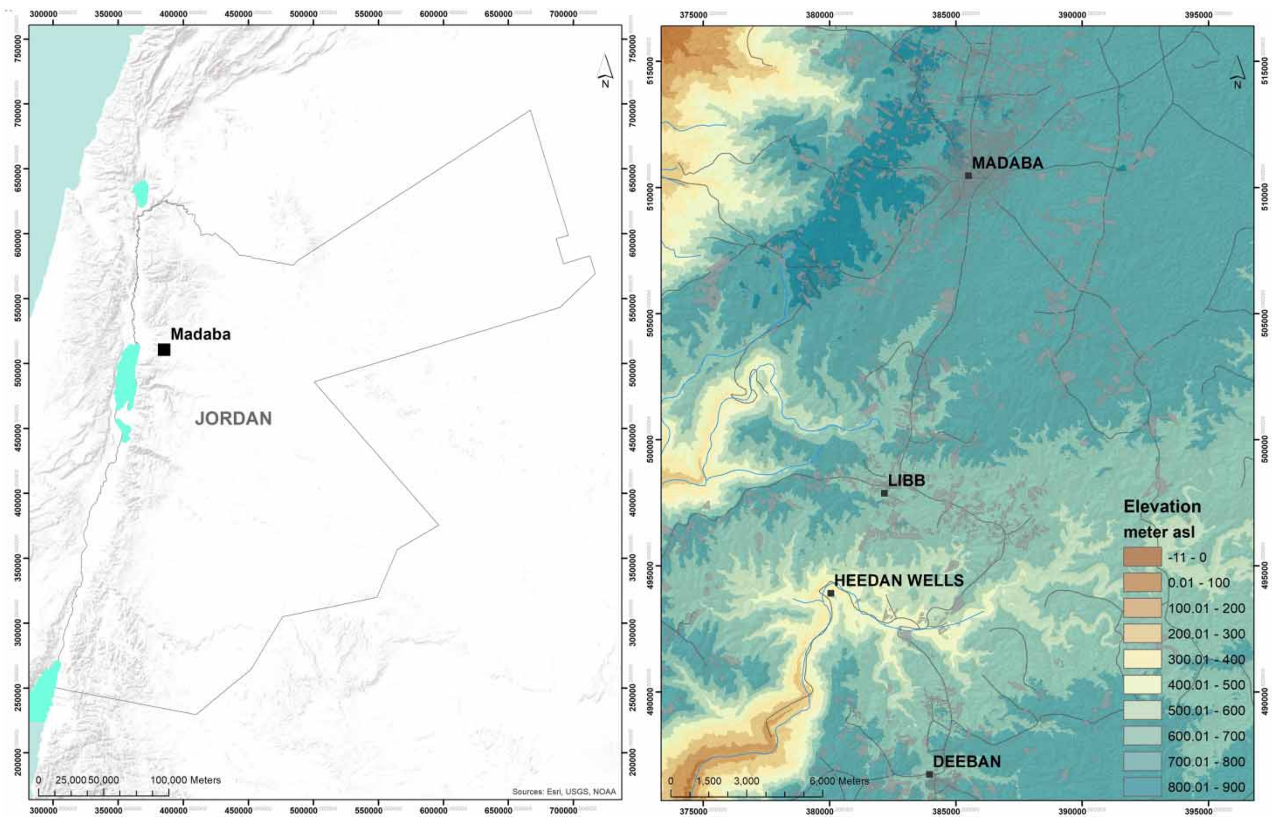

Figure 1 | The topographic map of Madaba Water Utility.

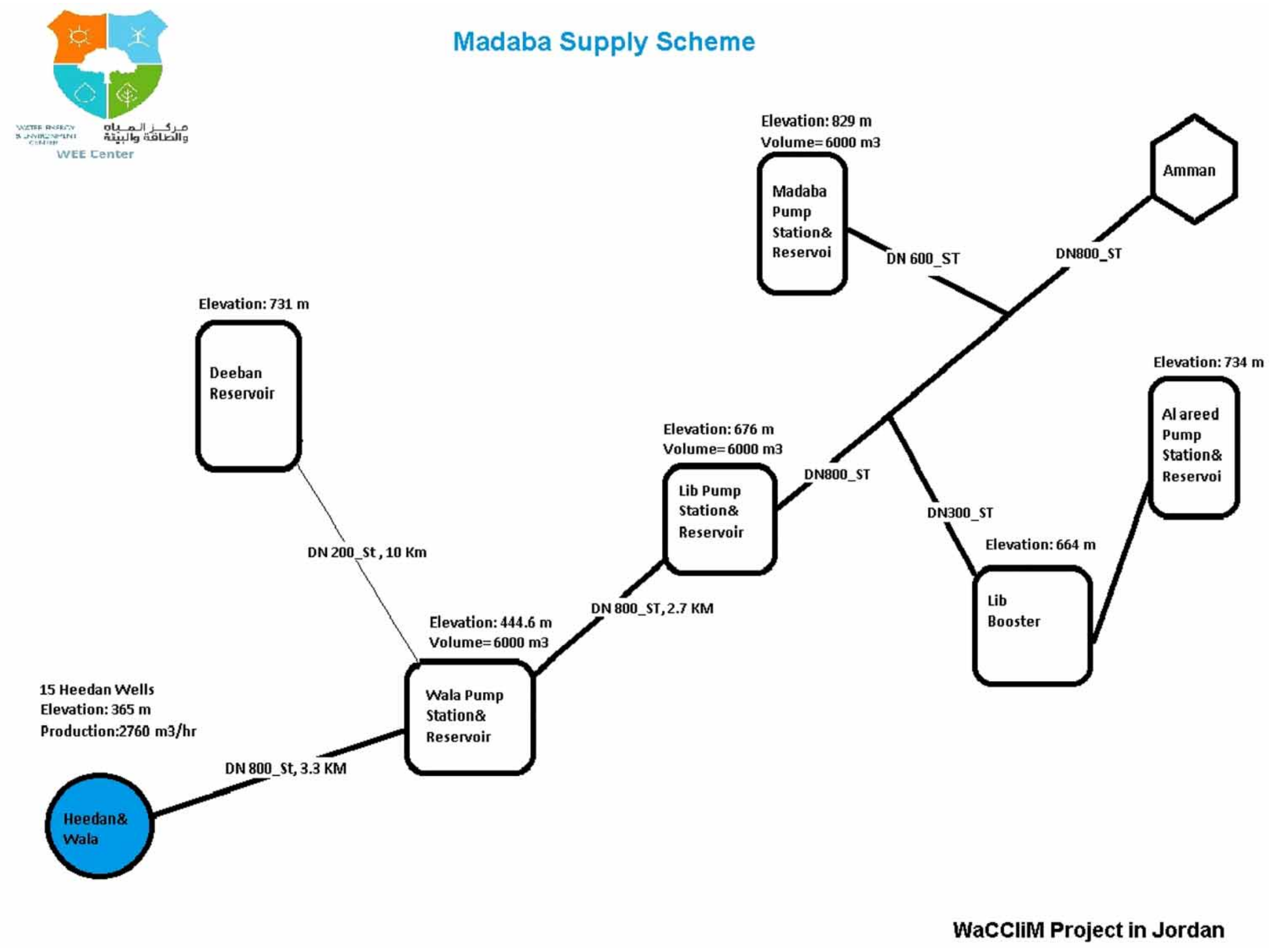

Figure 2 | Madaba water supply system.

directorate is supplied from two drinking water sources; one from Wala pumping station via DN200 mm transmission line to Dhiban Reservoir, while the other source is from Libb booster station supplying Libb and the surrounding villages with available pressure of about 18 bars via the booster pump. The oldest tertiary network from 1975 is galvanized iron material and is laid all over Madaba city. The customers of Madaba directorate are supplied from Madaba pumping stations while some areas are supplied by gravity from Madaba reservoir. Tankers also supply customers who are connected to the distribution system, but for some reason receive insufficient water from the network. Madaba is divided into distribution zones or rationing zones, some are supplied by gravity while the others are supplied by pumping. The drinking water supply is guaranteed by main transmission lines on an intermittent supply schedule, usually 1–2 days per week for each zone, with the maximum supply time of 48 hr in Madaba city and the surrounding villages. The distribution schedule is implemented by opening or closing certain regulation valves.

The wastewater collection system in Madaba is not a combined system, it is a gravity system. The wastewater treatment plant (WWTP) of Madaba operates at a rate of 7,100 m^3/day and is managed by Miyahuna. The domestic sewage system in Madaba serves about 92,778 people by collecting their wastewater and taking it for treatment, while the number of people in Madaba who are not connected to the domestic sewage system and rely on septic tanks for handling their wastewater is 20,396. With wastewater collection and treatment services covering 63% of the population of Jordan, untreated wastewater (i.e., septic tanks) is still one of the key challenges (MWI 2016c). Discharges of untreated wastewater affect not only public health and water bodies but also contribute to GHG emissions.

The ECAM software

The ECAM tool was used to assess the GHG emissions of each stage of the urban water cycle. Activity data needed to calculate GHG emissions of the water utility per the IPCC (2006) methodology and IWA PI system were input into the tool. These data included, among other inputs, population, water volumes, energy consumption, and type of wastewater treatment. The ECAM software allows water utilities and users to assess the performance of utilities regarding their GHG emissions and their relative weight, and to identify potential areas for improvement, particularly regarding energy savings. Figure 3 summarizes the main component of the GHG Assessment and all the needed input data when using the ECAM tool.

The advantage of the ECAM tool is that it allows focusing on specific water supply and wastewater treatment facilities, as opposed to the 'top-down' approach that is intended by the IPCC guidelines to give broad regional or national level estimates, which lack sufficient detail to give a truly accurate assessment at the WWTP level (Pagilla *et al.* 2009). The accuracy and applicability of the carbon emissions assessment is a function of the methods/measurements and assumptions used, as the carbon emissions are largely dependent on the operational emissions of water supply and wastewater treatment plants. For this reason, if considerable focus is not given to assumptions and measurements, using the tool could lead to erroneous baseline estimates, which deviate from reality. This would be reflected in the proposed mitigation measures as well.

The data to construct the ECAM model were obtained from Jordan Water Company (Miyahuna) and Miyahuna–Madaba Utility. Several site visits and meetings with stakeholders have been conducted. Garmin Oregon 650t GPS device and ArcGIS 10.1 were used during the site visits to Madaba Utility's different operations: Wala and Heedan wells, Wala pumping station, Libb pumping station, Libb booster and Madaba main tank. Throughout the sites visits, on-site measurements of the energy performance of the operating wells were undertaken. At the WWTP, the operation of the plant was explained and an excursion to the different stages of the system was conducted. Data acquisition regarding electrical equipment and their energy consumption in the WWTP was obtained.

RESULTS AND DISCUSSION

ECAM Quick Assessment

The ECAM tool starts off by performing Quick Assessment, which includes the whole water supply and wastewater handling services allowing a straightforward assessment with a rough estimation of GHG to be made by the utility.

The Quick Assessment evaluates the energy use and the GHG emission in regard to the service that the utility provides. This service includes delivering drinking water to end users (indicators per serviced population and per m^3 authorized consumption), and collecting and treating the wastewater prior to discharge to the environment (indicators per serviced population and per kg of biochemical oxygen demand (BOD) removed are the ones that make the most sense to assess the performance of this service).

Basic data have been provided to the tool for the water supply system that involves population, energy and water consumptions, and the cost associated with running the system. In addition, data of the electrical energy purchased from the grid were collected at the drinking water or wastewater entire system level; such data are also used to calculate GHG emissions. Table 1 shows the complete list of inputs at this stage of ECAM.

The Quick Assessment results show that total GHG emissions from the entire water and wastewater system in Madaba are approximately 23.928 million kg CO_2. The water supply is the major contributor to GHG which accounts for 17.547 million kg CO_2 (73.3%) of GHG emissions, while approximately 6.381 million kg CO_2 (26.7%) of GHG emissions are generated by the wastewater process, as shown in Figure 4.

In terms of energy consumption in the water and wastewater system in Madaba Utility, the Quick Assessment

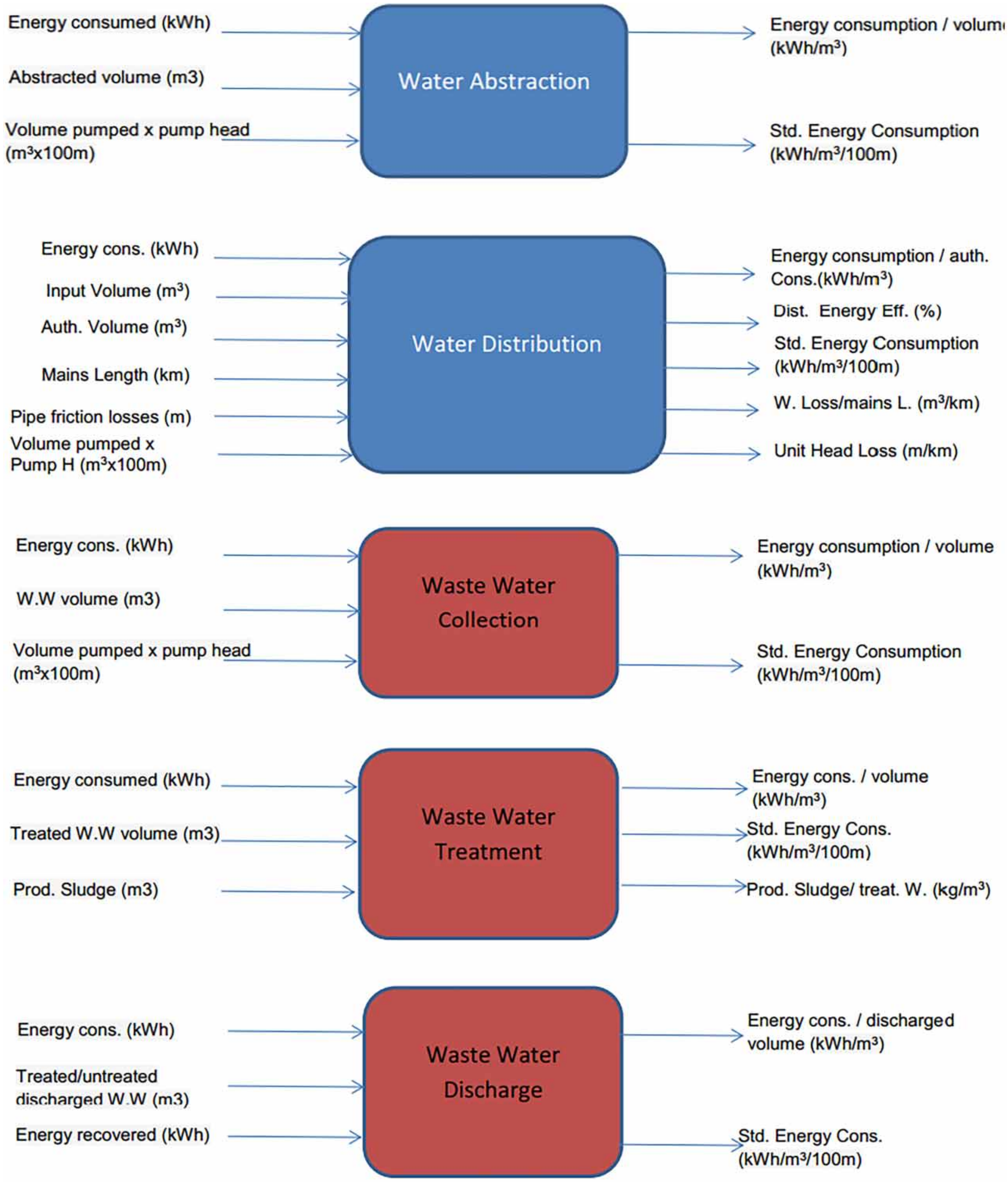

Figure 3 | Summary of ECAM tool processes.

revealed that approximately 27.250 million kWh (89.7%) of the energy is consumed in the abstraction and distribution system of water supply, whereas wastewater collection, treatment, and discharge consumed only 3.126 million kWh (10.3%), as shown in Figure 5(a). The actual costs of energy consumed in the water supply system and wastewater system are calculated annually and found to be approximately 3.636 million USD (52% of the total supply costs) and 417,092 USD (59% of the total wastewater costs), respectively, as shown in Figure 5(b), taking into consideration that the water supply system and wastewater utility serve 98.501% and 48.831% of Madaba's population, respectively.

Table 1 | Inputs to the Quick Assessment stage in ECAM tool

Water supply	
Resident population (person)	190,000
Serviced population (person)	187,152
Annual average authorized consumption (m^3/year)	5,167,715
Energy consumed from the grid per month (kWh/month)	2,239,688.96
Monthly energy costs (USD/month)	298,854
Monthly running costs (USD/ month)	572,978
Wastewater	
Resident population (person)	190,000
Population connected to sewers (person)	92,778
Serviced population (person)[a]	92,778
Treated wastewater daily flow (m^3/day)	7,100
Energy consumed from the grid per month (kWh/month)	256,933.97
Monthly energy costs (USD/month)	34,281.61
Monthly running costs (USD/month)	57,533.92

[a]The actual serviced population is higher than 92,778. Therefore, the GHG emissions of the additional indirectly serviced population were calculated manually because ECAM version 1 did not account for the population that have septic tanks and have wastewater delivered by tanks. However, this item was added to ECAM version 2.

Initial assessment in ECAM (GHG Assessment)

The GHG Assessment is a stage in which the tool provides more detailed and accurate values to calculate the GHG emissions of the drinking water and wastewater systems.

GHG emissions are separated into two categories in the ECAM tool: (1) electricity-related GHG emissions which account for any electricity consumption which has resulted in GHG emissions when generated (indirect emissions); and (2) non-electricity-related GHG emissions of water and wastewater systems, such as untreated sewage collected and discharged to irrigation, treated sewage, methane released from WWTP, and sludge transport; the latter category is considered as a direct emission.

Water supply (drinking water)

At this stage, the model introduces more detailed input data in terms of non-revenue water (NRW) that contributes to the GHG and provides PI on the service level. The NRW in Madaba water system is one of the major issues affecting Madaba Water Utility, where there is a considerable difference between the amount of water put into the distribution system (8,744,483 m^3) and the amount of water billed to consumers (5,167,715 m^3). The NRW percentage is calculated by the ECAM tool.

The energy assessment focuses on electricity consumption at each stage of water supply, starting from Heedan wells (abstraction) until it is delivered into the distribution network. The inputs needed for this stage are listed in Table 2.

High levels of NRW (40.9%) reflect huge volumes of water being lost through leaks and/or not being invoiced to customers. However, it is worth mentioning that the ECAM tool does not take into account the imported water in the distribution system. GHG emissions related to water consumption constitute approximately 10.370 million kg CO_2 per year in addition to 7.177 million kg CO_2 per year, which are generated by NRW, as shown in Table 3. This tool is outstanding for the water sector because it sheds

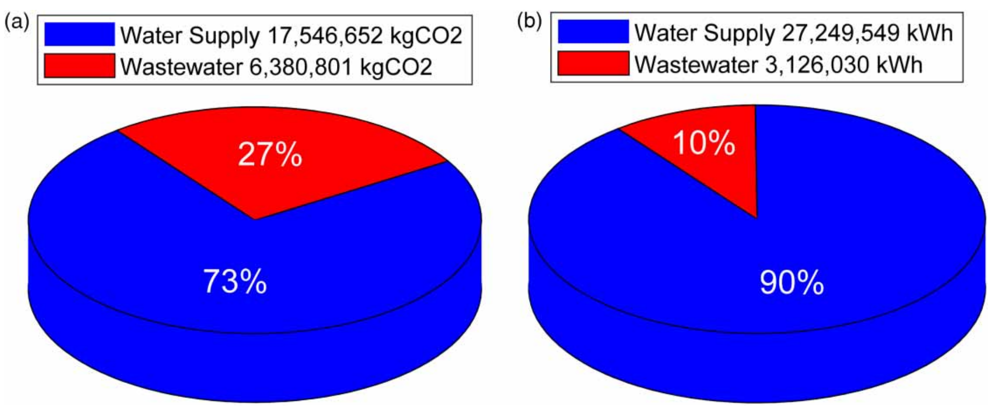

Figure 4 | (a) Calculated GHG emissions from ECAM tool and (b) calculated energy consumption from ECAM tool.

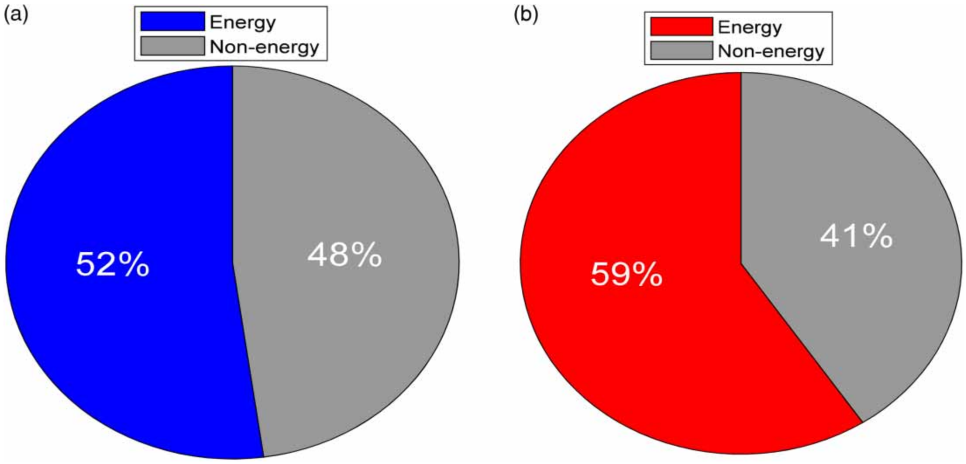

Figure 5 | Calculated costs (in USD) from the Quick Assessment in ECAM tool for (a) water supply system and (b) wastewater system.

Table 2 | Inputs to the initial GHG Assessment stage in ECAM tool

Input water supply

Description	Current value	Unit
Resident population	190,000	People
Serviced population	187,152	People
Volume of authorized consumption[a]	5,468,080	m^3
Energy consumed from the grid	27,249,549	kWh
Energy costs	3,636,056	USD
Total running costs	6,875,739	USD
Percentage of NRW	40.9	%

Note: The NRW % is calculated by the ECAM.
[a]Volume of authorized consumption is 5,468,080 m^3 but for NRW calculations, it must be billed authorized consumption.

light on the GHG emission contribution of the water sector and gives the opportunity to seek climate financing. The NRW numbers calculated by ECAM are slightly different than those determined by Miyahuna Company (Miyahuna Madaba 2015). The source of this discrepancy is that ECAM considers only the internal networks of Madaba, while Miyahuna considers the transported water to Amman as revenue water which decreases the NRW number.

Wastewater

Table 4 shows that Madaba WWTP is recognized as a significant energy consumer and source of GHG emissions with a total of 6.381 million kg CO_2 per year approximately. The electricity consumption for wastewater treatment was about 3 million kilowatt-hour (kWh) in 2016, accounting for approximately 2.013 million kg CO_2 per year of total GHG emissions. With the rapid development of WWTPs in Madaba, more energy is expected to be consumed in the future for WWTP construction and operation.

According to the GHG inventory, WWTPs were listed as the largest contributors to methane (CH_4) emissions of approximately 4.088 million kg CO_2 and nitrous oxide (N_2O) emissions of 279,742 kg CO_2. Table 4 shows the inventory of the GHG from Madaba WWTP.

Detailed Assessment ECAM analysis (GHG Assessment and energy performance)

At the Detailed Assessment level, the ECAM tool is assessing the energy performance of a given sub-stage to identify potential energy savings. Some of the assessment results are compared with known benchmarks so that inefficiencies can be highlighted, and decision-makers can prioritize improvements in the utilities' most promising stages. The Energy Performance step in which the six stages of the water cycle are as follows:

- Water supply: abstraction, treatment, distribution
- Wastewater: collection, treatment, discharge

Furthermore, the corresponding facilities such as pump stations, plants, network divisions of water supply and wastewater should be accounted for. At this stage, the

Table 3 | Outputs of the initial GHG Assessment stage in ECAM tool

Outputs – GHGs

Origin	Per year (kg CO_2/year)	Per inhabitant (kg CO_2/year/inhabitant)	Per serviced population (kg CO_2/year/serviced population)	Per water volume (kg CO_2/m^3)
Electricity	17,546,652	92.35	93.76	3.4
Total GHG	17,546,652	92.35	93.76	3.4

Outputs – Service level indicators

Description	Current value	Unit
Serviced population	98.5	%
Authorized consumption per person per day	75.65	L/serviced population/day
NRW (%volume) over the entire drinking water system	40.9	%
GHG emissions related to NRW	7,177,131	kg CO_2/yr
GHG emissions related to water consumption	10,369,521	kg CO_2/yr

Table 4 | Calculated GHG emissions of the initial GHG Assessment stage in ECAM tool for wastewater

Outputs – GHGs

Origin	Per year (kg CO_2/yr)	Per inhabitant (kg CO_2/yr/inhabitant)	Per serviced population (kg CO_2/yr/serviced population)	Per water volume (kg CO_2/m^3)	Per BOD_5 removed (kg CO_2/kgBOD)
Electricity	2,012,927	10.59	21.7	0.84	1
Sludge transport	0	0	0	0	0
CH_4 in WWTP	4,088,132	21.52	44.06	1.71	2.04
N_2O treated wastewater	279,742	1.47	3.02	0.12	0.14
CH_4 untreated wastewater	0	0	NA	NA	NA
N_2O untreated wastewater	0	0	NA	NA	NA
Total GHG	6,380,801	33.58	68.77	2.67	3.18

energy performance has been assessed in terms of relative importance of the stages (abstraction, distribution) in comparison to the entire water cycle, as represented in the graphs below the input and output tables. At sub-stage level, energy PI are calculated to assess if there is the potential to reduce consumption or improve energy production by comparing to benchmark values. These PI (e.g., standardized pumping energy), when documented at the sub-state level (i.e., facility level), are then averaged to provide an overview of the overall efficiency of the stage. They also appear averaged for the entire water utility and wastewater utility under the summary page of the energy assessment.

Water supply

The energy consumption of all water abstraction locations in Heedan wells, Libb, and Wala are provided by Miyahuna in a single meter. This prevented the study team from entering the data in sub-stages into the ECAM tool. Inputs and outputs of this stage are shown in Tables 5 and 6, respectively, and they confirm the previous results.

The water supply system in Madaba does not contain treatment; therefore, the water treatment part of the ECAM tool is overlooked.

It is notable that the operating pressure of the distribution system in Madaba is very high which largely contributes to

Table 5 | Inputs to the detailed GHG Assessment stage/water supply abstraction

Description	Current value	Unit
Energy consumed from the grid	21,428,000	kWh
Volume of abstracted water	8,744,483	m^3

Table 6 | Outputs of the detailed GHG Assessment stage/water supply abstraction

Description	Current value	Unit
Outputs – Energy performance		
Energy consumption per abstracted water	2.45	kWh/m^3
Outputs – Service level indicators		
Serviced population	98.50	%
Authorized consumption per person per day	75.65	L/serv.pop/day
NRW (%volume) over the entire drinking water system	40.9	%

the high level of NRW. Inputs and outputs of the distribution stage are shown in Tables 7 and 8, respectively, and they verify the earlier results; especially, the NRW percentage of 40.9%. The energy considered here includes the main Madaba reservoir pumping station, Libb booster, and other facilities.

Table 7 | Inputs to the detailed GHG Assessment stage/water supply distribution

Description	Unit	Current value
Energy consumed from the grid	kWh	5,820,815
Input volume	m^3	9,018,190
Volume of authorized consumption	m^3	5,167,715

Table 8 | Outputs of the detailed GHG Assessment stage/water supply distribution

Description	Current value	Unit
Outputs – Energy performance		
Energy consumption per authorized consumption	1.13	kWh/m^3
Outputs – Service level indicators		
Serviced population	98.5	%
Authorized consumption per person per day	75.65	L/serv.pop./day
NRW (%volume) over the entire drinking water system[a]	40.9	%

[a]A detailed analysis has been provided in the assessment part.

Wastewater

Inputs and outputs in the estimation of GHGs from wastewater are estimated and given in Tables 9 and 10. In WWTP of Madaba, there is no energy consumed from the grid for collecting the wastewater. It flows by gravity to reach the treatment plant. The energy consumed at this stage is left at zero, thus there are no GHG emissions.

The energy consumption of the entire WWTP is metered once. This means that the treatment and discharge of wastewater are not separated when it comes to the energy bill. After a thorough assessment, it can be estimated that 80% of the total WWTP energy is consumed during the treatment process, which leaves 20% to discharge the wastewater after the treatment. The estimated energy consumed from the grid is the first entry of the inputs shown in Table 10.

The remaining energy consumed by WWTP is accounted for in the discharge process. Table 10 exhibits the energy consumed per unit volume of discharged wastewater.

Additional to the wastewater treatment steps, transportation of the sludge from the customers to the WWTP site

Table 9 | Inputs to the detailed GHG Assessment stage/wastewater collection

Description	Unit	Current value
Collection		
Energy consumed from the grid	0	
Volume of wastewater conveyed to treatment or to an outfall for untreated discharge	2,592,363	m^3
Treatment		
Energy consumed from the grid	2,500,824	kWh
Volume of treated wastewater	2,389,500	m^3
Influent BOD_5 load	2,066,113	kg
Effluent BOD_5 load	62,127	kg
BOD_5 mass removed	2,003,986	kg
Discharge		
Energy consumed from the grid	625,206	kWh
Volume of treated or untreated discharged wastewater	2,389,500	m^3

Table 10 | Outputs of the detailed GHG Assessment stage/wastewater treatment

Description	Current value	Unit
Collection		
Wastewater is collected by gravity therefore overlooked in terms of energy		
Treatment		
Outputs – Energy performance		
Energy consumption per treated wastewater	1.05	kWh/m^3
Energy consumption per BOD_5 mass removed	1.25	kWh/kg BOD removed
Outputs – Service level indicators		
Serviced population	48.83	%
Treated wastewater per person per day	70.56	L/serv.pop./day
Discharge		
Outputs – Energy performance		
Energy consumption per discharged wastewater	0.26	kWh/m^3
Outputs – Service level indicators		
Serviced population	48.83	%
Treated wastewater per person per day	70.56	L/serv.pop./day

generates GHG emissions due to the fuel utilization, and consumes an amount of energy equal to 5.27 TJ. The GHG generated from the sludge transport from septic tanks to wastewater treatment contributed to approximately 397,596 kg CO_2 in 2016, as shown in Table 11. The fuel consumption is calculated assuming two times the distance to Madaba WWTP site (round trip) times the number of trips times at an average diesel consumption of 25 L per 100 km.

Emissions of wastewater from septic tanks

It was found that emissions from septic tanks (from households not connected to the sewage system) amount to approximately 3.797 million kg CO_2/year. This gives 0.18615 ton CO_2/capita per year, which is higher than the corresponding total anthropogenic CO_2 of the GHG emissions to the atmosphere (about 0.1 ton CO_2/capita.yr) stated by the Water Environment Research Foundation in 2010 (WERF 2010).

Summary of the Detailed Assessment

The majority of GHG emissions from water and wastewater treatment processes are attributable to energy usage, with 69.6% of GHG emissions from energy being utilized in water and wastewater systems. Energy usage is also very high in wastewater treatment facilities which contribute to 19.0% of GHG emissions in wastewater systems. The energy consumption in wastewater treatment plants is associated with process requirements as well as pumping of CH_4, N_2O, and sludge transport from septic tanks to the WWTP. Figure 6 shows a summary of energy consumption and the inventory of GHG emissions in Madaba water cycle, respectively. The annual GHG emissions for the operation of water utilities in Madaba were estimated to be approximately 28.122 million kg CO_2, of which 62% came from water supply electricity, 7% from wastewater treatment electricity, 15% from wastewater CH_4 emissions, 14% wastewater septic tanks, and the remainder are attributed to wastewater N_2O emissions and sludge transport. Table 12 shows a breakdown for all the results according to their category.

Table 11 | Additional GHG emissions generated by transport from septic tanks to Madaba WWTP

Input – GHG transport				Value	Unit
Number of trips from customers to WWTP				280	Trips/week
Distance to Madaba WWTP				20	km
Output – GHG transport to WWTP					
	Per year (kg CO_2/year)	**Per total inhabitants (kg CO_2/yr/inhab)**	**Per serviced population (kg CO_2/year/serv. pop)**	**Per water volume (kg CO_2/m^3)**	**Per BOD removed (kg CO_2/kg· BOD)**
Sludge transport	397,596	397,596	2.09	4.29	0.17

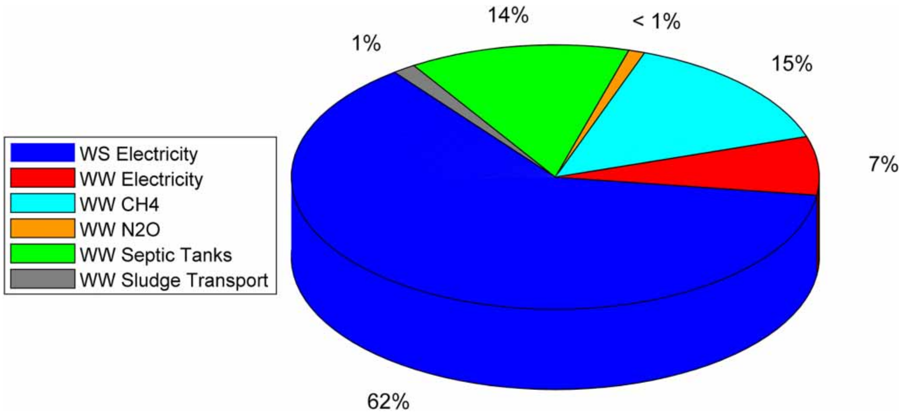

Figure 6 | Distribution of detailed calculated GHG emissions of Madaba water cycle.

Table 12 | Breakdown of the calculated GHG emissions (in kg CO_2) of Madaba water cycle

Total GHGs 28,121,764	**Water supply 17,546,652**	Electricity WS	17,546,652	**ECAM 23,927,453**
		Fuel engines	0	
	Wastewater 10,575,112	Electricity WW	2,012,927	
		From CH_4	4,088,132	
		From N_2O	279,742	
		Wastewater from septic tanks	3,796,715	**Additional emissions 4,194,311**
		Sludge transport to WWTP	397,596	

The assessment of GHG sources and emissions identified in this research can support strategies for energy reduction targets, energy efficiency, and benchmarking. The ECAM analysis and findings of this work can be applied in other cities in Jordan and help other stakeholders to undertake GHG reduction measures. This study provides concrete findings and a basis to foster dialogue among water stakeholders (water policy- and decision-makers, climate change experts, companies, academics, etc.).

CONCLUSIONS

In the present study, the ECAM tool was employed to present a baseline assessment of carbon emissions in water utilities in Madaba. The analysis was focused on water abstraction and distribution systems of water supply, as well as wastewater collection, treatment, and discharge. Significant direct and indirect emission sources were investigated through ECAM analysis. Considering the scope defined in this work using the ECAM tool, the Quick Assessment revealed that 89.7% of the energy is consumed in abstraction and distribution system of water supply, whereas, wastewater collection, treatment, and discharge consumed only 10.3% in Madaba. Consequently, the Detailed Assessment showed that the water supply is the major contributor to GHG which accounts for 62% in Madaba. Taking into account the additional emissions released due to sludge transport from septic tanks to the WWTP in addition to the ECAM results, 38% of GHG emissions result from sewage treatment, and are associated with treatment process requirements considered in this work. This study forged the communication between the water stakeholders in Jordan and can be considered as a successful case for the integration of energy efficiency measures into water utilities and strategies.

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