2019
July

Renewable Energy Sources in Gaza's WASH Sector for Public and Private WASH Facilities

This study was implemented by Oxfam, in close coordination with WASH Cluster members under the umbrella of the Solar System Task Force led by the Palestinian Water Authority

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ACKNOWLEDGEMENTS

The list of dedicated and committed individuals and institutions responsible for the completion of this study is long, and they all deserve our deepest regards, thanks and gratitude. We thank you all for your generous support and feedback. Specifically, the following deserve the most gratitude:

- United Nations Office for the Coordination of Humanitarian Affairs
- Palestinian Water Authority
- Coastal Municipalities Water Utility
- Action Against Hunger
- International Committee of the Red Cross
- Palestinian Energy and Natural Resources Authority
- Gaza Electrical Distribution Corporation Ltd
- Municipalities of the Gaza Strip

GLOSSARY/ACRONYMS

AAH	Action Against Hunger
AHP	Analytical Hierarchy Process
ASES	American Solar Energy Society
CMWU	Coastal Municipalities Water Utility
CPV	Concentrated Photovoltaic
CSTP	Concentrated Solar Thermal Power
CTEG	Concentrator Thermoelectric Generator
DSSC	Dye-Sensitized Solar Cell
ECHO	European Commission Humanitarian Aid
FI	Feasibility Index
FSC	Fuel Save Controller
GEDCO	Gaza Electrical Distribution Corporation Ltd
GENI	Global Energy Network Institute
GIS	Geographic Information Systems
GJ	Gigajoule
GW	Gigawatt
GVC	Gruppo di Volontariato Civile (Italian NGO)
ICRC	International Committee of the Red Cross
IEA	The International Energy Agency
IRENA	The International Renewable Energy Agency
KfW	German Development Bank
KVA	Kilovolt-Ampere
kW	Kilowatt
kWh	Kilowatt Hour
kWp	Kilowatt Peak
MJ	Megajoule
MCM	Million Cubic Metres
MW	Megawatt
Mwh	Megawatt Hour
NIS	New Israeli Shekel

NPV	Net Present Value
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
PbP	Payback Period
PENRA	Palestinian Energy and Natural Resources Authority
PHG	Palestinian Hydrology Group
PriDP	Private desalination plants
PSSH	Peak Sunshine Hour
PubDP	Public desalination plants
PV	Photovoltaic
PWA	Palestinian Water Authority
REN Alliance	The International Renewable Energy Alliance
SEIA	Solar Energy Industries Association
SPS	Sewage pump stations
STE	Solar Thermoelectricity
SWH	Solar Water Heaters
UNDP	United Nations Development Programme
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WPS	Water pump stations
WW	Water well
WWTP	Wastewater Treatment Plant

Executive summary

This report presents the findings of the assignment entitled 'Comprehensive Study of Renewable Energy Sources in Gaza's WASH Sector for Public and Private WASH Facilities', funded by ECHO 2018–2019 (Linking Humanitarian Approaches with Sustainable Resilience in the Gaza Strip). The study was implemented by Oxfam from October 2018 to April 2019, in close coordination with WASH Cluster members under the umbrella of the Solar System Task Force led by the Palestinian Water Authority, through Enfra consultants. The thematic objective of the study was to assess available renewable solar energy technologies and then to prioritize the most efficient and feasible technology that can be utilized for public and private WASH facilities in the Gaza Strip.

The Gaza Strip is a densely populated area with limited water and power resources. The groundwater aquifer is the only available source, with a deficit of 145 million cubic metres (MCM) per year between demand and supply. Consequently, the quality of the aquifer has deteriorated and water desalination plants are being constructed in a variety of ways: small, medium and large-scale plants; using sea water or brackish water as a source; and including public, private, household and community levels. There are 266 water wells that operate on a daily basis to provide residents with domestic water. There are 49 sewage pump stations and 6 wastewater treatment plants (see Table 1.1).

Table 1.1 – Number of WASH facilities under study in the Gaza Strip

Water wells	Water desalination plants		Water pump stations	Sewage pump stations	Wastewater treatment plants
	Public	Private[1]			
266	52	21	42	49	6

Currently, the Gaza Strip depends on the public electricity grid and the only existing power station. In addition to the electricity produced by the power station, there are two additional electricity sources from Egypt and Israel. The existing power resources provide 25–75% of the daily demand, according to the study findings. WASH facilities face a serious problem as diesel fuel for generators – usually used during periods of electricity shortage – is expensive and not continuously available, due to existing political and financial circumstances.

The field survey found that there are 6 WASH facilities which have already installed a photovoltaic (PV) system: 5 of them not working yet; only 1 (Rafah wastewater treatment plant) is operating.

Solar energy plays a significant role in ensuring a sustainable energy future and reducing future carbon emissions. There are two main types of solar energy technologies; namely, PV technology and thermal technology. The recommended direct technology to produce heat from solar energy is solar thermal technologies, while the optimum direct technology to generate electricity is through PV technologies. Based on the literature review, the consultant found that solar PV technologies is the optimum technology recommended for producing electricity; therefore this type of technology received full consideration in this study.

[1] Who are willing to work during an emergency, based on Gruppo di Volontariato Civile (GVC) study.

Since 2013, PV systems have increasingly been used in the Gaza Strip to help to address the shortage of power at private and public levels, including for WASH facilities. There are more than 40 suppliers working in the solar technology sector and several official workshops specialized in the repair and maintenance of PV systems. The available PV components are of high quality and comply with local and international standards. All components and equipment are imported from well-known manufacturers, including some brand names. The technical capacity of local suppliers is still limited and capacity building is required for suppliers, engineers and contractors.

The daily average solar radiation intensity on a horizontal surface, peak sunshine hour (PSSH), is 5.31 kWh/m^2. Total annual sunshine hours are about 700,1 hours (Ouda. M, 2003). Five types of PV systems were considered: off-grid, on-grid, on-grid with backup, diesel hybrid and direct water pumping. The advantages and disadvantages of each were considered and a comparison between these five systems was made, leading to identification of the most suitable PV system for each of the WASH facilities included in this study.

The consultant computed the capital and operational cost of PV systems for 20 years, assuming that the capital cost is $1,200/Kilowatt Peak (kWp) and the maintenance cost is $60/year (5% of capital cost) for 20 years (the lifetime of the system). Accordingly, the capital and operational cost is $2,280/kWp. The PV power production is based on 5.3 kWh/kWp/day for 20 years. WASH facilities could benefit from 30% of electricity production for sewage pump stations to 70% for all other facilities. As a result, the cost of producing 1 kWh from a PV system is 0.3 NIS/kWh for all WASH facilities except sewage pump stations, where the cost reaches 0.71 NIS/kWh.

The financial analysis carried out in this study showed that for WASH facilities except sewage pump stations, the Net Present Value (NPV) of the PV system ranges from $2,209 to $4,582/kWp, with a payback period from 3 to 5 years. The NPV for WASH facilities except sewage pump stations ranges from $942 to minus $75/kWp, with a payback period from 7 to 14 years. It is clear that PV systems are financially feasible for WASH facilities with high NPV and short payback periods; whereas for sewage pump stations, which have low NPV and high payback periods, PV systems are not financially feasible.

As the cost of producing 1 kWh from a PV system is 0.3 NIS/kWh, while the cost of producing the electricity from fuel is 0.5 NIS/kWh, and based on the computed NPV, the installation of solar PV systems proves to be money-saving and the capital cost of the installation can be paid back in less than 5 years. Implementation of feasible projects will result in 9.75 megawatt hours (Mwh) of energy savings annually. Feasible and moderately feasible projects will save 29.6 Mwh per year. The cost of implementation of feasible and moderately feasible facilities is about $9m, while cost of implementation of feasible facilities is about $4.7m.

There are 438 WASH facilities in the Gaza Strip, of which 417 facilities have standby power generators to bridge the shortage of power from the public electricity grid. Most critical facilities that receive fuel from the UN system and are technically feasible to be targeted with solar PV systems, according to the study results. The highest priority facilities are illustrated in the following tables. The sizes and cost estimates of the proposed PV systems are also shown.

Sewage pump stations (PS)					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
RF.2.SP.02	Jumizit Al Sabiel PS	Rafah	98	Feasible	88,200
RF.2.SP.04	Tal Al Sultan PS	Rafah	61	Feasible	54,900
RF.2.SP.03	Al Juninah PS	Rafah	59	Feasible	53,100
				Total capital cost ($)	196,200

Water pump stations					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
KH.1.WP.01	Al Sa'ada booster	Khanyounis	169	Feasible	152,100
KH.1.WP.02	Ma'an booster	Khanyounis	78	Feasible	70,200
BS.1.WP.01	Eastern booster station-regional	Bani Suhaila	26	Feasible	23,400
RF.1.WP.05	Rafah ground tank	Rafah	143	Feasible	100,100
				Total capital cost ($)	345,800

Water wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
GZ.1.PW.01	Al Shajaia 2 water well	Gaza	54	Feasible	105,300
GZ.1.PW.24	Al Shaekh Ejleen 5 water well	Gaza	45	Feasible	44,100
MG.1.PW.02	Al Kauthar well F264	Al Moghraqa	71	Feasible	63,900
QR.1.PW.02	Al Matahin	Al Qarara	72	Feasible	64,800
WS.1.PW.01	Wadi Salqa	Wadi Alsalqa	21	Feasible	18,900

Water wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
BL.1.PW.03	Al Mashrou water well	Bait lahia	90	Feasible	131,400
JB.1.PW.06	Al Zohor water well	Jabalia	23	Feasible	34,200
RF.1.PW.11	Al Shoukah well	Al Shoukah	59	Feasible	53,100
RF.1.PW.31	Al Malizei well	Al Shoukah	59	Feasible	53,100
RF.1.PW.03	Abu Hashem water well P124	Rafah	118	Feasible	106,200
RF.1.PW.07	Al Eskan water well P153	Rafah	66	Feasible	59,400
RF.1.PW.04	Canada P 144	Rafah	24	Feasible	21,600
				Total capital cost ($)	756,000

The study indicated that increasing the production of water wells by installing a PV system would minimize the shortage of water supplies, especially in summer months. This will improve public health and meet the needs of residents. Meeting community needs will positively influence the relationship between communities and municipalities, which in turn will improve municipalities' revenues. Increasing the operation hours of desalination plants will enable service providers to produce greater quantities of desalinated water in order to satisfy the needs of the community at lower prices. Such production will improve public health and sustain the service.

The study showed that the process of installing PV systems reduces the production of CO_2 by 0.76kg of CO_2/kWh and minimizes the energy content by 10.9 megajoules (MJ)/kWp. This is due to the fact that 100 litres of diesel produces 0.27 tonnes of CO_2 (2.7kg CO_2/L) with energy content of 3.84 gigajoules (GJ). Diesel generators consume 0.284 L/kWh and, consequently, produce 0.76kg of CO_2/kWh and energy content of 10.9 MJ/kWp.

In general, the study indicated that the PV system alternative is feasible. The most facilities that would benefit most from PV systems have been classified based on specific criteria, as shown in Table 1.2. Each criterion has been given a specific weight based on its significance. Accordingly, a Feasibility Index (FI) has been identified for each WASH facility, with a maximum FI of 100.

Table 1.2 – Feasibility index (FI) for the WASH facilities under study

Facility	Land availability (10 points)	Hours of facility operation (points)	Operational hours of generator (3 points)	Cost of production (3 points)	Production capacity (5 points)	Water quality (5 points)	Total points
Water wells	√	√	√	√	√	√	31
Desalination plants	√	√	√	√	√		26
Water pump stations	√	√	√	√	√		26
Wastewater pump stations	√	√	√	√	√		26

The facilities were classified based on the FI; the facilities which obtained a FI score of more than 60 are considered as the most suitable for PV systems and deserve the highest priority for funding. The second group is facilities with a FI ranging from 40–60; this group requires certain improvements to enhance the benefits from solar technologies before the installation of a PV system is approved. The last group has a FI value of less than 40; these facilities are considered infeasible for the installation of PV systems. Table 1.3 presents the classification of WASH facilities based on the FI index and the corresponding numbers.

Table 1.3 – Classification of WASH facilities

Facility	$\boldsymbol{FI} \leq \mathbf{40}\ \%$	$\mathbf{40}\ \% < FI\ \leq 60\ \%$	$\boldsymbol{FI}\ > 60\ \%$	**Total**
Water wells	95	128	43	**266**
Public desalination plants	15	30	7	**52**
Private desalination plants[2]	10	7	4	**21**
Sewage pump stations	10	30	9	**49**
Water pump stations	8	19	15	**42**
Total	**138**	**214**	**78**	**430**

[2] Who are willing to work during emergency based on GVC study.

1 Introduction

1.1 Background

The Gaza Strip is a densely populated area that relies on the aquifer as its main freshwater resource. The yearly groundwater abstraction from the aquifer in the Gaza Strip reaches approximately 183 million cubic metres (MCM), while, according to the Palestinian Water Authority (PWA), the yearly natural recharge does not exceed 55–60 MCM. As a result of this lack of equilibrium between abstraction and natural recharge, groundwater quality in the Gaza Strip has dramatically deteriorated. The groundwater level has declined during the last few years to about 10–15m below sea level. This has led to the invasion of seawater in large parts of the inland aquifer as well as the upwards leakage of the underlying saline brackish water. This has led to an increase in the salinity of the groundwater to an unacceptable level, where more than 97% of pumped groundwater exceeds World Health Organization (WHO) standards in terms of chloride concentration in drinking water. For sanitation, the Gaza Strip has also been suffering from serious infrastructure challenges in wastewater collection/disposal and treatment. The PWA estimates that yearly wastewater generation within the Gaza Strip reaches approximately 40 MCM. This is partially treated in 6 wastewater treatment plants before being dumped into the Mediterranean.

Currently, municipal wastewater collection/disposal coverage does not exceed 73% of the total population of the Gaza Strip, while the remainder of the population rely on septic tanks and/or cesspits for the disposal of their wastewater. The six wastewater treatment plants in the Gaza Strip are overloaded as they receive greater quantities of wastewater than their design capacities allow. Accordingly, these plants do not work efficiently and the effluent generated is usually of poor quality that is not compliant with the WHO and/or Palestinian Authority (PA) standards. All figures quoted were obtained during meetings conducted with PWA and the Coastal Municipalities Water Utility (CMWU).

The context described above, especially for domestic water, made it necessary for policy makers in the Gaza Strip (PWA) to adopt desalination as a solution for the supply of good-quality drinking water for the population. The main service provider in the Gaza Strip, CMWU, has therefore established 52 public desalination plants for desalinating brackish water. There are about 70 private desalination plant working in the Gaza Strip. According to a study carried out by the Italian NGO, GVC, these include 21 private desalination plants which are willing to operate during emergencies.

Other public water and sanitation facilities operated by CMWU/municipalities include (i) 266 municipal domestic water wells, (ii) 42 water pump stations, (iii) 49 sewage pump stations and 6 wastewater treatment plants. According to CMWU, the public WASH facilities need approximately 36 megawatts (MW) per day to operate.

Since 2006, the Gaza Strip has been suffering from a chronic electricity shortage, which negatively affects all aspects of living conditions. This situation has severely affected the availability of essential services, particularly health, water and sanitation services; in July 2018, the overall shortage in electricity reached 80%.

As with other services, the functioning of WASH services is highly correlated to the electricity shortage situation, which has suffered the following effects:

- The daily per capita domestic water has decreased from 84 litres to 53 litres.
- At the public desalination plants, capacity has been reduced to 20%.
- More than 100,000 cubic metres of raw wastewater is dumped into the Mediterranean daily.
- Flooding may occur in the locations of the wastewater pump stations (low points), especially during rainy seasons. This is a critical public health issue.

In response to this situation, the PWA has developed its own strategy to solve the WASH crisis in the Gaza Strip, as well as to maintain the needed electricity supplies for WASH facilities, by considering a range of potential options for water supply. These include seawater desalination, transfer of water from Israel, wastewater reuse for agricultural purposes, in addition to utilization of renewable energy resources, including solar energy, for the operation of WASH facilities. According to PWA strategy, by 2022, the power demand of WASH facilities in the Gaza Strip will reach 92 MW.

At the humanitarian level, the WASH Cluster has adopted renewable energy, solar energy, for the operation of WASH facilities. The WASH Cluster has provided recommendations to various organizations to invest in solar energy resources to support humanitarian WASH projects, thereby enhancing their sustainability and operation.

In general, the Gaza Strip suffers from a shortage of power sources as the public network provides electricity just 25–75% of the time. Water facilities are negatively affected by this and most use diesel generators to overcome the power shortage. However, there are two main problems in using generators: the first is the high cost of diesel ($1.3/litre) and the second is the lack of continuous availability of diesel due to the unstable political and financial circumstances.

Therefore, Oxfam contracted Enfra consultants to conduct a ‘Comprehensive Study of Renewable Energy Sources in Gaza’s WASH Sector for Public and Private WASH Facilities’. The main aim of this study is to map all water facilities which have the potential to use solar energy and provide a feasibility study on utilizing such renewable energy.

1.2 Overall objective

This study is to assess the available renewable solar energy technologies and then to prioritize the most efficient and feasible technology that can be utilized for public and private WASH facilities in the Gaza Strip. The study aims to identify t he benefits of utilization of renewable solar energy for the operation of public and private WASH facilities in the Gaza Strip in order to supply vulnerable communities with essential water and sanitation services. Further, this study aligns with the aims of PWA to use solar energy as an alternative renewable energy resource for the operation of WASH facilities in the Gaza Strip.

1.3 Specific objectives

There are several specific objectives to be achieved by the study, as follows:

- Review WASH facilities in the Gaza Strip (mainly municipal water wells, municipal water pump stations, public desalination plants, private desalination plants, sewage pump stations and wastewater treatment plants) to identify and review the existing level of solar energy usage.

- Study the feasibility of using solar energy for the operation of WASH facilities in the Gaza Strip, focusing on the new available technologies that can utilize solar energy with the highest efficiency and most economically. The main question of the study is to what extent the usage of solar energy for the operation of WASH facilities in the Gaza Strip is feasible.
- Identify future solar energy projects and their prioritization for the operation of WASH facilities in the Gaza Strip.
- Transfer the knowledge, capacity building and technical guidance, in relation to assessing WASH projects incorporating solar energy, to WASH stakeholders in the Gaza Strip.
- Develop a standardized technical approach for the installation and operation/maintenance of solar energy systems in WASH facilities in the Gaza Strip.

2 Methodology

2.1 Approach and methodology flowchart

The consultant was tasked with gathering, reviewing and verifying information related to the targeted WASH facilities in the Gaza Strip. The WASH facilities included in this study comprise water pump stations, public and private desalination plants, water wells, wastewater pump stations and wastewater treatment plants. The consultant analysed and assessed the available quantitative and qualitative data of the WASH facilities. Based on the results, the feasible, moderately feasible and non-feasible WASH facilities for installing solar technology were identified. Figure 2.1 summarizes the stages of the methodology, which are described in detail below.

2.2 The inception report

The consultant submitted an inception report as the first deliverable for the study, in October 2018. The inception report set out a clear way forward for the execution of the assignment. This report was prepared to clarify the overall strategies, methodology and action plans adopted for managing and conducting the assignment within the designated timeframe as well as the expected level of quality. Furthermore, the report included a detailed implementation plan for the assignment, with a plan for the effective utilization of resources and responsibilities.

Data collection methodology

The data collection methodology comprised two stages. The first stage included reviewing and verifying existing data on the WASH facilities, whereby a literature review was conducted on the different types of solar technologies worldwide and locally, and their advantages and disadvantages. The second stage included assessing the situation for installing solar energy systems in WASH facilities in the Gaza Strip (mainly municipal water wells, wastewater pump stations and wastewater treatment plants, public desalination plants, private desalination plants and water pump stations); this was achieved by conducting field visits to the targeted facilities (see Annex 3.1). The following sections briefly describe the data collection methodology.

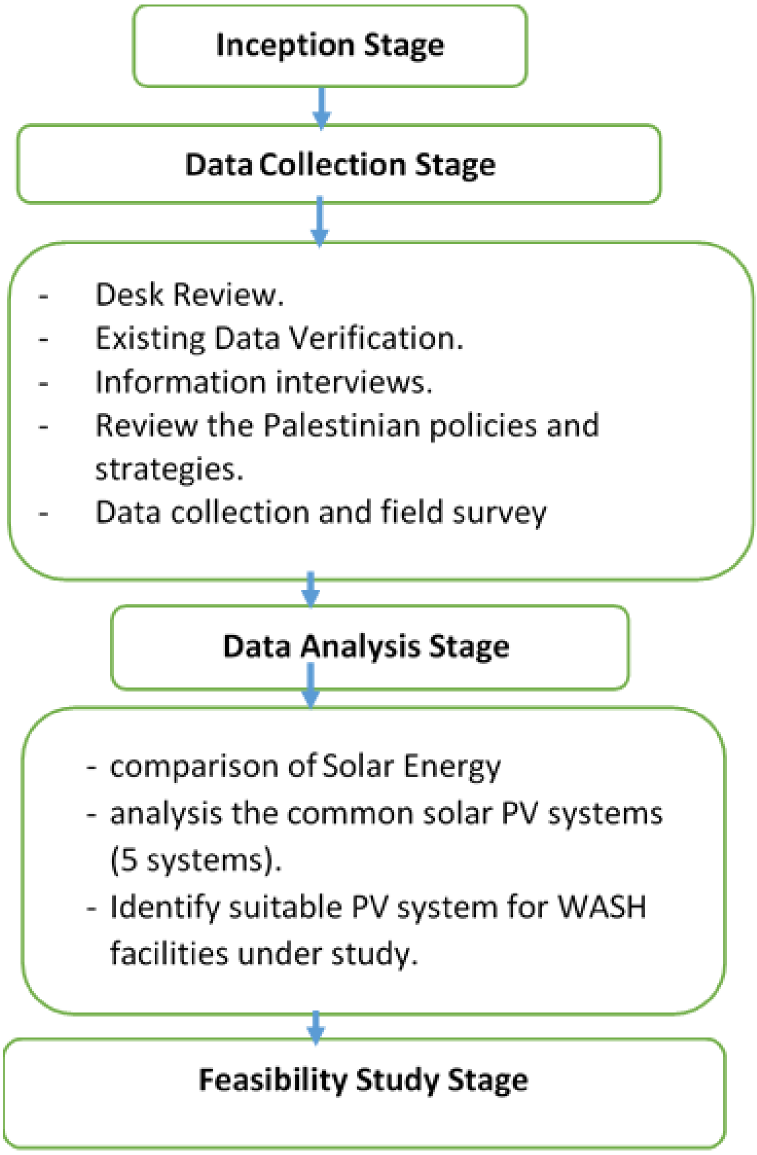

Figure 2.1 – Flow chart showing the applied methodology

2.3 Mobilization, review and verification of existing data

A kick-off meeting was held between Oxfam and Enfra on Tuesday 16 October 2018. Matters discussed included the methodology and work plan for the assignment, coordination, previous documents and data collection, and preparing the checklist.

Desk review

Enfra obtained up-to-date information on the targeted WASH facilities. The consultant reviewed the collected information from various local studies and reports.

The consultant also reviewed previous documents and literature on solar energy technologies to prioritize the most efficient and feasible technology that can be utilized for public and private WASH facilities in the Gaza Strip. This review process included the National Renewable Energy Strategy and the aims of PWA to use solar energy as an alternative renewable energy resource for the operation of

WASH facilities in the Gaza Strip. The reports and articles reviewed are as follows:

- Action Against Hunger (AAH) (2018). Technical Verification and Assessment of Public Desalination Plants in Gaza Strip, Gaza, the Occupied Palestinian Territory (OPT).

- AAH (2018). Technical Feasibility Study and Unit Design for Piloting a Hydropower Electric System, Gaza, OPT.

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- PWA (2012), Assessment of groundwater desalination Units in the Gaza Strip, General Directorate of Water Resources and Planning, OPT. (Report in Arabic).

- PWA (2015), Technical Report of the Quality Control Program for Desalination Stations, Case Study of the Governorates of Gaza and North Gaza, General Directorate of Water Resources

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Interviews

Having performed the above activities, pre-structured interviews were carried out with focal points of the relevant authorities and NGOs, working groups of the UN, private sector and other stakeholders for direct data and related documents collection (secondary data) as well as coordination of field visits. This included a list of the targeted WASH facilities and available data. Table 2.1 shows meetings conducted with relevant stakeholders; and the detailed schedule of the conducted field visits is listed in Annex 3.1.

Table 2.1 – List of interviews with relevant focal points

Institute
Palestinian Water Authority (Ramalah)
Palestinian Water Authority (Gaza)
Coastal Municipalities Water Utility (CMWU)
UNICEF (WASH Cluster Coordinator)
Municipality of Gaza
Gaza Electrical Distribution Corporation Ltd (GEDCO)
Palestinian Energy and Natural Resources Authority (PENRA)
Action Against Hunger (AAH)
United Nations Office for the Coordination of Humanitarian Affairs (OCHA)
International Committee of the Red Cross (ICRC)
UN Unit

Review the Palestinian policies and strategies

The consultant reviewed the Palestinian policies and strategies for renewable energy. This involved obtaining a clear vision of strategies and authorized laws/regulations that encourage the use of renewable energy, such as the Palestinian Renewable Energy Strategy which was issued by Palestinian Energy and National Resources Authority (PENRA) and decree laws related to renewable energy and energy efficiency.

2.4 Data collection and field survey

Throughout this stage, the usage of solar energy in the targeted WASH facilities of the Gaza strip (mainly municipal water wells, wastewater pump stations and wastewater treatment plants, public desalination plants, private desalination plants) was assessed. This was carried out by conducting field visits to the targeted facilities using various data collection tools.

The targeted WASH facilities were as follows (See Annex 3.2 for details):

- 266 municipal domestic water wells
- 49 wastewater pump stations
- 8 wastewater treatment plants
- 52 public desalination plants
- 21 private desalination plants
- 42 water pump stations.

The consultant prepared a list of the targeted WASH facilities based on the desk review; the consultant then discussed this with Oxfam and gained its approval of this list for further study and analysis. The consultant designed a checklist for collecting the necessary data through the field survey; this was approved by Oxfam (Annex 3.3 presents a checklist template for the WASH facilities). The consultant team then conducted the field survey and obtained all necessary data from the targeted WASH facilities.

2.5 Data analysis methodology

Data analysis was divided into two parts. The first part comprised analysing the solar technologies data in order to identify the suitable solar technology for each WASH facility. Based on solar technologies fundamentals and concepts, and more specifically the solar PV systems, the consultant identified the suitable PV system for each WASH facility under study, based on the following parameters:

- Type of WASH facility
- Operation period of the facility
- Availability of land for PV panels installation
- Availability of a diesel generator in the facility
- Availability of a water storage tank in the facility.

The second part included developing a baseline mapping of the targeted WASH facilities. This included a comprehensive list of WASH facilities with Geographic Information Systems (GIS) maps. Analysis of the data was carried out based on the following:

- Facility location
- Available area
- Water or wastewater production
- Operation hours
- Power consumption
- Availability of diesel generators.

2.6 Feasibility methodology

The consultant studied the feasibility of using solar PV systems for WASH facilities in the Gaza Strip based on the identified PV technologies for each WASH facility under study. A cost-benefit analysis was carried out, taking into consideration all aspects related to market analysis, capital cost and the operation and maintenance of the PV systems. This involved:

1. Identifying the current situation
2. Conducting meetings with stakeholders
3. Exploring current solar energy usage in WASH facilities in the Gaza Strip.

The consultant carried out data collection from all key parties that manage and operate water facilities using solar energy. This step enabled the establishment of an effective feasibility study that describes and assesses the cost of such technologies.

Financial feasibility

The consultant analysed existing information in literature and data regarding PV systems for WASH facilities in the Gaza Strip. The aim was to determine the capital and maintenance costs of such systems. Meetings with Gaza PV firms were also conducted to determine the current market prices. Based on the collected data, the consultant proposed the capital cost of each system.

The maintenance cost is estimated as 5% of capital cost per operational year, considering the system will work for 20 years before replacement.

To study the financial feasibility of PV systems, the consultant determined the Net Present Value (NPV) and the payback period. To determine such values, the consultant estimated the cost of electricity generated from diesel generators, based on the following:

- Total operation hours of generators are estimated to be 35,000 hours before replacement.
- A generator will work 7 hours daily for the whole year and will require 10% of its capital cost per year as maintenance cost.
- The consultant calculated the estimated cost based on generators with a capacity of 40 Kilovolt-ampere (KVA) and 110 KVA, as these two types of generators are widely used in the Gaza Strip.

Based on the capital cost, maintenance cost and yearly revenues, the consultant estimated the NPV and payback period.

The cost of generating kWh from a PV system was calculated based on the total cost of the system for 20 years and the revenues for the same period. The total electricity generated from PV systems is 5.3 kWh/kWp/day; 70% of this amount is used by WASH facilities (except wastewater pump stations, which benefit from 30%, as sewage pump stations do not work continuously).

Technical feasibility

To determine the technical feasibility, several evaluation criteria were set for each facility depending on type. Table 3.2 presents the criteria used for each facility.

The criteria have different weights according to the degree of importance; the weight of each criteria is presented in Table 2.2 in terms of points. The consultant discussed and gained approval for the criterion and the weighting system with Oxfam and all concerned stakeholders. An explanation of each criterion is presented below.

Table 2.2 – Matrix of WASH facility, criteria and the corresponding weighting factor

Criteria	Land availability, C1	Operation hours of facility, C2	Operation hours of generator, C3	Cost of water production, C4	Facility capacity, C5	Water quality, C6	Total Points
Weighting factor	10	5	3	Varies between 0 to max 3	5	5	
Water wells	√	√	√	√	√	√	31
Desalination plants	√	√	√	√	√		26
Water pumps	√	√	√	√	√		26
Wastewater pump stations	√	√	√	√	√		26

Land availability: This criterion is considered as the most important; it therefore has the highest weight (10 points). The major problem facing solar energy use is the need for suitable land for solar panels. This criterion represents the availability of land suitable for implementing the solar PV project. It also shows the capacity of the needed PV system (kWp) with respect to the capacity of the PV system based on the available area. If the required design area for a PV system for full utilization is ***DA*** and the available area is ***AA***, then:

$$C1 = \frac{AA}{DA} \times Land\ availability\ weighting\ factor\ (10)$$

Hours of facility operation: Operation hours of WASH facilities vary based on the type and capacity of the facility. More operation hours for the facility means that a PV system will be more beneficial. During data collection, the consultant gathered information on the required hours of operation per day. Operation hours per day are calculated as a percentage of 24 hours and multiplied by the weighting factor of the operation hours of facility (5). If the required operation hours of the facility are $\boldsymbol{(OH)_F}$, then:

$$C2 = \frac{(OH_F)}{24} \times \text{facility operation hours weighting factor } (5)$$

Operational hours of generator: Most WASH facilities have generators to partially bridge the shortage of power. It is clear that when a diesel generator operates for more hours per day, installing a PV system will be more beneficial. The consultant collected current generator hours per day and calculated this as a percentage of 24 hours. The percentage of generator operation per day is multiplied by the weighting factor of the operation hours of generator (3). For example, if the generator operation hours are ***(OH)***$_{G}$, then

$$C3 = \frac{(OH_G)}{24} \times \text{generator operation hours weighting factor (3)}$$

Cost of production: The consultant collected data regarding quantity of flow produced from the water wells and desalination plants or pumped by the water pump stations and wastewater pump stations. The cost of production is computed by dividing the operational daily cost of the facility by its daily production of water in m^3. Consequently, the consultant classified the cost of production into several ranges using the equation below. If the daily cost is equal to or less than a specific value, the weighting factor is considered 3; otherwise for a smaller daily cost the weighting factor is considered less than 3, as shown in Tables 2.3–2.7.

$$C4 = \frac{daily\ cost, USD}{daily\ production, m^3} \times \text{cost of production weighting factor (max. 3)}$$

Table 2.3 – Water pump stations cost of production

Ranges of cost of production ($/m^3)		Weighting factor
from	to	
0		3
> 0.01	= 0.04	2.4
> 0.04	= 0.06	1.8
> 0.060	= 0.08	1.2
> 0.100	= 0.180	0.6
More than 0.18		0

Table 2.4 – Sewage pump stations cost of production

Ranges of cost of production ($/m^3)		Weighting factor
from	to	
0		3
> 0.00	= 0.05	2.4
> 0.05	= 0.10	1.8
> 0.10	= 0.70	1.2
> 0.70	= 1.00	0.6
More than 1		0

Table 2.5 – Private desalination plants cost of production

Ranges of cost of production ($/m³)		Weighting factor
from	to	
0		3
> 0	= 0.01	2.4
> 0.01	= 0.04	1.8
> 0.04	= 0.08	1.2
> 0.08	= 0.10	0.6
More than 0.1		0

Table 2.6 – Public desalination plants cost of production

Ranges of cost of production ($/m³)		Weighting factor
from	to	
0		3
> 0	= 0.05	2.4
> 0.05	= 0.1	1.8
> 0.1	= 1	1.2
> 1	= 8	0.6
More than 8		

Table 2.7 – Water wells cost of production

Ranges of cost of production ($/m³)		Weighting factor
from	to	
0		3
> 0.01	= 0.09	2.4
> 0.09	= 0.13	1.8
> 0.130	= 0.18	1.2
> 0.180	= 0.260	0.6
More than 0.26		

Facility capacity: The flow capacity of the facility is also an important factor as it represents the number of residents that the facility serves. Therefore, the consultant considered the capacity of the facility as an important criterion to measure the benefits of the facility.

The consultant classified the facility capacities into several ranges using the equation below. If the daily flow rate equals or is less than a specific value (based on facility type), the weighting factor is considered 3; otherwise a smaller weighting factor is given based on the flow rate, as shown in Tables 2.8–2.12.

$$C5 = flow\ rate\ (m^3/hr) \times \text{facility capacity weighting factor (max. 3)}$$

Table 2.8 – Water pump stations (WPS) production capacity

WPS flow rate (m^3/hr)		**Weighting factor**
from	to	
100 or less		0
>100	= 200	0.6
>200	= 350	1.2
>350	= 500	1.8
>500	= 650	2.4
>650		3

Table 2.9 – Sewage pump stations (SPS) production capacity

SPS flow rate (m^3/hr)		**Weighting factor**
from	to	
95 or less		0
>95	= 200	0.6
>200	= 400	1.2
>400	= 800	1.8
>800	= 1,000	2.4
> 1,000	= 9,000	3

Table 2.10 – Private desalination plants (PriDP) production capacity

PriDP flow rate (m^3/hr)		**Weighting factor**
from	to	
100 or less		0
> 50	= 15	0.6
>150	= 300	1.2
>300	= 450	1.8
>450	= 600	2.4
> 600	= 800	3

Table 2.11 – Public desalination plants (PubDP) production capacity

PubDP flow rate (m^3/hr)		Weighting factor
from	to	
1 or less		0
>20	= 200	0.6
>200	= 400	1.2
>400	= 800	1.8
>800	= 1,000	2.4
>1,000	= 1,500	3

Table 2.12 – Water well (WW) production capacity

WW flow rate (m^3/hr)		Weighting factor
from	to	
30 or less		0
>30	= 70	0.6
>70	= 110	1.2
>110	= 150	1.8
>150	= 200	2.4
More than 200		3

Water quality: This parameter is valid only for water wells. The consultant recommends that any PV system investment should be carried out at water wells of good quality rather than of those of bad quality water. As the quality varies from well to another and from one governorate to another, the consultant classified the degree of quality per governorate. The consultant considered two parameters to measure the quality: chloride and nitrate. Then the water-quality weighting was calculated as the average between the two parameters, as presented in Annex 3.4.

Feasibility index: Based on the weights of each criteria, the consultant estimated the feasibility index (FI) per facility as follows:

$$\boldsymbol{FI = \frac{\sum Ci}{Total\ criteria\ score}\, x\ 100}$$

Based on the FI, the consultant classified the WASH facilities into three categories, as shown in Table 2.13.

Table 2.13 – WASH facilities classification according to FI

FI	Classification
FI>60	Feasible
40<FI<60	Moderately feasible
FI<40	Not feasible

3 Final report

Having performed all tasks of the study including data collection, review of all existing data, field survey, analysis of data, mapping baseline and feasibility tasks, the consultant submitted the draft final report to Oxfam for review. Upon receiving all comments from Oxfam, these comments were incorporated into the final version of the report.

3.1 Introduction: solar energy technologies

This chapter introduces the various solar energy technologies used worldwide and the main differences between them. The consultant reviewed the application of the solar technologies in the Gaza Strip in terms of size of sector, especially for WASH facilities. The criteria for solar technologies selection for WASH facilities were determined through identifying and comparing five PV solar systems, considering their advantages and disadvantages. Based on this assessment, the consultant identified the suitable PV system for each WASH facility, as indicated in Annex 4.1. Local market capacity, national energy strategy, and the legal and regulatory environment of solar technologies are also discussed in this chapter.

Solar energy technologies worldwide

Solar energy plays a significant role in ensuring a sustainable energy future and reducing future carbon emissions. It can be used for heating, cooling, lighting, electrical power, transportation and even environmental clean-up. It is estimated that the global average solar radiation, per square metre per year, can produce the same amount of energy as a barrel of oil, 200kg of coal or 140m^3 of natural gas.

There are two main types of solar energy technologies, namely photovoltaic (PV) technology and thermal technology; more details on these types are presented in the next section. According to the International Renewable Energy Agency (IRENA), global installed capacity for solar-powered systems has shown exponential growth, reaching 390 gigawatts (GW) at the end of 2017. About 385 GW is produced from PV systems and 5 GW is obtained from thermal solar power (concentrated solar power or CSP). This indicates that more than 98% of the produced solar energy comes from PV solar systems (https://www.irena.org/solar). IRENA reports that the solar energy produced in the Middle East area reached 2.35 GW by the end of 2017, which represents less than 1% of globally produced solar energy. The International Energy Agency (IEA) (https://www.iea.org) stated that, at the end of 2018, globally installed solar PV systems produce a cumulative total of approximately 402 GW.

3.2 Types of solar energy technologies

There are several kinds of solar technologies currently available. These include solar thermoelectricity (STE), dye-sensitized solar cell (DSSC), concentrated photovoltaic (CPV), PV solar panels and concentrated solar power (CSP), (Global Energy Network Institute, GENI, http://www.geni.org (2019)).

The non-concentrated PV solar panels and CSP are the two most mature technologies. They have been commercialized and are expected to experience increasing growth in the near future. **PV technologies** directly convert light to electricity; whereas CSP (solar thermal technologies) uses heat from the sun (thermal energy) to drive electric turbines, hot water and air heating or conditioning systems.The following section presents more details regarding these two types of solar energy technologies.

Solar thermal technologies

This involves harnessing solar energy for thermal energy (heat). Solar thermal technologies comprise flat or parabolic collectors (low and medium temperatures and high temperature collectors) concentrating sunlight, mainly using mirrors and lenses. Solar heating is the utilization of solar energy to provide process heat, especially in crop drying, water heating, cooking, or space heating and cooling. Solar thermal technologies can be divided into the following technologies:

Solar water heaters (SWH): Solar collectors are applicable worldwide and are even suitable in areas with low solar radiation and short periods of sunshine. The technology for solar thermal water heaters is present worldwide and significant deployments occur already in emerging economies and developing countries. Technologies include glazed flat plate collectors, evacuated tube collectors, and lower-temperature swimming-pool heaters made from plastic tubes.

Concentrated solar power (CSP) uses mirrors and tracking systems to focus sunlight from a large area into a small focused beam. The concentrated heat is then used as a heat source for various applications, such as conventional steam-based power plants, desalination of water, or for cooking. A wide range of concentrating technologies exists; the most developed are the parabolic trough and the solar power tower. Two less well developed technologies are dish concentrators and linear Fresnel reflectors. Various techniques are used to track the sun and focus light. Very common in CSP is the use of thermal energy storage, which can be used to provide heat at times when the sun is not shining. Energy storage via CSP is cost effective, and almost all CSP systems are built with a storage capacity of up to 15 hours. Solar cooking can be done at relatively small scale and low cost using a wide range of technologies such as box cookers, solar bowls and the Scheffler reflector.

Photovoltaic (PV) technologies

PV technologies obtain electricity directly from sunlight via an electronic process that occurs naturally in certain types of material called semiconductors. Electrons in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid. PV modules contain no moving parts and generally last 30 years or more with minimal maintenance. PV devices can be used to power anything from small electronics, such as calculators and road signs, up to homes and large commercial businesses. PV electricity output peaks at midday when the sun is at its highest point in the sky, and can offset the most expensive electricity when daily demand is greatest. Homeowners can install a few dozen PV panels to reduce or eliminate their monthly electricity bills, and utilities companies can build large ‘farms’ of PV panels to provide pollution-free electricity to their customers. Traditionally, PV modules are made using various forms of silicon, but many companies are also manufacturing modules that employ other semiconductor materials, often referred to as thin-film PV. Each of the various PV technologies have unique cost and performance characteristics that drive competition within the industry. Cost and performance can be further affected by the PV application and specific configuration of a PV system.

3.3 Comparison of solar energy technologies

Solar thermoelectricity (STE) uses parabolic disc technology to capture thermal energy based on the thermoelectric effect. Electricity is produced through a concentrator thermoelectric generator (CTEG). STE produces energy by converting differences in temperatures in the two parts into volts using a semiconductor. The efficiency of thermoelectric materials is still very low. Like most of the other solar technologies with concentration requirements, this system is unable to collect diffuse irradiation and must rely on direct radiation only. In order to have sufficient output to work efficiently, high temperatures are needed (~200C^0). In addition, thermoelectric material like Bismuth telluride is toxic and expensive. Cooling systems are required to decrease the temperature of the cold side in order to achieve total efficiency.

A dye-sensitized solar cell (DSSC) (invented in 1991) is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system. Sunlight enters the cell through the transparent cover, striking the dye on the titanium dioxide (TiO_2) surface. This creates an excited state of the dye, from which an electron is injected into the conduction band of the TiO_2. From there, it moves by diffusion (as a result of an electron concentration gradient) to the clear anode on top. Consequently, a certain electronic process is developed to generate electricity. Current efficiency is still relatively low compare with traditional semiconductor solar cells. Dyes will degrade when exposed to ultraviolet radiation that limits the lifetime and stability of the cells. This would negatively affect the cost and may lower the efficiency.

Concentrated photovoltaic (CPV) technology uses optics such as lenses to concentrate a large amount of sunlight onto a small area of solar photovoltaic materials to generate electricity. CPV systems are categorized according to the amount of solar concentration, measured using a specific *concentration ratio*. Like most concentration systems, CPV is unable to collect diffuse irradiation. Even a small cloud may drop the production to zero. Unlike concentrated solar power, the storage system that can mitigate this problem is expensive, since it is much easier to store heat than electric energy. This kind of instability will not be ideal when connected to the grid.

Concentrated solar power (CSP) systems use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat which drives a heat engine (usually a steam turbine) connected to an electrical power generator. Unlike the PV solar cells, converting energy from sunlight to electricity by CSP systems is based on the application of heat engine rather than PV effect which directly transfers photon energy into electricity energy. In terms of electricity, CSP is indirect technology which can be applied to generate electricity.

Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the PV effect. PV power generation employs solar panels composed of a number of solar cells containing a PV material. Materials presently used for PV include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium gallium selenide/sulfide. PV solar panel is the most commonly used solar technology to generate electricity energy. The basic idea of the PV effect depends on the fact that electrons will emit from matter (metals and non-metallic solids, liquids or gases) as a result of their absorption of energy from electromagnetic radiation of very short wavelength, such as visible or ultraviolet light. Electrons emitted in this manner may be referred to as ‘photoelectrons’.

Despite the optimistic predictions of the PV industry, this technology has disadvantages that will need more effort to overcome. Solar electricity is still more expensive than most other forms of small-scale alternative energy production. It is not produced at night and is greatly reduced in cloudy conditions. Therefore, a storage or complementary power system is required. Solar electricity production depends on the limited power density of the location's insolation.

PV technologies are the most commonly used solar energy collecting technologies around the world and will continue to see rapid and steady growth. Each of the PV technologies has its own advantages and drawbacks and it is not certain which one will dominate the market in the following decades; however, it is certain is that PV technologies will help countries to develop a clean and renewable future.

Based on the above discussion, most solar power systems fall into one of two major classes in terms of producing electricity: direct and indirect solar power. Direct solar power refers to a system that converts solar radiation directly to electricity using a PV cell. Indirect solar power refers to a system that converts solar energy first to heat and after that to electrical energy, as in the case of CSP. The problems with these technologies are inefficiency and a very high capital cost.

Based on research by several international agencies working in the field of solar energy (such as the IEA, IRENA, Solar Energy Industries Association (SEIA), The International Renewable Energy Alliance (REN Alliance) and the American Solar Energy Society (ASES), **the recommended direct technology to produce heat from solar energy is solar thermal technologies, while the optimum direct technology to generate electricity is through PV technologies. Therefore, the consultant recommends using solar PV technologies for producing electricity, and therefore PV technologies received the consultant's full consideration**.

4 Use of solar PV technologies in the Gaza Strip

OPT has a high solar energy potential, where the average solar energy ranges from 3.36 kWh/m^2 per day in January to 8.07 kWh/m^2 per day in June, and the daily average solar radiation intensity on a horizontal surface, peak sunshine hour (PSSH), is 5.31 kWh/m^2 per day. Furthermore, average total annual sunshine hours are about 5.31 hours (Ouda, 2003). The annual average temperature is 22C^0, while it exceeds 30C^0 during summer months. These figures are very encouraging for the use of PV generators for WASH facilities. The solar radiation data had a great effect on the performance of PV systems. Table 4.1 shows the average monthly values of solar energy in OPT based on historical data.

Table 4.1 – Average PSSH in OPT

Month	Mean PSSH kWh/m2/day (1989–2002)
Jan	3.36
Feb	3.97
Mar	4.33
Apr	5.19
May	6.46
Jun	7.78
Jul	7.40
Aug	6.76
Sep	5.88
Oct	4.73
Nov	4.31
Dec	3.53
Average	**5.31**

The consultant reviewed the solar energy technologies used for producing electricity in the Gaza Strip. The solar technologies applied in the Gaza Strip to produce electricity comprises installing PV systems.

The application of solar PV systems commenced in the Gaza Strip in approximately 2013. Today, thousands of private and public customers in the Gaza Strip utilize solar PV systems with a wide range of capacities. Funds have been allocated by several international organizations to install PV systems for various health, agricultural, educational and academic institutions in the Gaza Strip. The consultant reviewed the size of the installed PV systems in the Gaza Strip from all available literature and previous studies. From 2013 to 2017, there were about 330 projects installing PV systems for public and private institutions, as shown in Table 4.2. Table 4.2 indicates that the total PV capacities of these installations is about 5,611 kWp. The distribution of these 330 projects across various private and public facilities is shown in Table 4.3.

Table 4.2 – PV systems installed in the Gaza Strip

Year	2013	2014	2015	2016	2017	Total (cumulative)
Capacity kWp	20	87	131	2,842	2,531	5,611
No. of projects	1	5	60	76	188	330

Table 4.3 – Number and size of PV systems installed at institutions in the Gaza Strip

Type	No.	Range of capacity kWp
Schools	80	15–120
Universities	4	42–142
Health facilities	16	14–50
Private facilities	112	12–500
Municipalities facilities	3	13–40
Agriculture	113	40–50
Total	328	

4.1 PV systems for WASH facilities

According to data obtained from institutions operating in the Gaza Strip, several funding and implementing agencies have allocated funds for solar PV systems at various water and wastewater facilities. Table 4.4 presents the funding/implementing agencies, type of facility and the capacity of the installed PV systems.

Table 4.4 – Summary of PV projects and their available details in the Gaza Strip

#	Organization	Type and number of facilities	Name of facility	PV capacity kWp	Project status
1	Muslim Hands	1 water well	Al Kawther	50	Ongoing
2	Palestinian Hydrology Group (PHG)	5 pump stations	1. Wadi Gaza PS–Wadi Gaza 2. Al Zahraa PS–Al Zahra 3. Abomoala PS–El Nusirat 4. UNDP /Rafah PS–Rafah 5. Em Al Nasser PS–Em El Nasser (Al Qaria El Badwia)	30 each (total 150)	Approved for funds
3	AAH	9 desalination plants	Wadi Gaza–Wadi Gaza S82–Maghazi Abo Nasser, Al Aqsa–Deir Al Balah Al Hoda, Al Amal 1, Mahata 2–Khan Yunis Eastern Reservoir–Khuza'a, P124–Rafah El Batool–Shoka	Total 50	Approved for funds
4	Oxfam	2 facilities: water 1 pump station and 1 desalination plant	1- Mean reservoirs 2- Al Shoka UTL DP	150 25	Approved for funds
5	UNICEF	4 facilities: 1 water pump station and 3 water wells	1. Al shekh Redwan well 7 2. Al shekh Redwan well 7A 3. Al shekh Redwan well 1 4. Shijaiia well	150 150 150 80	Approved for funds
6	KfW (German Development Bank)	1 facility (wastewater treatment plant)	Burij WWTP	3,500	Approved for funds
7	KfW	1 facility (wastewater treatment plant)	Al Shieak Eijleen WWTP	1,200	Ongoing
8	ICRC	1 facility (water well)	CANADA well	175	Ongoing
10	JICA	1 facility (wastewater treatment plant)	Rafah–WWTP	200	Operational
11	UNICEF	2 facilities (wastewater treatment plant and water well)	Khanyounis wastewater treatment plant – Lagoons plant	230 50	Ongoing

4.2 Technologies selection of PV solar system for WASH facilities

PV power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. There are various types of PV solar systems; they comprise off-grid systems, grid-connected systems, hybrid systems, PV diesel hybrid systems and PV water pumping. This section presents more details about these five PV systems.

Off-grid PV system

This system allows the storing of PV solar power in batteries for use when the power grid goes down or if the user is not on the grid. Table 4.5 shows the typical system components of the off-grid PV system. This system ensures availability of electricity 24 hours a day due to the storage capacity of the batteries.

Table 4.5 – System components of off-grid system

No.	Components
1	PV panels with mounting
2	Charge controller
3	Battery inverter
4	Battery
5	Accessories such as DC & AC cable and DBs

On-grid system

An on-grid system is a system that only generates power when the utility power grid is available, otherwise the system will not operate. Therefore, the system should have a source of electricity to function. Once the system operates, it can feed surplus power back into the grid. Technically, this system is suitable when the operational hours are less than five hours daily (the optimum solar hours during the daytime). Table 4.6 shows the system components of the on-grid system.

Table 4.6: System components of on-grid system

No.	Components
1	PV panels with mounting
2	On-grid inverter
3	Accessories such as DC & AC cable and DBs

On-grid with backup system (hybrid)

Hybrid PV systems can be considered as an on-grid system upgraded to include a battery backup: a bank of deep-cycle batteries, which can be charged by both the utility grid and the solar panels. Thus, in the event of an outage, the backup battery can be switched on to provide backup power to the loads. Table 4.7 presents the components of the on-grid with backup system.

Table 4.7. Components of the on-grid with backup system

No.	Components
1	PV panels with mounting
2	On-grid inverter
3	Battery inverter
4	Battery
5	Accessories such as DC & AC cable and DBs

PV diesel hybrid system

A typical PV diesel hybrid system consists of a PV system, public grid, diesel generator and a fuel save controller (FSC) to ensure that the necessary amount of power is fed into the system (whether from PV panels during the daytime or from the generator). The FSC is a key component of the PV diesel hybrid system solution. It allows the use of cost-efficient solar energy to generate power in order to lower fuel consumption from diesel generators. The FSC performs a comprehensive grid management function which ensures maximum operational safety and minimal operational expenditures and CO_2 emissions. Table 4.8 shows the typical components of a PV diesel hybrid system.

Table 4.8 – Components of PV diesel hybrid system

No.	Components
1	PV panels with mounting
2	On-grid inverter
3	Accessories such as DC & AC cable and DBs
4	Fuel save controller
5	Synchronizing unit

PV water pump system

The PV system directly powers the water pump through a PV water pump inverter and operates only when the sun is shining. This system is much less expensive and easier to install than the other systems that depend on batteries or being on the grid.

The most common application of a PV water pump system is for pumping water for irrigation, livestock and domestic use. For public water networks, it is strongly recommended that the system includes water-storing tanks to benefit from the solar energy produced during periods of sunshine. This means that the PV water pump system is not recommended for domestic water networks. Table 4.9 presents the components of a PV water pump system.

Table 4.9 – Components of PV water pump system

No.	Components
1	PV panels with mounting
2	Pump controller
3	Pump
4	Accessories such as DC & AC cable and DBs

Comparison of the five PV systems

A comparison of the five PV systems is shown in Table 4.10.

Table 4.10 – The advantages and disadvantages of each PV system

System type	Advantages	Disadvantages
Off-grid	• It does not depend on public networks. • It works in remote areas where it is difficult to obtain alternative energy sources such as diesel generators.	• Surplus power from the PV system will not be utilized. • Life span of the battery bank is limited due the cycles of charging and discharging, and thus requires replacement, which increases the cost.
On-grid	• It does not depend on batteries. • Less cost than other PV systems. • Surplus power from the PV system will be utilized.	• It depends on the availability of the public grid.
On-grid with backup (hybrid)	• It operates with and without the public grid. • It works in remote areas. • Surplus power from the PV system will be utilized.	Life span of the batteries is limited due the cycles of charging and discharging, and they require replacement, which increases the cost.
PV diesel hybrid system	• It operates with and without public grid. • Surplus power from the PV system will be utilized in the presence of the public grid. • It does not depend on batteries. However, batteries can be provided to reduce fuel consumption during the night.	• The generator should be suitable for synchronization. • The system requires a main fuel save controller (FSC), which increases the cost.
PV water	• It operates without the public	• It needs water-storing tanks

System type	Advantages	Disadvantages
pumping	grid. • It works in remote areas. • Less cost compared to other PV systems.	and is therefore unsuitable for domestic water networks. • Works only during the presence of sunshine.

4.3 Proposed PV systems for WASH facilities

Based on the concepts of the on-grid, PV water pumping and PV diesel hybrid systems, the consultant identified the optimum system for each WASH facility, based on the following considerations:

1. The aim of installing a PV system for WASH facilities is to improve the service rather than to save power.
2. Grid availability in the Gaza Strip ranges from 25–75% of the day (6–18 hours per day).
3. Solar availability in the Gaza Strip is 5.31 hours daily, on average.
4. Most of the WASH facilities in the Gaza Strip have diesel generators.

Off-grid and on-grid with backup PV systems

These PV systems do not require grid electricity to operate; they are stand-alone systems. They require enough land availability for installing the required PV panels based on the loads. The backup batteries have high costs and a limited life span, which means they require periodic replacement. The replacement period of batteries is short (replacement every five years). Therefore, the consultant's assessment of use of batteries for large-capacity PV systems is not encouraging. The consultant does not recommend either off-grid or on-grid with backup PV systems for any of the WASH facilities.

On-grid PV systems

On-grid PV systems require continuous electricity supply from the grid as long as the system is operating. As the grid availability ranges from 25% to 75% per day, the performance of the on-grid PV system is only 1.5–4.5 hours per day. Therefore, installing the on-grid PV system will not increase the operating hours of the facility beyond the outage of the grid. This PV system is more suitable when power saving is the aim of the PV technology. Consequently, this kind of system is not recommended for facilities which operate for more than 6 hours; the benefits would be very limited.

PV water pumps

The operation of the PV water pump system does not depend on any source of power, such as grid electricity or generator. As sunshine is not steady during sunny periods, the amount of abstracted water from the well will be variable; the pressure of the abstracted water may not be sufficient to enable it to reach its final destinations. To overcome this problem, a storage tank is recommended. In addition, and in order to utilize the full capacity of the system, there should be enough land available for installing the necessary PV panels to generate the power necessary for the pump to operate at full capacity during the 5 hours of solar availability daily. The system is recommended for water wells where enough land is available and storage tanks are provided.

PV diesel hybrid system

This PV diesel hybrid system utilizes power from different sources, such as a generator and solar panels, in addition to power from the public grid. Therefore, the system ensures a continuous supply of electricity. It should be mentioned that the connected generator has to be an electronic one in order to be able to synchronize with the PV system. As most WASH facilities require more than 6 operating hours daily, **the installation of this type of system is recommended**.

Based on the above discussion, the consultant identified the suitable PV system for each WASH facility, as indicated Annex 4.1. Examples of the proposed PV systems for 10 WASH facilities (as mentioned in Annex 4.1) are presented in Table 4.11.

Table 4.11 – Examples of proposed PV system for WASH facilities

Facility code	Facility name	Facility type	Total electricity consumption (kWh)	Total daily operation (hr)	% of the available area for PV system	Proposed system
MG.1.PS.01	Al Moghraqa PS	Sewage pump station	88	8	55%	PV diesel hybrid
ON.2.SP.01	Um Al-Nasssrr pump station	Sewage pump station	27	6	100%	On-grid
KH.1.WP.02	Ma'an pump station	Water pump station	60	12	100%	PV diesel hybrid
RF.1.WP.07	Rafah UNDP PS (El Balad)	Water pump station	100	4	100%	PV water pump
3M-003	El Hoor	Private desalination plant	42	6	33%	On-grid
DS141/2018	Al Sahed	Private desalination plant	60	22	58%	PV diesel hybrid
NU.1.DP.01	Forqan well desalination plant	Public desalination plant	39	6	35%	On-grid
BS.1.DP.01	Bani Suhila Area desalination plant	Public desalination plant	110	15	95%	PV diesel hybrid
DB.1.PW.20	Al Basheer well	Water well	44.5	18	78%	On-grid

Facility code	Facility name	Facility type	Total electricity consumption (kWh)	Total daily operation (hr)	% of the available area for PV system	Proposed system
RF.1.PW.09	Abu Zohri	Water well	48.5	13	88%	PV diesel hybrid

4.4 Local market capacity and equipment available

There are more than 40 local PV systems suppliers in the Gaza Strip selling various capacities of PV systems. The main suppliers are located in Gaza City and Khanyounis City. All PV equipment is imported from many countries in Europe and Asia. This section presents the capacity of the local market and the available equipment types and manufacturers.

Local market capacity

The entire population of the Gaza Strip can access solar PV system traders from the north or the south. There are more than nine large companies specializing in solar PV systems (both selling and installing); these companies participate in 'Request for Quotations' for funded projects. Other retailers are only selling PV components rather than importing them from abroad. Interviews conducted with PV system traders mentioned that the stores of the local suppliers often run out of the various components of PV systems (such as panels, inverter or batteries); items that arrive at the market are sold immediately, sometimes items are sold even before reaching the market.

PV system cost

The prices of various PV components in the Gaza Strip market have **decreased by about 20%** compared to their prices three years ago. The main reasons for this are as follows:

- Globally, prices of solar PV panels decreased by 50% between the end of 2009 and the end of 2015.
- Competition between solar PV system companies in the Gaza Strip is high, as more new companies have entered this field. In 2014, there were fewer than five companies; today, there are more than 40.

Market capacity

The market capacity depends on the quantity of available material. The main constraints in upgrading market capacity are: skilled workers who can professionally install solar power systems; and the restrictions on cross borders. In terms of skilled workers, each company has an average of two to three teams of four workers. The number of skilled workers could easily be increased, given the high educational level of unemployed technicians and engineers in the Gaza Strip. Regarding the restrictions on cross borders, about 40,000 PV panels entered the Gaza Strip in 2018. In light of the current high demand, and if no limitations are placed on quantities allowed into Gaza, the number of PV panels and other components is likely to increase significantly in the future.

Market-related barriers to upscaling in the Gaza Strip: Despite the increasing adoption of solar energy by households, coupled with the interest of a large number of international donors, the sector is prone to some challenges. These include policy, personnel, financial, technological, and consumer-related challenges.

Crossing borders/barriers: The uncertainty traders face regarding crossing borders and the 'dual-use items list' imposed by the Israeli authorities prevents them from importing large quantities, in order to avoid unseen risks. These risks include their imported goods getting stuck at the port, which would lead to huge financial losses. Traders do not have problems in storing large quantities in their warehouses in the Gaza Strip, but they will not place orders for large quantities (more than 0.3 MW of solar PV panels) as the Israeli authority may suddenly add solar PV panels to the list of dual-use items (as happened in 2015). As a result, the supplied quantity will always be lower than the demand, and there will be always a time gap between purchasing and delivery.

Unskilled technicians: There are solar technicians who do not have the necessary professional skills, yet still have connections with solar distributors and retailers who subcontract them. This happens because there are no governmental regulations, which would allow only licensed technicians to provide design and installation services for solar PV systems. Normally, to become licensed, technicians have to undertake a solar training course and understand solar PV regulations, which currently do not exist in the Gaza Strip.

4.5 Strategy, legal and regulatory environment

The most up-to-date law for renewable energy in OPT is the Decree Law related to renewable energy and energy efficiency, issued in 2015. Article 2 of the Decree Law states that the objective of the law is to encourage utilization of renewable energy sources and their applications, increase their contribution to total energy balance and achieve secure energy provision in line with renewable energy strategy. The law also aims to ensure environmental protection and fulfilment of sustainable development requirements.

The Decree Law has specified the roles and responsibilities of the various institutions and bodies involved in the regulation, monitoring, production, distribution and transfer of energy. It also describes the role and responsibility of the Energy Research Center in conducting research to define the best alternatives and locations for renewable energy production and raising awareness and capacity building in this sector.

The second relevant law is the Electricity Decree Law No.13, issued in 2009. The Electricity Decree has the main objective of restructuring and improving the electricity sector, as well as fostering national and foreign investment in order to obtain an adequate power supply and properly priced services. The Electricity Decree stipulates the establishment of an Electricity Regulatory Council. It also identifies the Council's duties and responsibilities.

The Electricity Decree is the first step in sector regulation and in achieving a new structure. In addition, it stipulated the establishment of a fully government-owned National Transmission Company, which is obligated to allow generators and suppliers to use the national grid. It is also authorized to purchase and sell power from any source and to resell the purchased power to distribution companies.

Additionally, the Electricity Decree defined the penalties for actions such as stealing, destroying or vandalizing any component of the electricity network's infrastructure. Later in 2012, the Decree was amended to modify some of the penalties related to offences in the electricity sector.

With regard to renewable energy sources, the Electricity Decree Law explicitly mentions that the Environmental Quality Authority (EQA) must encourage research into alternative energy sources, as well as regulating its exploitation using by-laws. Finally, the environmental law is addressing the issue to some extent, indirectly, and provides some ground for encouraging clean energy production and reduction of emissions.

5 Baseline situation

5.1 Background

A baseline study was conducted to review the current situation of solar energy usage in WASH facilities of the Gaza Strip (mainly municipal water wells, municipal water pump stations, public desalination plants, private desalination plants, wastewater pump stations and wastewater treatment plants). The geographical scope of the baseline study is the Gaza Strip's five governorates; namely North Gaza, Gaza, Middle Area, Khan Younis and Rafah, as shown in Figure 5.1.

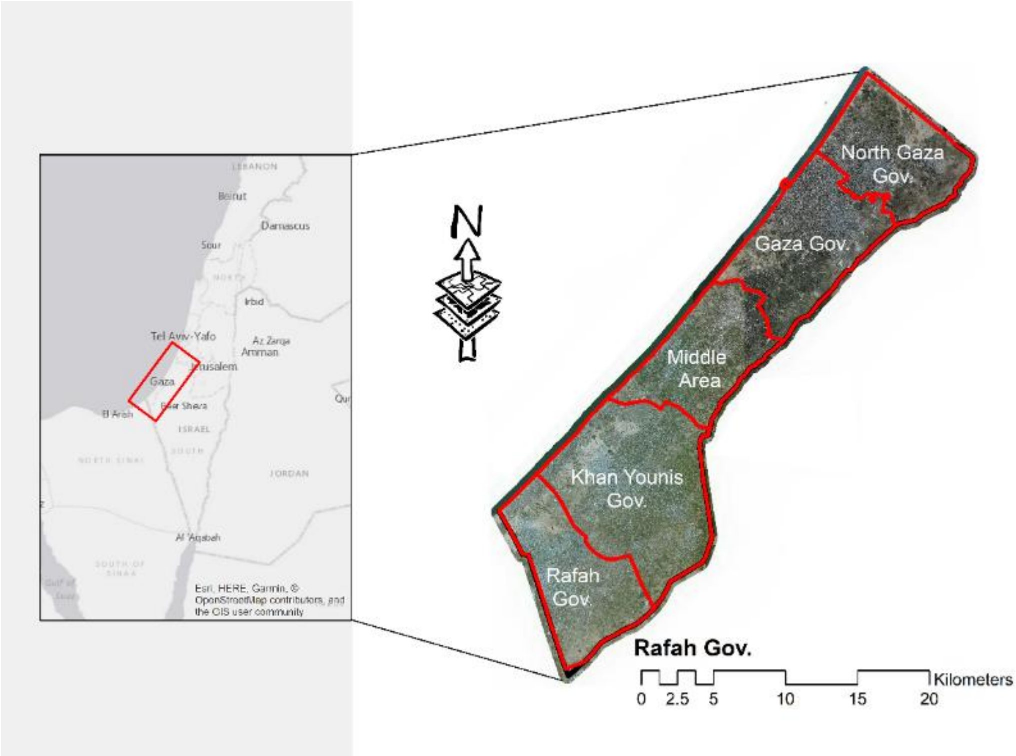


Figure 5.1 – Administrative map of Gaza Strip governorates

To achieve the objectives of the baseline study, three methods were used to gather the required data: field visits, meetings and checklists. The data was then verified and validated by conducting meetings with the following parties:

- Palestinian Water Authority (PWA)
- Costal Municipalities Water Utility (CMWU)
- Environmental Quality Authority (EQA)
- Municipalities/local units
- International associations
- Local and international associations and WASH Cluster members.

The main points and information covered in the meetings were:

- The type, status and capacity (in m^3) of each of the WASH facilities in each municipality (operational or non-operational)
- Construction area in m^2
- Total power consumption (kWh)
- Generator availability
- Daily operation of generator (hrs/day)
- Number of available pumps and total daily operation.

The required data was collected, analysed and mapped using Geographic Information Systems (GIS 10.1). All sites were described by spatial and attribute data using GIS Environment.

5.2 Data collection

The target area was identified and extracted from satellite imagery (Google Earth). The extracted image was then imported to GIS software, specifically ArcGIS 10.1, and then geo-referenced and digitized to produce a digital map. The coordinates of each facility were imported into the ArcGIS 10.1 as a text file, then converted to a shape file to show the spatial distribution on the digital maps as well as the satellite images. The following symbols were used to show the types of WASH facilities:

Code of Public Desalination Plants
Code of Private Desalination Plants
Code of Municipal Wells
Code of Water Pump Stations
Codes of Sewage Pump Stations

In order to keep track of the location of each facility, a coding system was applied for sites, as XY00. The first two letters (XY00) are for the local authority/municipality code, and the two numbers (00) are the serial number of facilities. Data collected from different sources for each facility are presented in Annex 3.1.

5.3 Outcomes of the data collection and processing

Detailed findings of the study of WASH facilities are given below for each facility type.

Municipal wells

Data for municipal wells reveals that there are 266 active wells in the Gaza Strip. These are distributed over the five governorates, as follows:

- North Gaza: 55 wells (Fig 5.2a)
- Gaza: 74 wells (Fig 5.2b)
- Middle Gaza: 60 wells (Fig 5.2c)

- Khan Younis: 48 wells (Fig 5.2d)
- Rafah: 29 wells (Fig 5.2e).

Discharge capacity and water quality: Data shows that the discharge capacity of all wells ranges from 29 to 225m^3/hr, with an average discharge of 79m^3/hr. The consultant also estimated water quality (chloride and nitrate) based on the updated PWA maps.

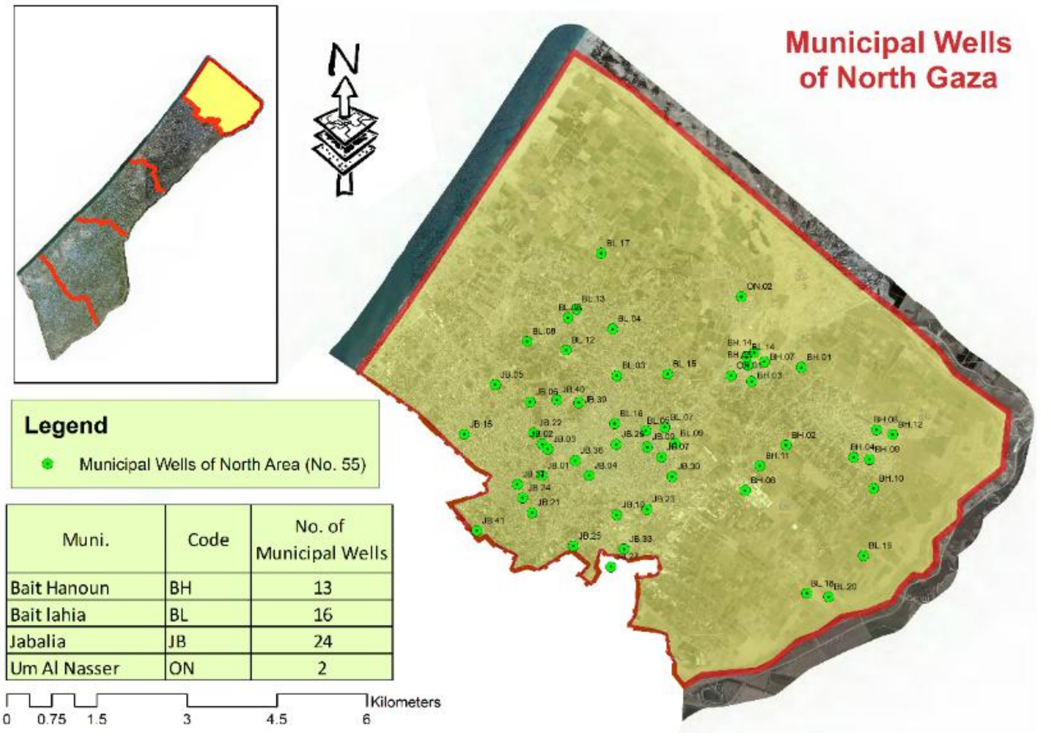
Construction area: Data shows that the construction area of all wells ranges from 15 to 15,000m^2, with an average area of 477m^2. The area distribution per well in all governorates is as follows:

- North Gaza: 60 to 1,670m^2; average area 320m^2/55 wells
- Gaza: 30 to 15,000m^2; average area 705m^2/74 wells
- Middle Gaza: 15 to 1,500m^2; average area 236m^2/60 wells
- Khan Younis: 20 to 3,800m^2; average area 500m^2/48 wells
- Rafah: 140 to 3,209m^2; average area 645m^2/29 wells.

Availability of generators: Among the 266 active wells, there are 226 wells with generators. Of these 226, 43 wells have zero daily operation of their generators (8 in North Gaza, 29 in Gaza, 5 in Middle Area and 1 in Rafah), which means that the generators are not working. The consultant obtained/estimated the generator capacity and its daily operational hours.

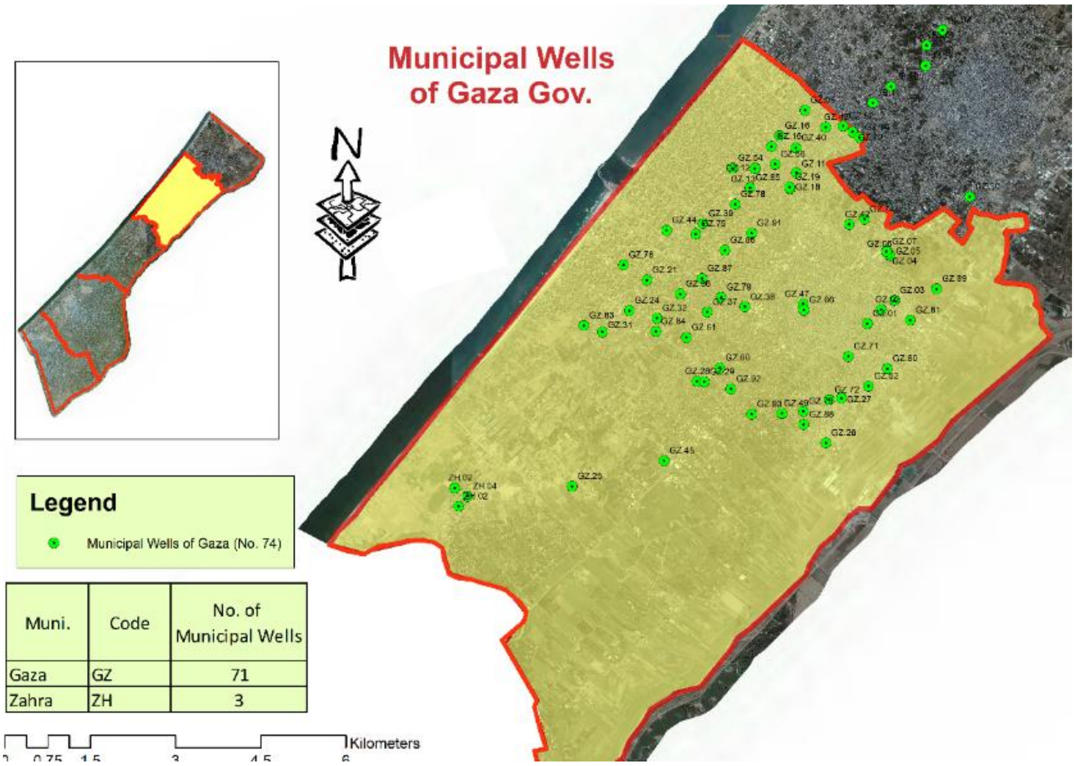
Power source: Based on the availability of power source(s), daily operation is classified into three types.

- Type 1 – wells that operate using municipal electricity only:
  - A total of 40 wells have no generators and depend on electricity, with an average daily operation of 7.6 hours (min. 2 hours, max. 12 hours). The average power electricity consumption is 41 kWh (min. 11 kWh, max.146 kWh).
  - A total of 43 wells have generators but with zero operation, which means that they depend mainly on the grid, with an average daily operation of 8.1 hours (min. 2 hours, max. 22 hours).
- Type 2 – wells that operate using generators only:
  - Only 2 wells operate using generators, with an average daily operation of 7.5 hours. The average power consumption is 48.5 kWh.
- Type 3 – wells that use both grid electricity and generators:
  - A total of 181 wells operate using electricity and generators, with an average daily operation of electricity of: 8.9 hours (min. 3 hours, max. 22 hours). The average power electricity consumption is 44.5 kWh (min. 9 kWh, max. 125 kWh).
  - The average daily operation of generators is: 4.6 hours (min. 1 hour, max. 12 hours).



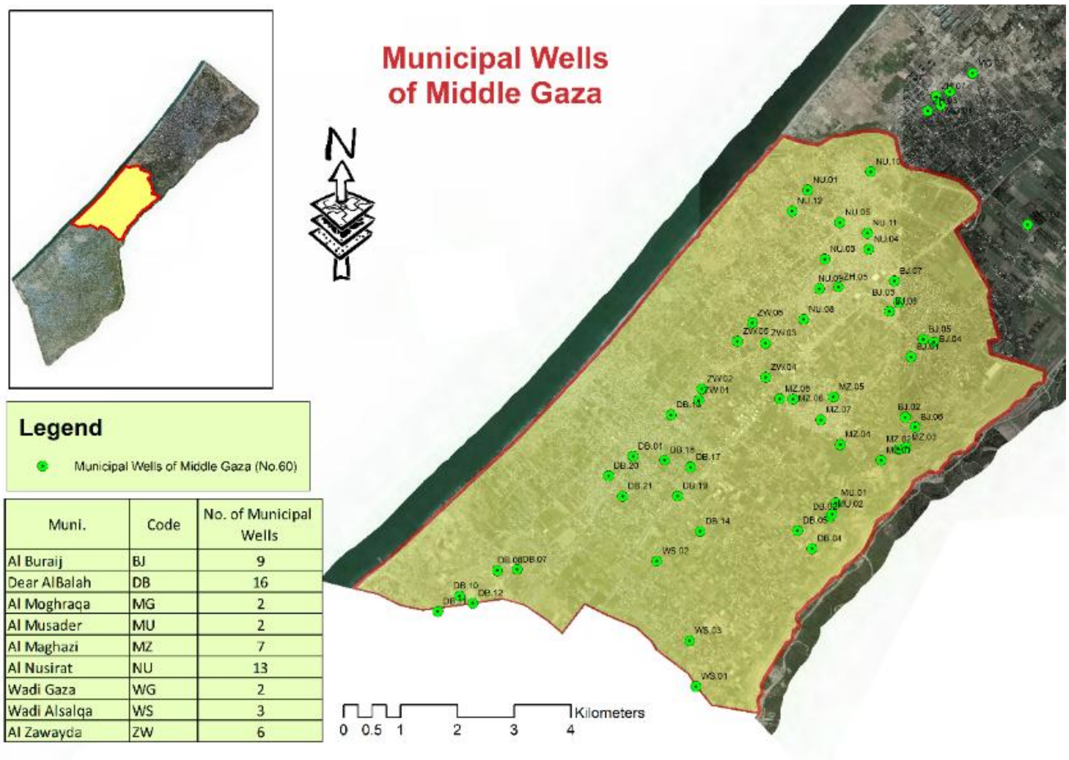
Muni.	Code	No. of Municipal Wells
Bait Hanoun	BH	13
Bait lahia	BL	16
Jabalia	JB	24
Um Al Nasser	ON	2

(a) Governorate of North Gaza



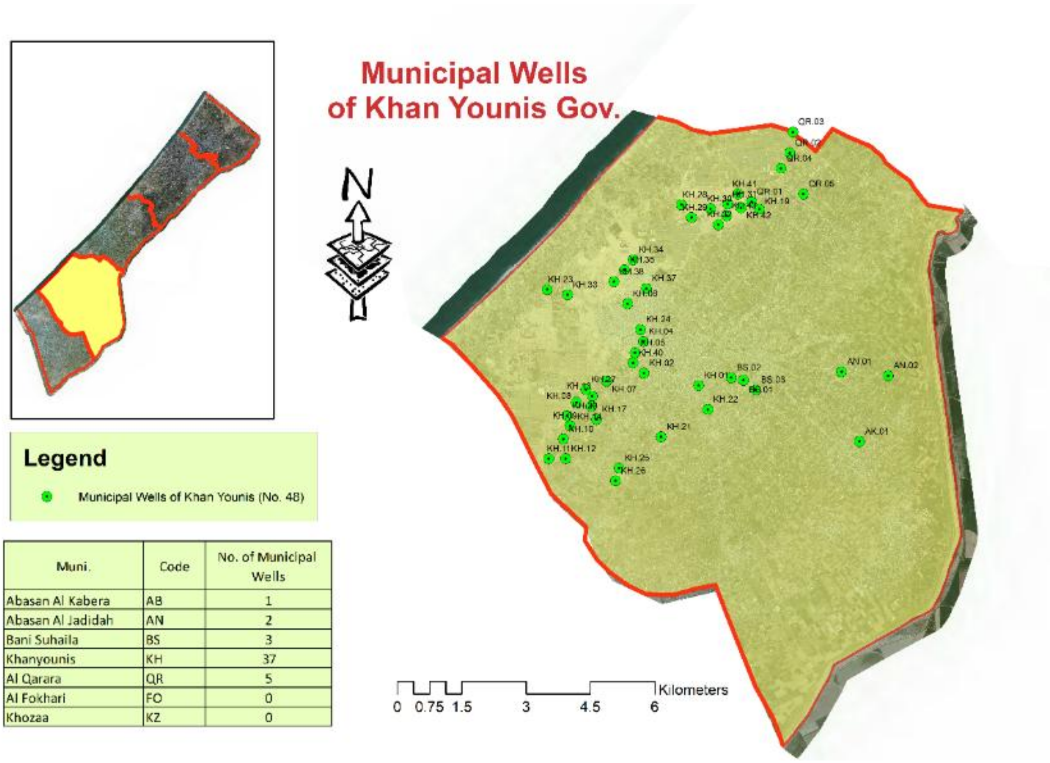
Muni.	Code	No. of Municipal Wells
Gaza	GZ	71
Zahra	ZH	3

(b) Governorate of Gaza



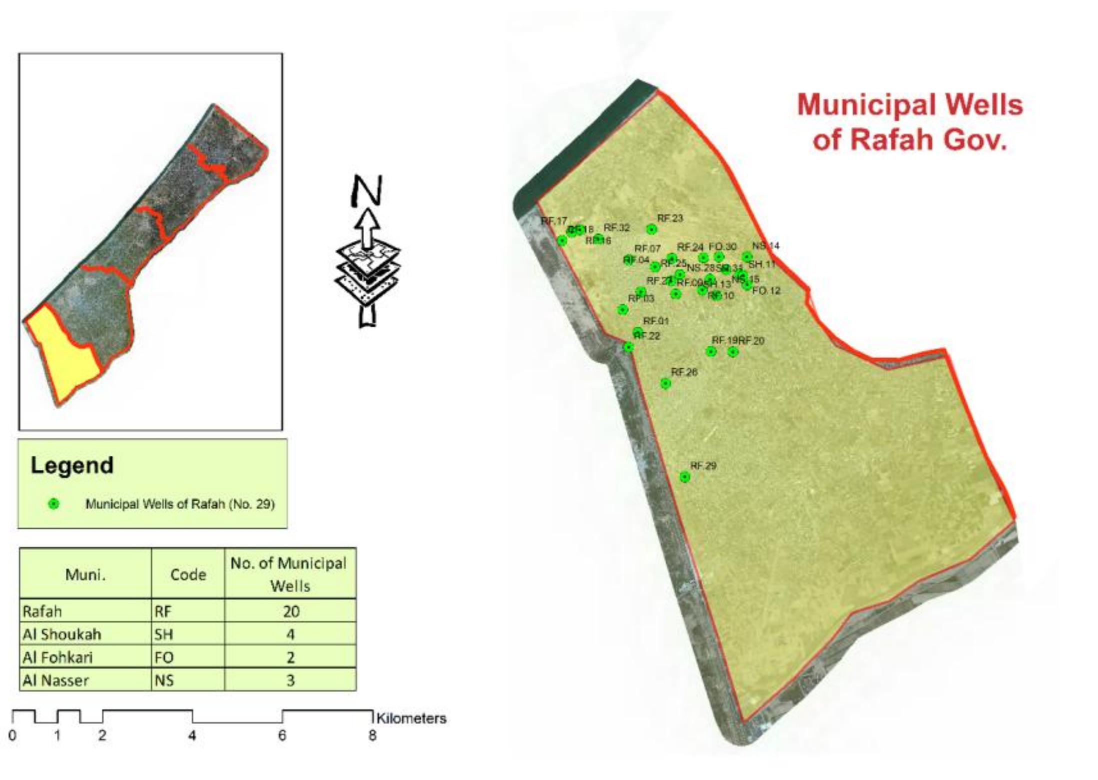
Muni.	Code	No. of Municipal Wells
Al Buraij	BJ	9
Dear AlBalah	DB	16
Al Moghraqa	MG	2
Al Musader	MU	2
Al Maghazi	MZ	7
Al Nusirat	NU	13
Wadi Gaza	WG	2
Wadi Alsalqa	WS	3
Al Zawayda	ZW	6

(c) Governorate of Middle Area



Muni.	Code	No. of Municipal Wells
Abasan Al Kabera	AB	1
Abasan Al Jadidah	AN	2
Bani Suhaila	BS	3
Khanyounis	KH	37
Al Qarara	QR	5
Al Fokhari	FO	0
Khozaa	KZ	0

(d) Governorate of Khan Younis



(e) Governorate of Rafah

Figure 5.2 – Distribution of wells in the Gaza Strip

Public desalination plants

There are 52 public desalination plants (operated by CMWU and municipalities) and 21 privately owned desalination plants with different capacities, which are willing to operate in emergencies, according to GVC. Therefore, these 21 private desalination plants are considered for subsequent analysis under this study. Figure 5.3 shows the distribution of public desalination plants in the Gaza Strip. Public desalination plants for the five governorates are as follows:

- North Gaza: 3 public desalination plants (Fig 5.3a).
- Gaza: only 1 public desalination plant (Fig 5.3b)
- Middle Gaza: 16 public desalination plants (Fig 5.3c)
- Khan Younis: 23 public desalination plants (Fig 5.3d)
- Rafah: 9 public desalination plants (Fig 5.3e).

Discharge capacity: Data shows that the discharge capacity of all public desalination plants ranges from 24 to 1,200 m^3/day, with an average discharge of 167m^3/day.

Construction area: Data shows that the construction area of all public desalination plants ranges from 16 to 2,400m^2, with an average area of 392m^2. The area distribution of public desalination plants in each governorate is as follows:

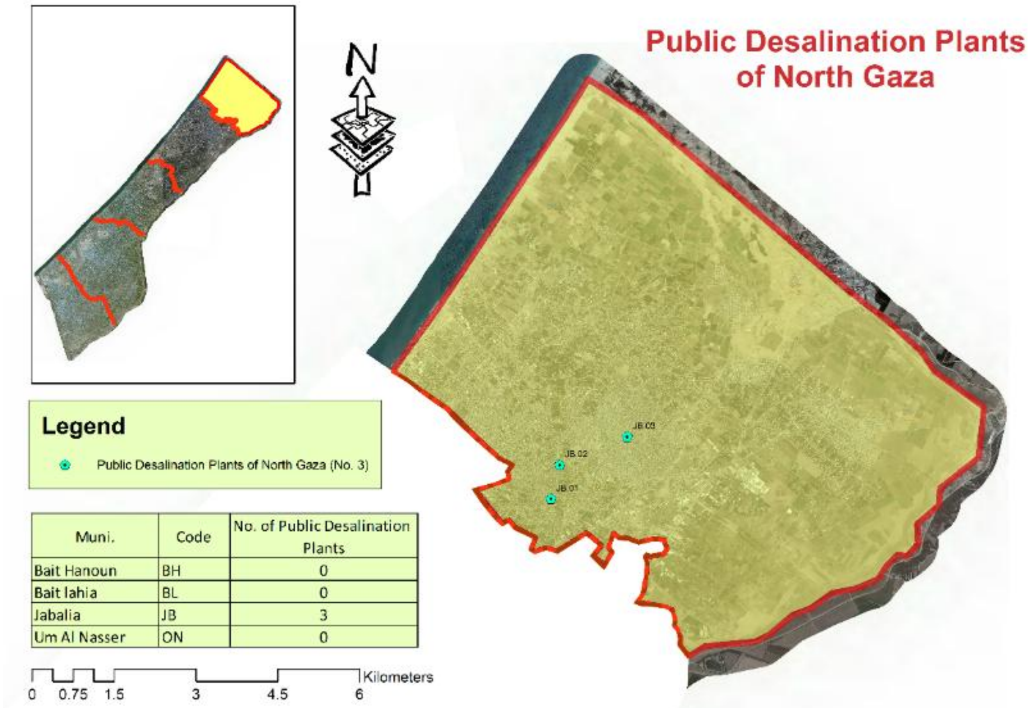
- North Gaza: 80 to 300m^2; average area 167m^2/3 public desalination plants

- Gaza: 308m^2/1 public desalination plant
- Middle Gaza: 16 to 900m^2; average area 304 m^2/16 public desalination plants
- Khan Younis: 20 to 2,400 m^2; average area 450m^2/23 public desalination plants
- Rafah: 20 to 1,511m^2 ; average area 487m^2/9 public desalination plants.

Availability of generators: Among the 52 public desalination plants, 33 plants have generators. Out of these 33 plants, 8 have zero daily operation of generators (2 in the Middle Area, 4 in Khan Younis and 2 in Rafah), which means generators are not working.

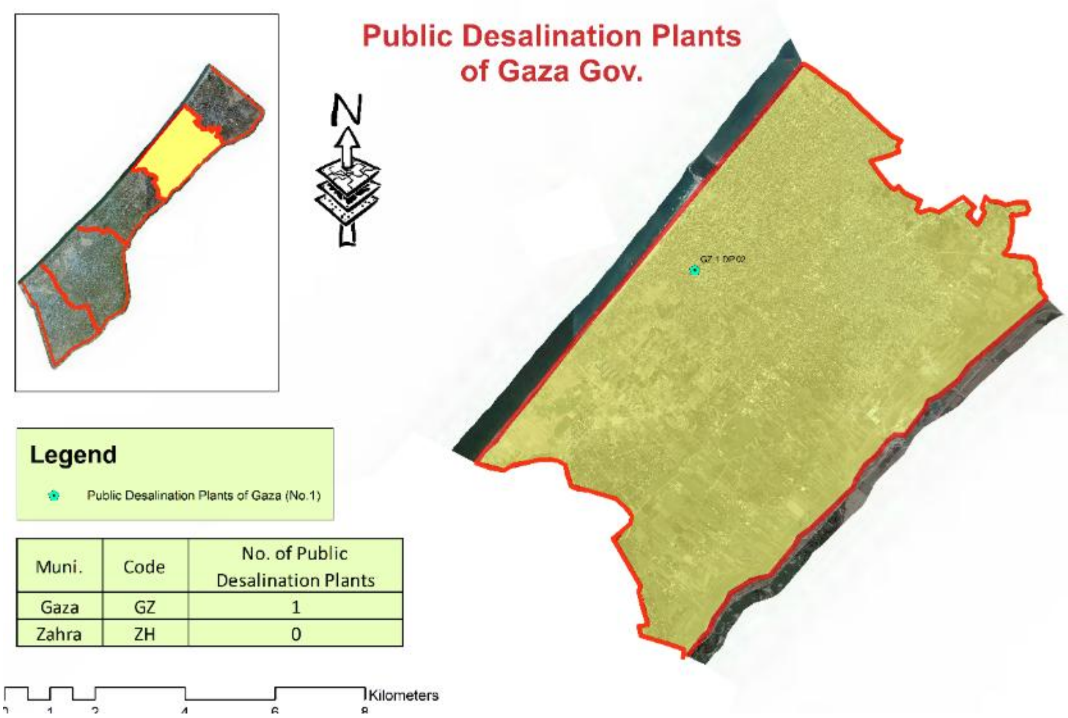
Power source: Based on the power source, daily operation is classified into three types.

- Type 1 – public desalination plants that operate using municipal electricity only:
  - Total public desalination plants that have no generators and depend on electricity: 19, with an average daily operation of 6.9 hours (min. 0 hours, max. 12 hours). The average power electricity consumption is 13 kWh (min. 3.75 kWh, max. 50 kWh).
  - Total public desalination plants that have generators but with zero operation: 7, which means they depend mainly on electricity, with an average daily operation of 5.2 hours (min. 0 hours, max. 15 hours).
- Type 2 – public desalination plants that operate using generators only:
  - Total public desalination plants operating using only generators: 1. The power consumption is 92 kWh. Its average daily operation is 0 hours, which means this plant is not operational.
- Type 3 – public desalination plants that operate using both electricity and generators:
  - Total public desalination plants operating using electricity and generators: 25
  - Average daily operation of electricity: 5.08 hours (min. 2 hours, max. 10 hours). The average power electricity consumption is 24.6 kWh (min. 2 kWh, max. 132 kWh).
  - Average daily operation of generators: 3.6 hours (min. 1 hour, max. 12 hours).



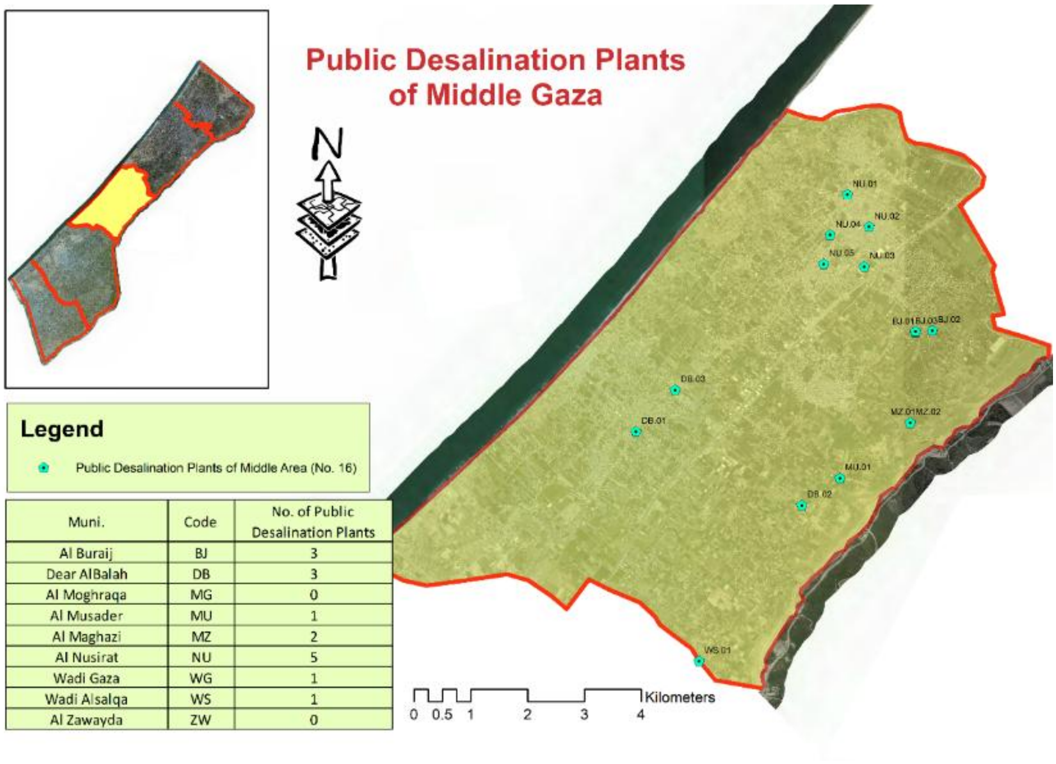
Muni.	Code	No. of Public Desalination Plants
Bait Hanoun	BH	0
Bait lahia	BL	0
Jabalia	JB	3
Um Al Nasser	ON	0

(a) Governorate of North Gaza



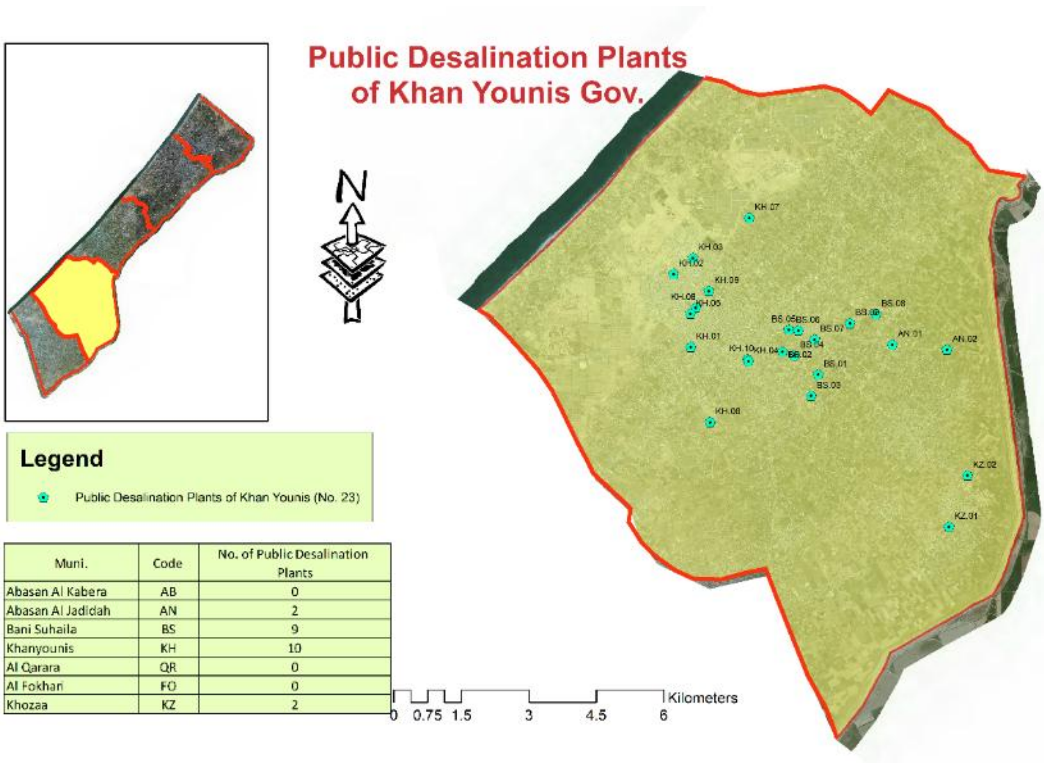
Muni.	Code	No. of Public Desalination Plants
Gaza	GZ	1
Zahra	ZH	0

(b) Governorate of Gaza



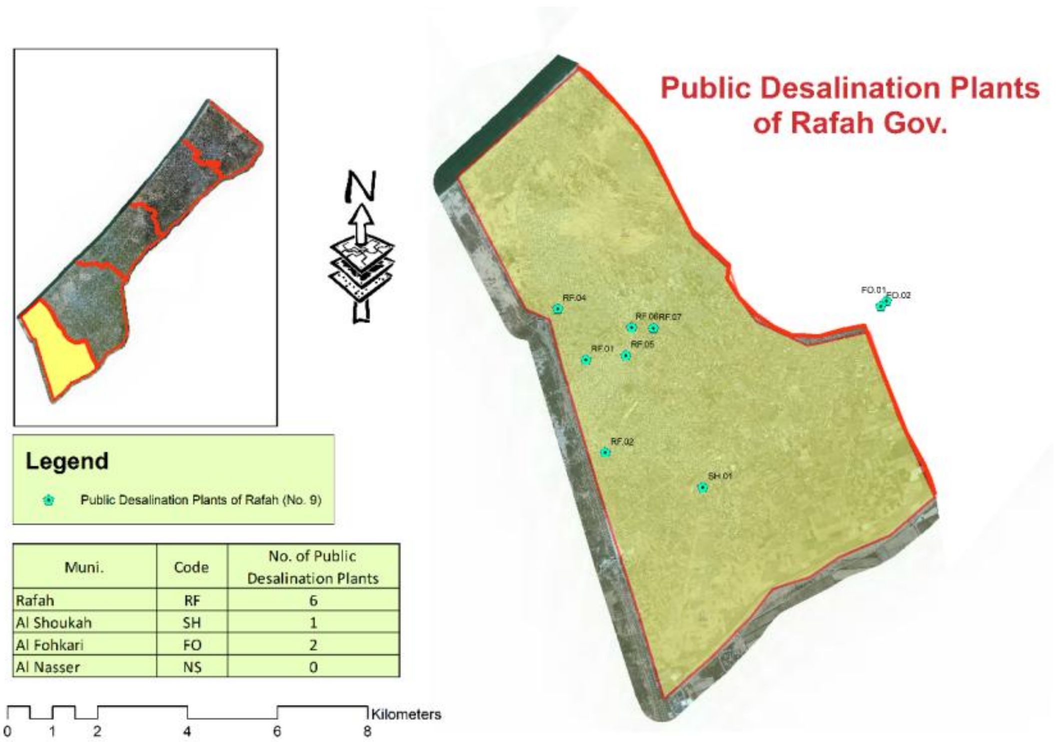
Muni.	Code	No. of Public Desalination Plants
Al Buraij	BJ	3
Dear AlBalah	DB	3
Al Moghraqa	MG	0
Al Musader	MU	1
Al Maghazi	MZ	2
Al Nusirat	NU	5
Wadi Gaza	WG	1
Wadi Alsalqa	WS	1
Al Zawayda	ZW	0

(c) Governorate of Middle Area



Muni.	Code	No. of Public Desalination Plants
Abasan Al Kabera	AB	0
Abasan Al Jadidah	AN	2
Bani Suhaila	BS	9
Khanyounis	KH	10
Al Qarara	QR	0
Al Fokhari	FO	0
Khozaa	KZ	2

(d) Governorate of Khan Younis



(e) Governorate of Rafah

Figure 5.3 – Distribution of public desalination plants in the Gaza Strip

Private desalination plants

There are 21 private desalination plants, which are distributed across the five governorates as follows:

- North Gaza: 4 private desalination plants (Fig 5.4a)
- Gaza: 5 private desalination plants (Fig 5.4b)
- Middle Gaza: 5 private desalination plants (Fig 5.4c)
- Khan Younis: 4 private desalination plants (Fig 5.4d)
- Rafah: 3 private desalination plants (Fig 5.4e).

Discharge capacity: The discharge capacity of all private desalination plants ranges from 35 to 1,300 m^3/day, with an average discharge of 204 m^3/day.

Construction area: The construction area of all wells ranges from 16 to 700m^2, with an average area of 269m^2. The area distribution of private desalination plants in each governorate is as follows:

- North Gaza: 4 private desalination plants, with area ranging from 150 to 550m^2; average area 350m^2
- Gaza: 5 private desalination plants, with area ranging from 110 to 500m^2; average area 222m^2
- Middle Gaza: 5 private desalination plants, with area ranging from 16 to 700 m^2 ; average area 221m^2
- Khan Younis: 4 private desalination plants, with area ranging from 30 to 700m^2; average area

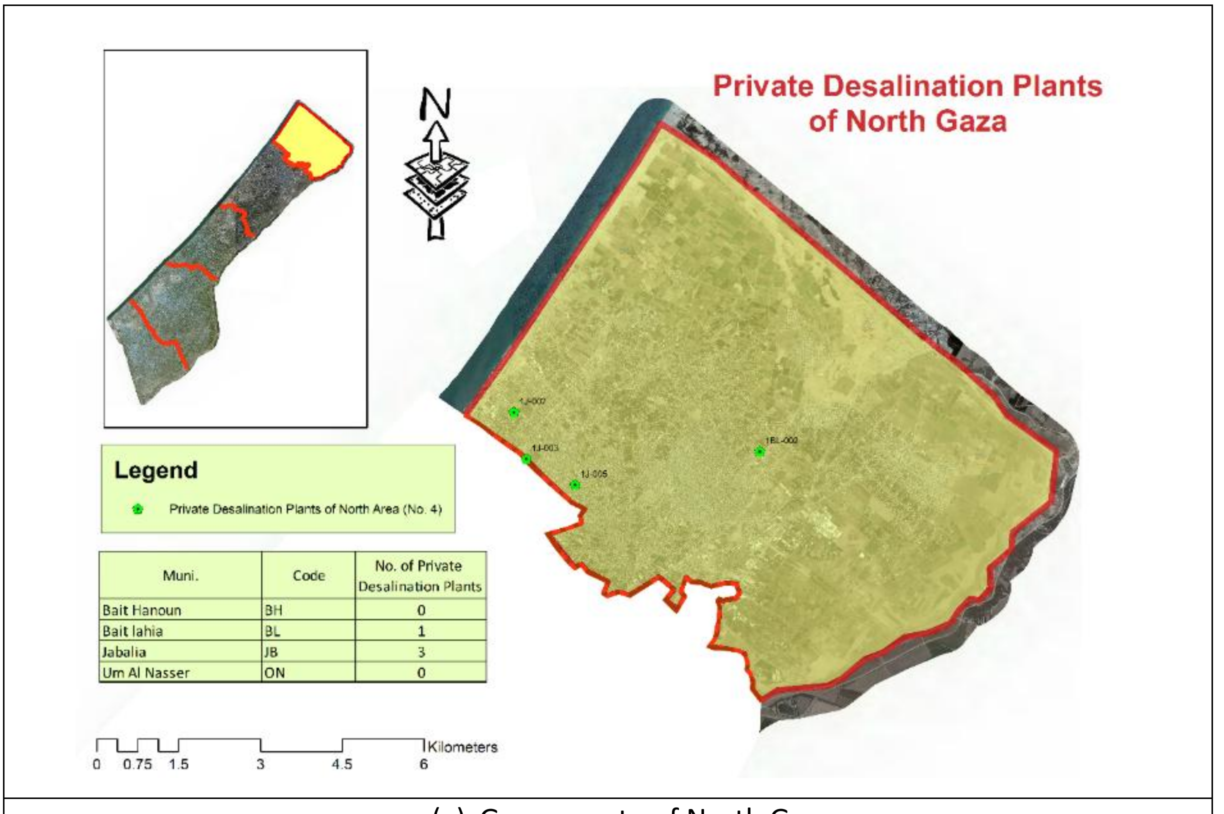
283m^2

- Rafah: 3 private desalination plants, with area ranging from 200 to 500m^2; average area 300m^2.

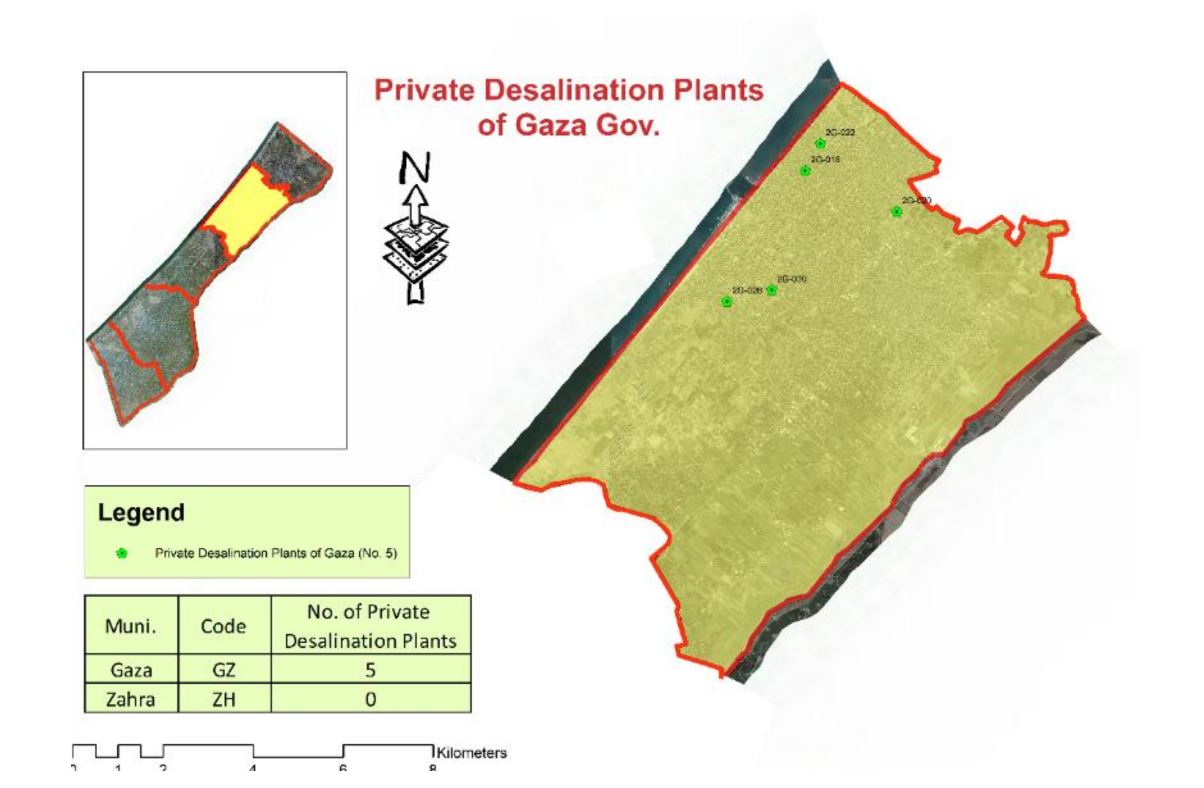
Availability of generators: Among the 21 private desalination plants, only 18 plants have generators.

Power source: The source of power for daily operation is classified into two types:

- Type 1 – private desalination plants that operate using municipal electricity only:
  - Total private desalination plants that have no generators and depend on electricity: 3, with an average daily operation of 8.3 hours (min. 5 hours, max. 10 hours).
- Type 2 – private desalination plants that operate using both electricity and generators:
  - A total of 18 private desalination plants operate using electricity and generators.
  - Average daily operation of electricity: 6.5 hours (min. 4 hours, max. 16 hours).
  - Average daily operation of generators: 2.9 hours (min. 1 hour, max. 6 hours).

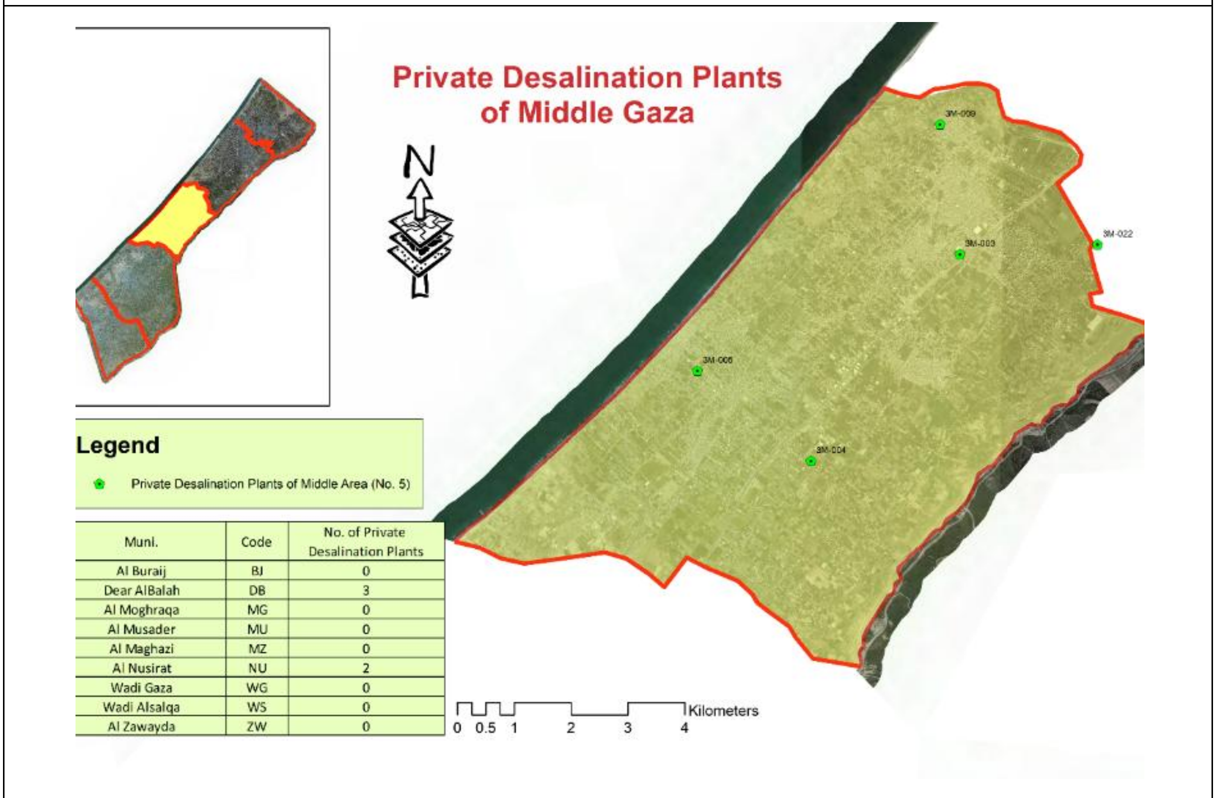


(a) Governorate of North Gaza



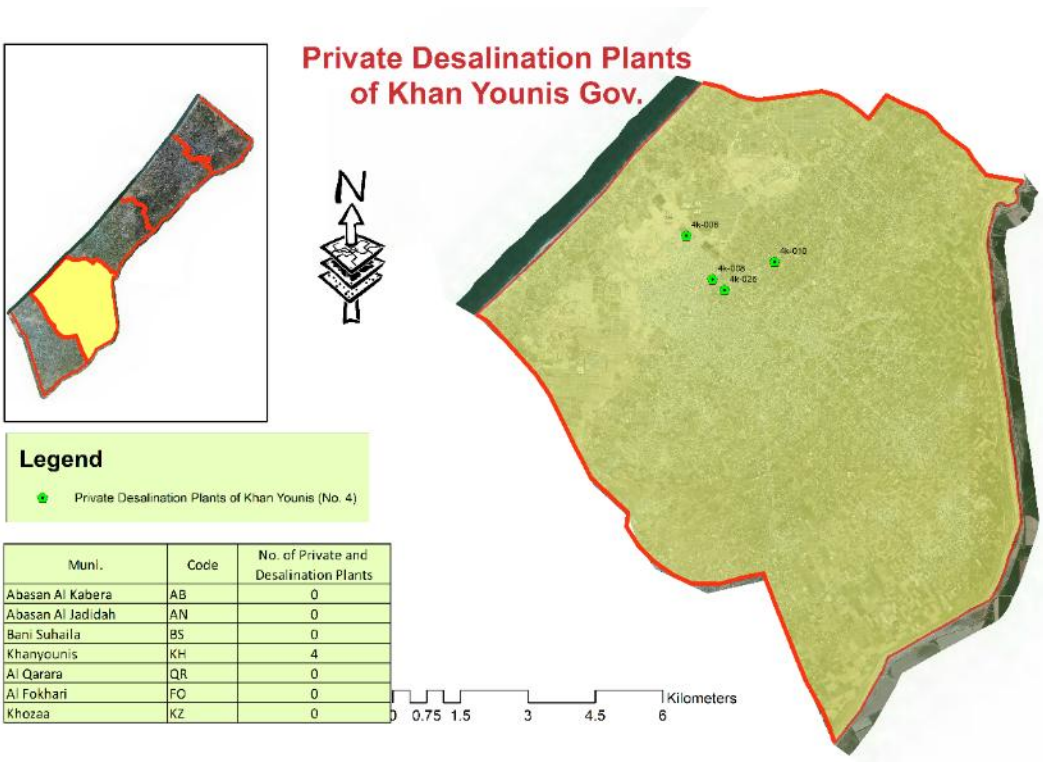
Muni.	Code	No. of Private Desalination Plants
Gaza	GZ	5
Zahra	ZH	0

(b) Governorate of Gaza



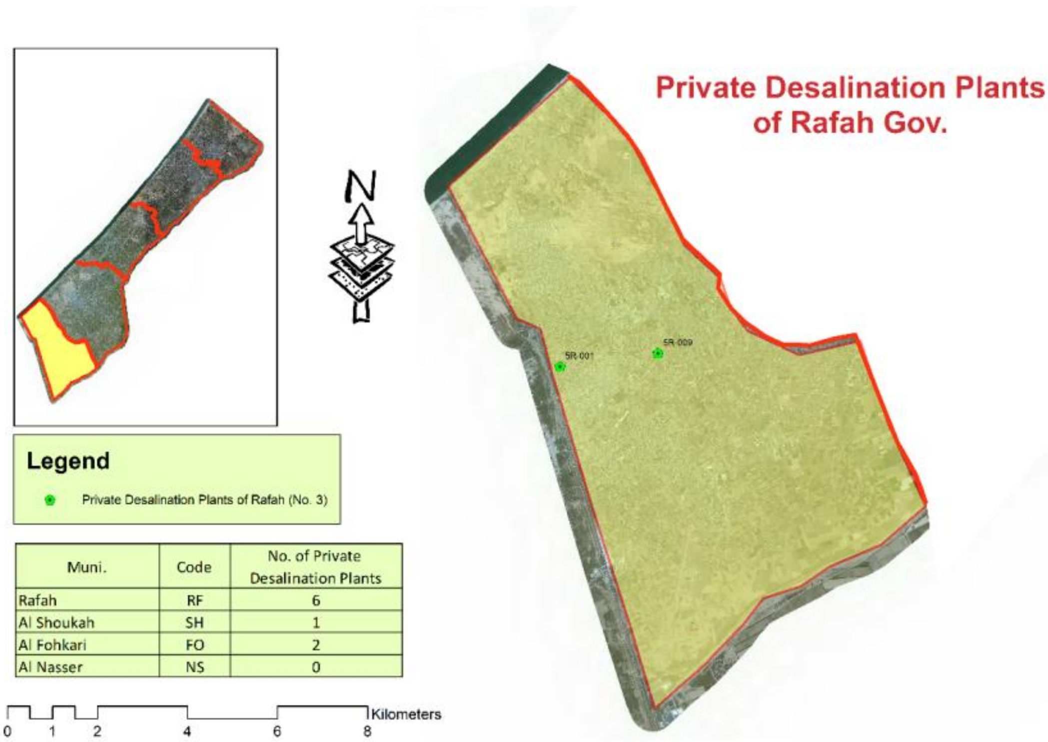
Muni.	Code	No. of Private Desalination Plants
Al Buraij	BJ	0
Dear AlBalah	DB	3
Al Moghraqa	MG	0
Al Musader	MU	0
Al Maghazi	MZ	0
Al Nusirat	NU	2
Wadi Gaza	WG	0
Wadi Alsalqa	WS	0
Al Zawayda	ZW	0

(c) Governorate of Middle Area



Muni.	Code	No. of Private and Desalination Plants
Abasan Al Kabera	AB	0
Abasan Al Jadidah	AN	0
Bani Suhaila	BS	0
Khanyounis	KH	4
Al Qarara	QR	0
Al Fokhari	FO	0
Khozaa	KZ	0

(d) Governorate of Khan Younis



Muni.	Code	No. of Private Desalination Plants
Rafah	RF	6
Al Shoukah	SH	1
Al Fohkari	FO	2
Al Nasser	NS	0

(e) Governorate of Rafah

Figure 5.4 – Distribution of private desalination plants in the Gaza Strip

Water pump stations

A reviewing of the available data reveals that there are 42 water pump stations in the Gaza Strip, which are distributed across the five governorates as follows:

- North Gaza: 5 water pump stations (Fig 5.5a)
- Gaza: 5 water pump stations (Fig 5.5b)
- Middle Gaza: 9 water pump stations (Fig 5.5c)
- Khan Younis: 11 water pump stations (Fig 5.5d)
- Rafah: 12 water pump stations (Fig 5.5e).

Discharge capacity: Data shows that the discharge capacity of all water pump stations ranges from 100 to 750m^3/hr, with an average discharge capacity of 340m^3/hr.

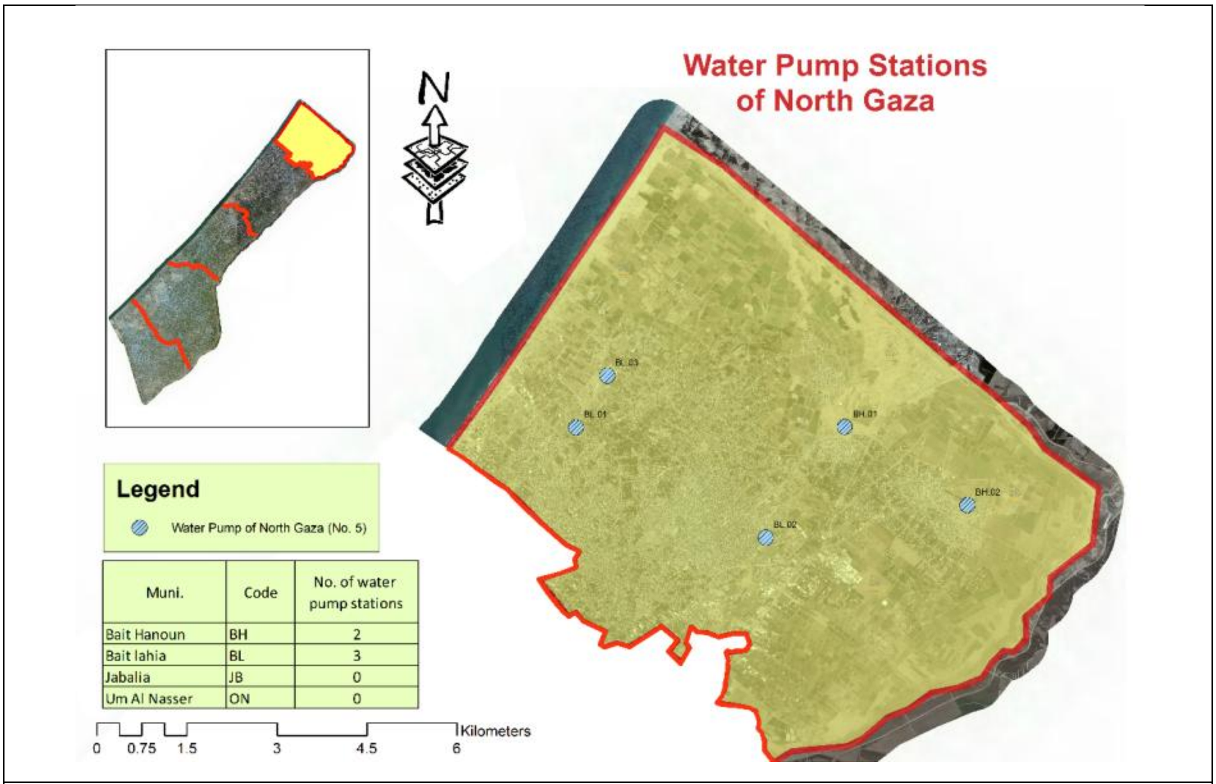
Construction area: Data shows that the construction area of all water pump stations ranges from 80 to 3,800m^2, with an average area of 1,345m^2. The area distribution of water pump stations per governorate is as follows:

- North Gaza: 487 to 2,000m^2, with an average area of 1,417m^2
- Gaza: 140 to 3,410m^2, with an average area of 1,736m^2
- Middle Gaza: 80 to 2,000m^2, with an average area of 1,398m^2
- Khan Younis: 200 to 3,800m^2, with an average area of 1,346m^2
- Rafah: 200 to 1,989m^2, with an average area of 1,114m^2.

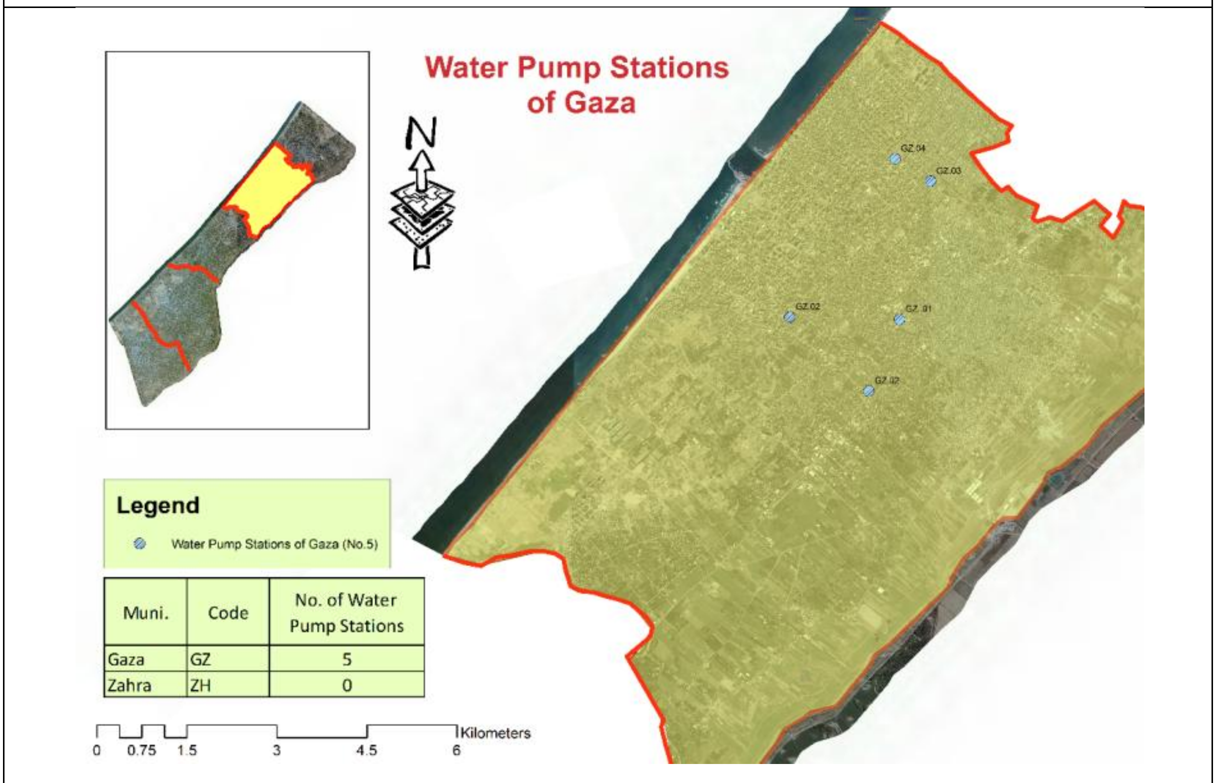
Availability of generators: Out of the 42 water pump stations, 34 have generators.

Power source: Based on the power source, daily operation is classified into two types:

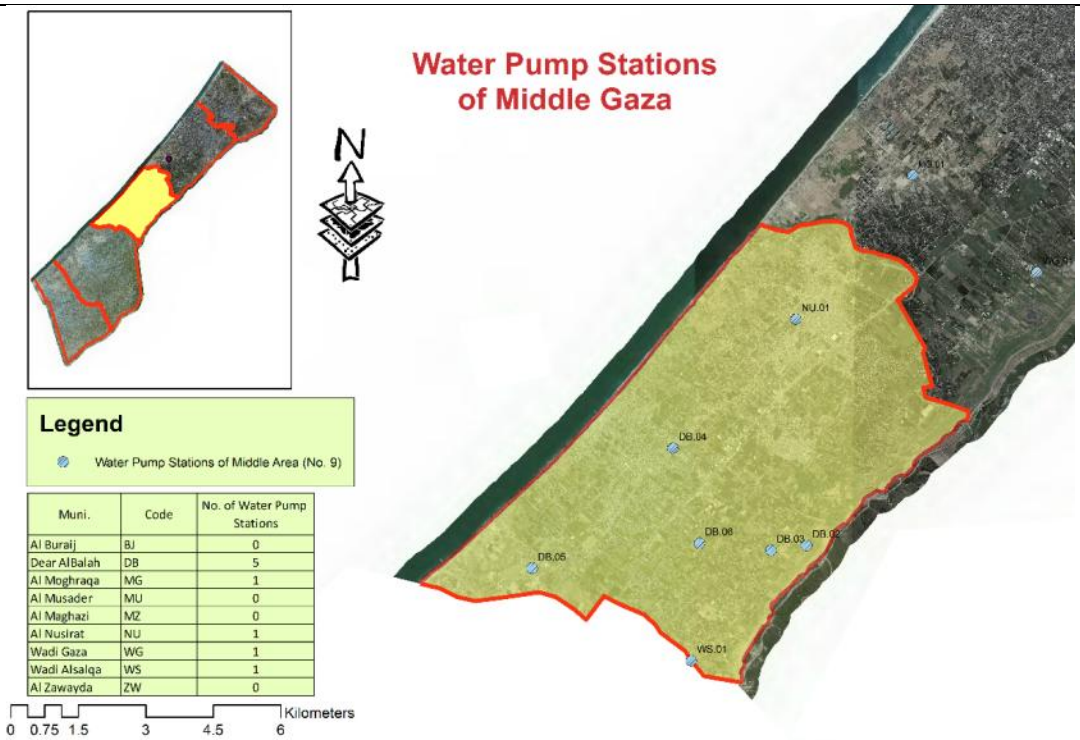
- Type 1 – only use municipal electricity for operation:
    - A total of 8 water pump stations have no generators and depend on electricity, with an average daily operation of 9.75 hours (min. 8 hours, max. 12 hours). The average power electricity consumption is 80.25 kWh (min. 20 kWh, max. 225 kWh).
- Type 2 – use both electricity and generators to operate:
    - Water pump stations that use electricity and generators to operate: 34. Average daily operation of electricity is 7 hours (min. 2.5 hours, max. 12 hours) while the average daily operation of generators is 3.3 hours (min. 0.5 hours, max. 10 hours). The average power electricity consumption is 114.5 kWh (min. 11 kWh, max. 540 kWh).



(a) Governorate of North Gaza

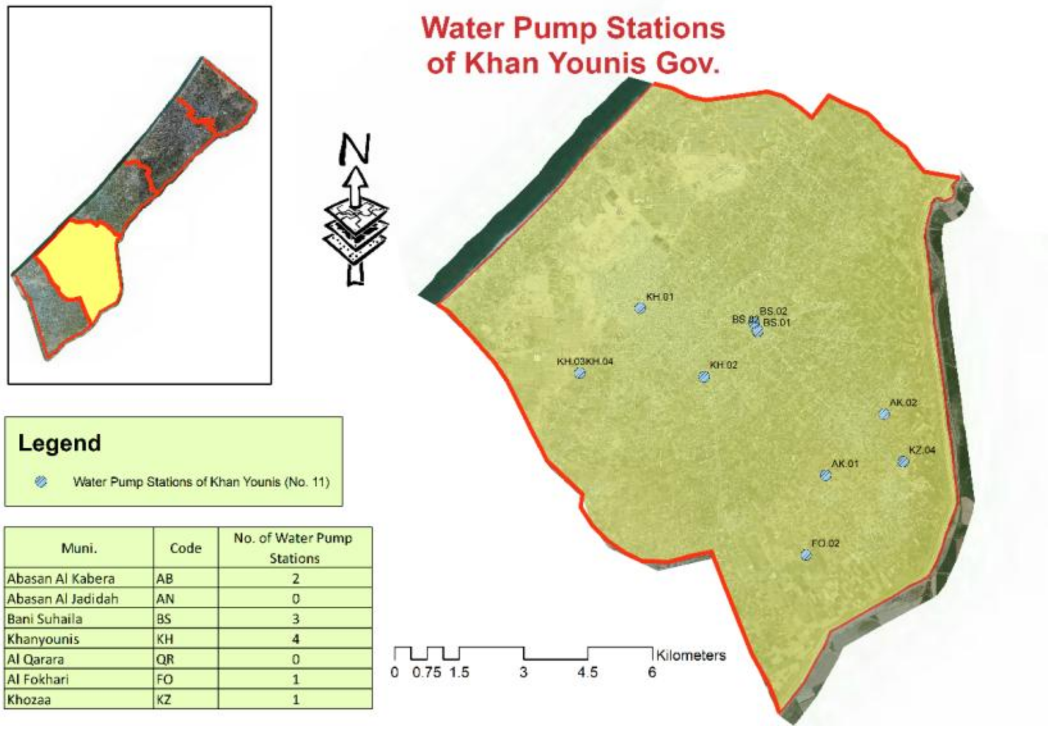


(b) Governorate of Gaza



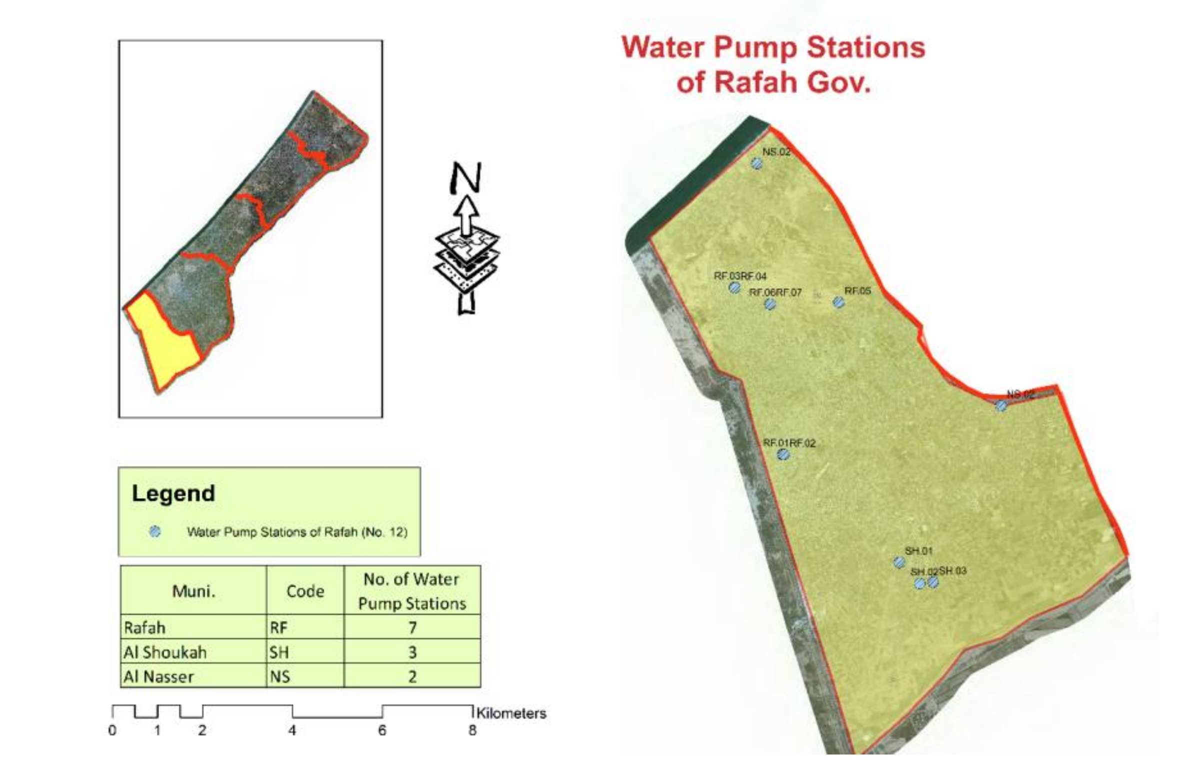
Muni.	Code	No. of Water Pump Stations
Al Buraij	BJ	0
Dear AlBalah	DB	5
Al Moghraqa	MG	1
Al Musader	MU	0
Al Maghazi	MZ	0
Al Nusirat	NU	1
Wadi Gaza	WG	1
Wadi Alsalqa	WS	1
Al Zawayda	ZW	0

(c) Governorate of Middle Area



Muni.	Code	No. of Water Pump Stations
Abasan Al Kabera	AB	2
Abasan Al Jadidah	AN	0
Bani Suhaila	BS	3
Khanyounis	KH	4
Al Qarara	QR	0
Al Fokhari	FO	1
Khozaa	KZ	1

(d) Governorate of Khan Younis



(e) Governorate of Rafah

Figure 5.5 – Distribution of water pump stations in the Gaza Strip

Sewage pump stations

A review of the available data revealed that there are 49 sewage pump stations distributed across the five governorates as follows:

- North Gaza: 16 sewage pump stations (Fig 5.6a).
- Gaza: 11 sewage pump stations (Fig 5.6b)
- Middle Gaza: 11 sewage pump stations (Fig 5.6c)
- Khan Younis: 6 sewage pump stations (Fig 5.6d)
- Rafah: 5 sewage pump stations (Fig 5.6e).

Discharge capacity: Data shows that the discharge capacity of all sewage pump stations ranges from 5 to 8,000 m^3/hr, with an average discharge of 667m^3/hr.

Construction area: Data shows that the construction area per pump station ranges from 30 to 5,000 m^2, with an average area of 822m^2. The area distribution of sewage pump stations per governorate is as follows:

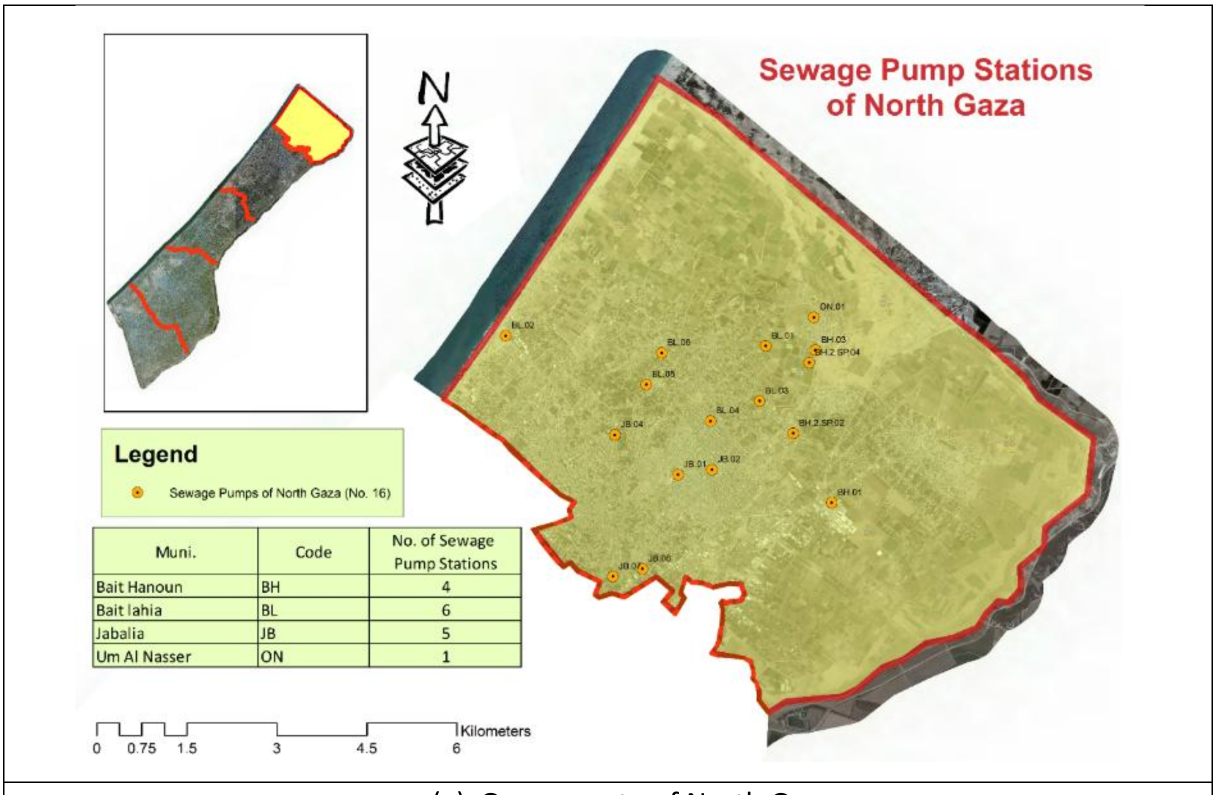
- North Gaza: 16 sewage pump stations, with a construction area ranging from 250 to 5,000m^2; average area 954m^2
- Gaza: 11 sewage pump stations, with construction area ranging from 100 to 3,000m^2; average area 1,082m^2

- Middle Gaza: 11 sewage pump stations, with construction area ranging from 30 to 2,000m^2; average area 541m^2
- Khan Younis: 6 sewage pump stations, with construction area ranging from 100 to 1,600m^2; average area 645m^2
- Rafah: 5 sewage pump stations, with construction area ranging from 197 to 1,083m^2; average area 662m^2.

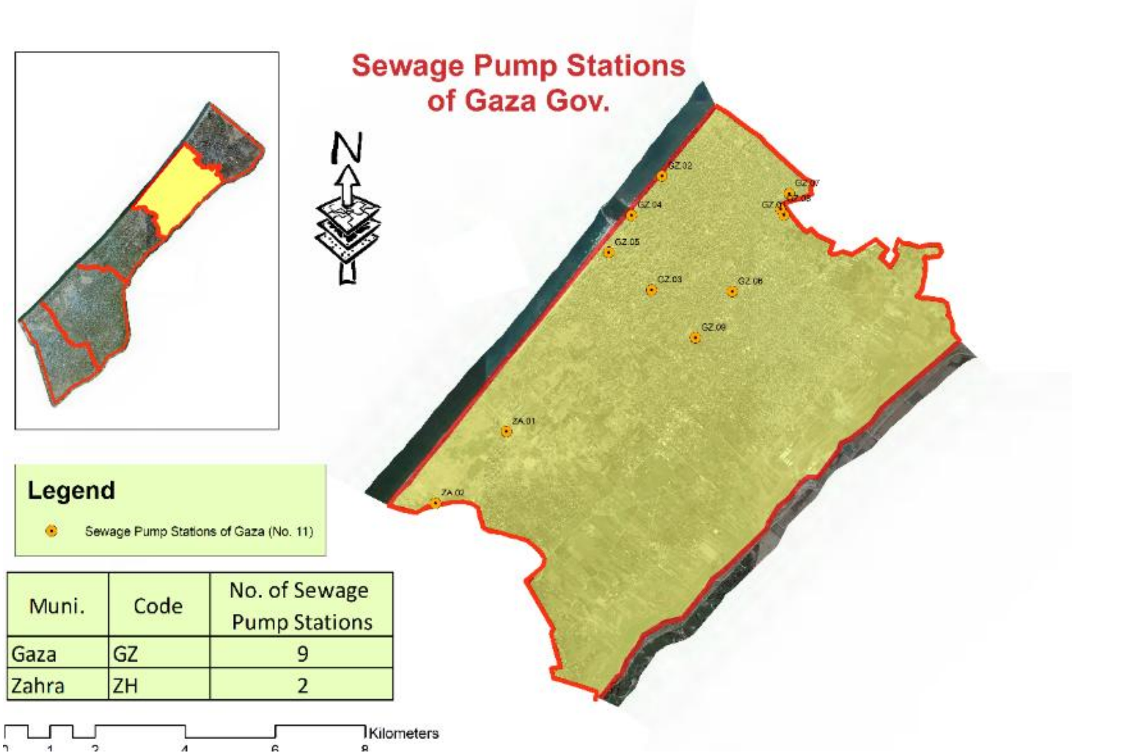
Availability of generators: Of the 49 sewage pump stations, 48 have generators.

Power source: Based on the power source, daily operation is classified into three types of sewage pump stations.

- Type 1 – uses municipal electricity only:
    - Only 1 sewage pump station has no generator and depends on electricity, with 8 hours of daily operation and with power consumption of 50 kWh.
- Type 2 – uses generators only:
    - A total of 2 stations operate using only generators, with daily power consumption of 0.75 hours and with an average power consumption of 11.5 kWh.
- Type 3 – uses both electricity and generators:
    - A total of 46 stations operate using electricity and generators. The average daily operation of electricity is 6.2 hours (min. 1 hour, max. 18 hours), while the average daily operation of generators is 6.6 hours (min. 1 hour, max. 18 hours). The average power consumption is 128.55 kWh (min. 5 kWh, max. 1,320 kWh).

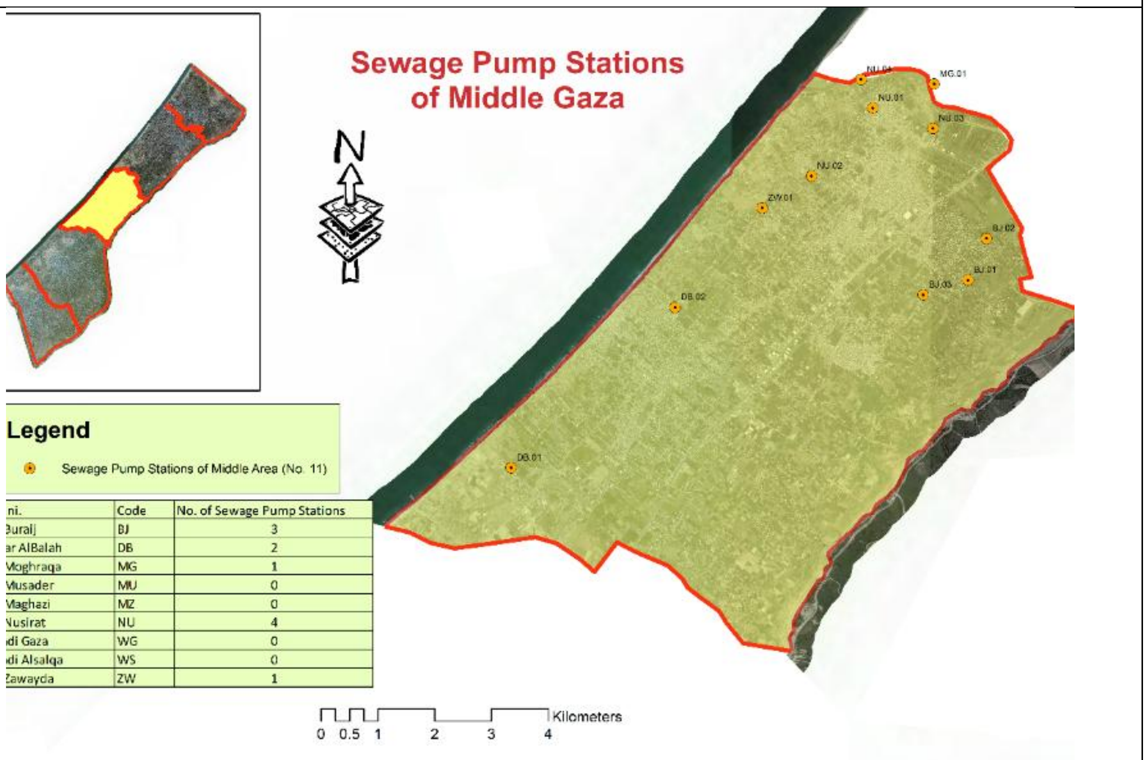


(a) Governorate of North Gaza



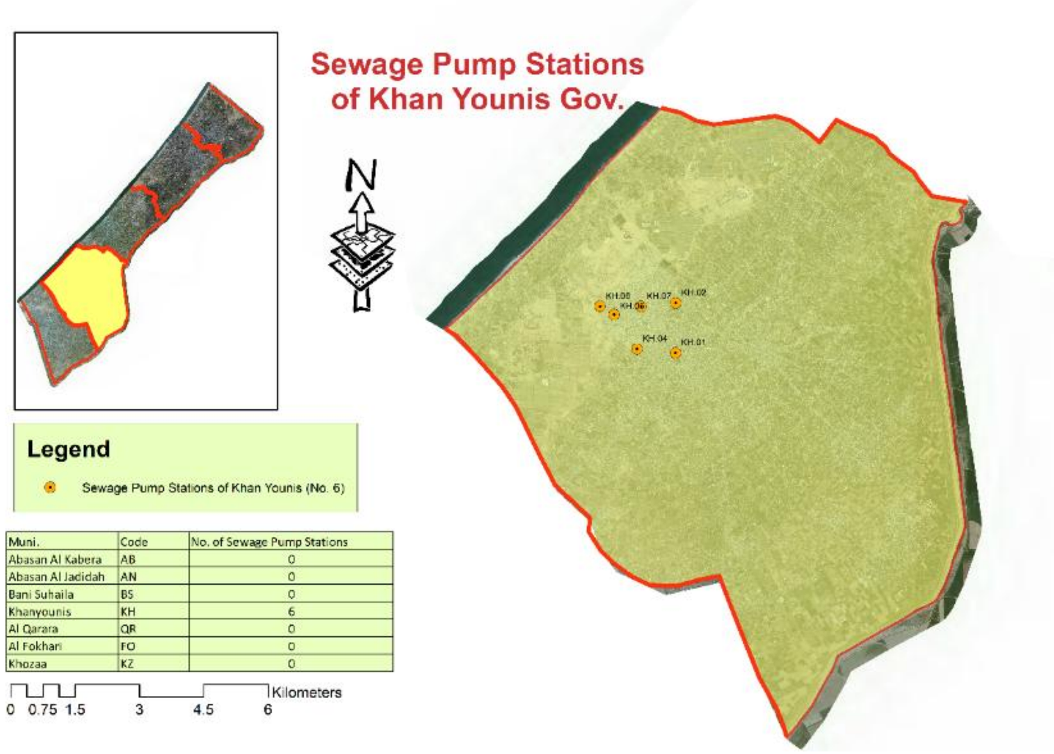
Muni.	Code	No. of Sewage Pump Stations
Gaza	GZ	9
Zahra	ZH	2

(b) Governorate of Gaza



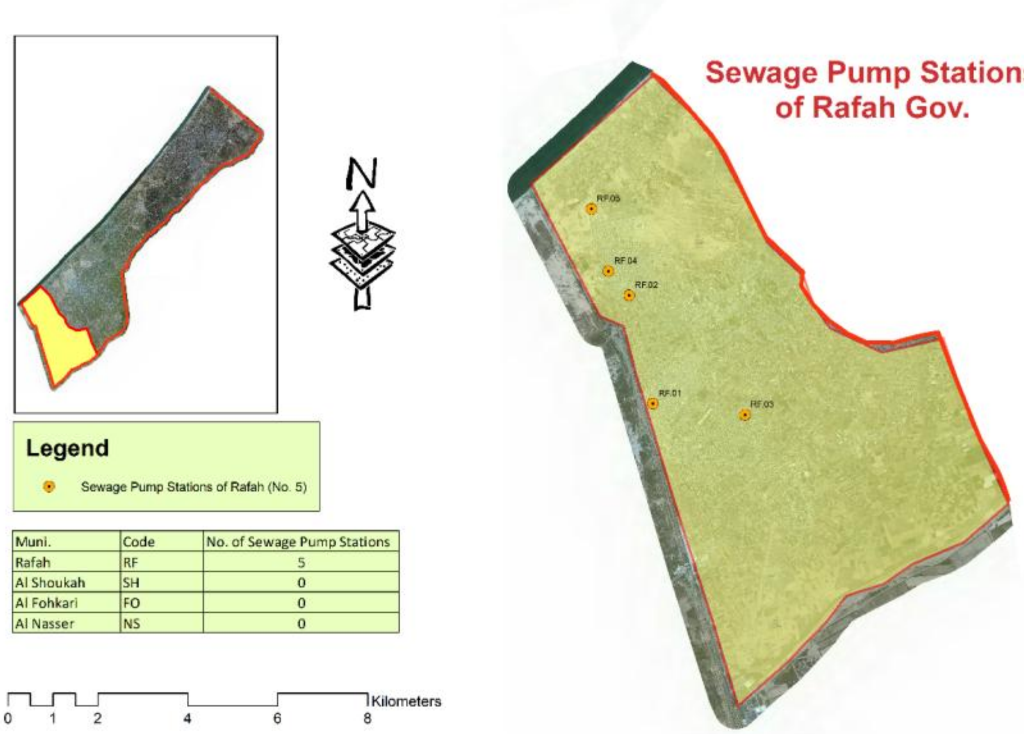
ni.	Code	No. of Sewage Pump Stations
uraij	BJ	3
ar AlBalah	DB	2
Moghraqa	MG	1
Musader	MU	0
Maghazi	MZ	0
Nusirat	NU	4
di Gaza	WG	0
di Alsalqa	WS	0
Zawayda	ZW	1

(c) Governorate of Middle Area



Muni.	Code	No. of Sewage Pump Stations
Abasan Al Kabera	AB	0
Abasan Al Jadidah	AN	0
Bani Suhaila	BS	0
Khanyounis	KH	6
Al Qarara	QR	0
Al Fokhari	FO	0
Khozaa	KZ	0

(d) Governorate of Khan Younis



Muni.	Code	No. of Sewage Pump Stations
Rafah	RF	5
Al Shoukah	SH	0
Al Fohkari	FO	0
Al Nasser	NS	0

(e) Governorate of Rafah

Figure 5.6 – Distribution of sewage pump stations in the Gaza Strip

Sewage treatment plants

There are 8 treatment plants in the Gaza Strip, which are either operational, under construction or planned for closure. These are distributed across the five governorates of the Gaza Strip as follows:

- Northern Gaza: 1 planned for closure, and 1 under new operation (Fig 5.7a)
- Gaza: 1 existing plant (Fig 5.7b)
- Middle Gaza: 1 existing and 1 under construction (Fig 5.7c)
- Khan Younis: 1 existing and 1 under construction (Fig 5.7d)
- Rafah: 1 existing plant (Fig 5.7e).

Figure 5.7 – Distribution of sewage treatment plants in the Gaza Strip

The existing and under-construction sewage treatment plants have their own plans for PV system installation. Regarding the under-construction plants, PV systems are part of a KFW project at the Gaza Central treatment plant while there are plans with PWA and CMWU for the Rafah treatment plant. Therefore, the consultant will not include the sewage treatment plants as part of the study for PV feasibility.

6 Feasibility study

This chapter discuss the financial, social and environmental, and technical feasibility of installing PV systems for WASH facilities in Gaza. Within financial feasibility, Net Present Value (NPV) and payback periods were calculated with the cost of electricity production from PV. The technical feasibility is based on many criteria such as land availability, power consumption, availability of generators, facility size and water quality. Social and environmental benefits are also determined, based on improving the service by increasing hours of operation and reducing CO_2 emissions.

6.1 Financial feasibility

For a solar PV system, two costs are incurred annually:

1. Initial investment costs of installing the system, which is assumed to occur at beginning of the project (year 0).

2. Maintenance cost for the maintenance of the system (inventor, panels, water pumps), based on the maintenance cost of electrical equipment and the experience in Gaza. It is assumed to be 5% of the initial investment cost of the system; this cost occurs each year.

As stated in the methodology chapter, the consultant estimated the capital costs of a PV system based on current ongoing projects and current market prices. Table 6.1 presents a summary of the planned, ongoing and installed PV systems in Gaza for WASH facilities.

Table 6.1 – Summary of installed, ongoing and planned PV systems for WASH facilities

Institution	No of projects	Facility type	PV type	PV capacity kWp	Cost $/kWp		Project status
					Range	Average	
GVC	10	Private desalination plants	Hybrid diesel system	36–47	839–1,003	880	Ongoing
UNICEF	1	WWTP	On-grid	250	1,600		Ongoing
	1	Seawater desalination plant	On-grid	680	1,765		Completed
	4	Water wells	On-grid	80–150	1,250–1,333	1,290	Under tender
	1	Water wells	On-grid	40	1,250		Ongoing
PHG	5	Sewage pump stations	On-grid	23-40	2,126–1,551	1,579	Ongoing
AAH	10	Private desalination	Off-Grid	10			Ongoing

Institution	No of projects	Facility type	PV type	PV capacity kWp	Cost $/kWp		Project status
					Range	Average	
		plants					
	10	Private desalination plants	Off-Grid	10			Planned

Source: Compiled by author using data collected

Table 6.1 shows that the capital cost differs from project to project depending on the PV type and capacity, and taking into consideration year of installation, as prices vary significantly in Gaza. The ongoing projects show that the capital cost ranges from $880/kWp to $1,765/kWp, with an average of $1,322/kWp. Tables 6.2–6.6 represent the consultant's estimations for all PV types, with the estimated cost ranging from $700–$1,500/kWp. The consultant therefore used an average estimated cost of $1,200/kWp as the most feasible figure for financial analyses.

Table 6.2 – Cost analysis of off-grid system

	Off-grid system	
No.	Components	$
1	PV panels with mounting	500
2	Charge controller	50
3	Battery inverter	600
4	Battery	250
5	Accessories such as DC & AC cable and DBs	100
	$/kWp: 1,500	

Table 6.3 – Cost analysis of on-grid system

	On-grid system	
No.	Components	$
1	PV panels with mounting	500
2	On-grid inverter	100
3	Accessories such as DC & AC cable and DBs	100
	$/kWp: 700	

Table 6.4 – Cost analysis of on-grid with backup system

	On-grid with backup system (hybrid)	
No.	Components	$
1	PV panels with mounting	500
2	On-grid inverter	100
3	Battery inverter	600
4	Battery	250
5	Accessories such as DC & AC Cable and DBs	100
	$/kWp: 1,550	

Table 6.5 – Cost analysis of PV diesel hybrid system

PV diesel hybrid system		
No.	Components	$
1	PV panels with mounting	500
2	On-grid inverter	100
3	Accessories such as DC & AC cable and DBs	100
4	Fuel save controller	100
5	Synchronizing	100
	$/kWp: 900	

Table 6.6 – Cost analysis of PV direct water pump

PV direct water pumping		
No.	Components	$
1	PV panels with mounting	500
2	Pump controller	100
3	Pump	100
4	Accessories such as DC & AC cable and DBs	100
	$/kWp: 800	

To estimate the cost saving due to PV installation, the consultant considered savings from the grid and from diesel generators, taking into account that the availability of the public electricity grid in Gaza ranges from 25–75% of daytime.

Most WASH facilities depend on generators as a backup to the public electricity grid. The consultant estimated the cost of kWh generated from diesel generators, as shown in Table 6.7.

Table 6.7 – Cost of electricity generated from diesel generators

Generator capacity	KVA	40	110
Capital cost	$	16,000	25,000
Maintenance cost	Percent of capital cost per year	10%	10%
Fuel consumption	Litre/hours	10	22
Fuel cost	$/Litre	1.4	1.4
Life hours	Hours	35,000	35,000
Daily operation	Hours	7	7
Electricity production	kWh	30	82.5
Calculation			
Years of operation	Years	13.7	13.7
Yearly production	kWh	76,650	210,787.5
Yearly maintenance cost	$	1,600	2,500
Yearly fuel cost	$	35,770	78,694

Cost of kWh			
Capital cost	$/kWh	0.015	0.009
Maintenance cost	$/kWh	0.021	0.012
Fuel cost	$/kWh	0.467	0.373
Total cost	$/kWh	0.503	0.394
	NIS/kWh	1.810	1.418

It is clear that the cost of generating electricity from diesel generators ranges from 1.4 to 1.8 NIS/kWh. The consultant estimated a cost of 1.6 NIS/kWh as the average cost.

The NPV and the payback period (PbP) were calculated for each facility type based on an assumed value of the minimum attractive rate of return (MARR) of 4.5%.

The consultant assumed that availability of the public electricity grid ranges from 25–75% of daytime. All WASH facilities except sewage pump stations can benefit 70% of the PV time, while sewage pump stations can benefit 30% of the PV time.

The following assumptions are used:

Yearly maintenance percent	5	Percent of capital cost
Daily production kWh	5.3	kWh/day
Cost of power production – generator	1.6	NIS/kW
MARR	4.5 %	
Project lifetime	20	Years
Cost of power production – grid	0.6	NIS/kW
NIS/$	3.6	

Based on these assumptions, the consultant calculated the NPV and payback period. Detailed financial analysis and calculations are included in Annex 6.1.

Tables 6.8–6.11 present the NPV and payback period for each facility type for different public electricity grid availability. Table 6.12 presents the summary of the NPV and payback period.

Table 6.8 – NPV and payback period for WASH facilities except sewage pump stations (grid availability 25%)

Years	Yearly cost $	Yearly revenues $	Yearly cost/profit $	Accumulation saving $
0	1,200	0	-1,200	-1,200
1	0	512	512	-688
2	0	512	512	-177
3	60	512	452	275
NPV ($)			4,582	

Table 6.9 – NPV and payback period for WASH facilities except sewage pump stations (grid availability 75%)

Years	Yearly cost $	Yearly revenues $	Yearly cost/profit $	Accumulation saving $
0	1,200	0	-1,200	-1,200
1	0	321	321	-879
2	0	321	321	-558
3	60	321	261	-297
4	60	321	261	-36
5	60	321	261	225
NPV ($)			2,209	

Table 6.10 – NPV and payback period for sewage pump stations (grid availability 25%)

Years	Yearly cost $	Yearly revenues $	Yearly cost/profit $	Accumulation saving $
0	1,200	0	-1,200	-1,200
1	0	219	219	-981
2	0	219	219	-761
3	60	219	159	-602
4	60	219	159	-443
5	60	219	159	-283
6	60	219	159	-124
7	60	219	159	35
NPV ($)			942	

Table 6.11 – NPV and payback period for sewage pump stations (grid availability 75%)

Years	Yearly cost $	Yearly revenues $	Yearly cost/profit $	Accumulation saving $
0	1,200	0	-1,200	-1,200
1	0	138	138	-1,062
2	0	138	138	-925
3	60	138	78	-847
4	60	138	78	-770
5	60	138	78	-692
6	60	138	78	-614
7	60	138	78	-537
8	60	138	78	-459
9	60	138	78	-382
10	60	138	78	-304
11	60	138	78	-227
12	60	138	78	-149
13	60	138	78	-71
14	60	138	78	6
NPV ($)			-75	

Table 6.12 – Summary of NPV and payback period (PbP)

Grid availability	25%		75%	
	NPV $	PbP	NPV $	PbP
All facilities except sewage pump station	4,582	3	2,209	5
Sewage pump stations	942	7	-75	14

The NPV for WASH facilities except sewage pump stations ranges from $2,209 to $4,582/kWp with payback periods of 3 to 5 years, while for sewage pump stations the NPV ranges from minus $75 to $942/kWp with payback periods of 7 to 14 years. It is clear that PV systems are financially feasible for WASH facilities with high NPV and short payback periods, except for sewage pump stations, which have low NPV and high payback periods.

To calculate the production cost of PV systems, the consultant calculated the capital and operational cost for 20 years, which is equal to $2,280. This assumes capital costs of $1,200/kWp and maintenance costs of $60/year (5% of capital cost) for 20 years (the lifetime of the system). Power production is based on 5.31kWh/kWp/day for 20 years. The WASH facilities could benefit from 30–70% of production. According to these calculations, the cost of kWh production from PV ranges from 0.3–0.71 NIS/kWh.

6.2 Social and environmental benefits

Improving WASH services in Gaza will have a positive impact socially, environmentally and on public health. The availability of water supply and desalinated water will be enhanced; discharge of wastewater to the sea will be reduced and pollution from diesel generators will be minimized. The benefits are summarized below.

General benefits

1. The PV system can be considered as a sustainable independent source of energy as it is not affected by the internal unsettled Palestinian situation, which has a very negative impact on the continuous supplies of fuels and consequently on operation hours of WASH facilities.
2. Renewable energy technologies require more labour resources than mechanized fossil fuel technologies. This results in a greater prospect of creating jobs through market augmentation. The main players in the solar market include engineers, contractors, consultants, labourers etc. Currently more than 40 PV companies are working in Gaza and greater adoption of PV systems as a source of energy would significantly increase the number of these companies, in turn creating more jobs.
3. Increased installation of PV systems would decrease the unit cost of the equipment (panels, invertors, batteries etc.). This will minimize the capital cost and make the system more feasible as the cost of providing services decreases.

Installing PV systems will increase the operation hours of water wells and desalination plants. This will increase production, with the following impacts:

1. Increase of production from water wells will minimize the shortage of water supplies, particularly in summer months. This will improve public health and meet the needs of residents. Meeting community needs will also improve relations between communities and municipalities, with a positive impact on municipalities' revenues.
2. Currently, many residents dig private wells in their homes in order to meet their water needs. Increasing the operation hours of the municipal water wells will encourage the community to stop such illegal activities.
3. Increasing the operation hours of the desalination plants will enable service providers to produce greater quantities of desalinated water to meet the needs of the community at lower prices. Such production will improve public health and sustain the service.
4. Installing PV systems will reduce production of CO_2 by 0.76kg of CO_2/kWh and will reduce the energy content by 10.9 MJ/kWp. This is due to the fact that 100 litres of diesel produces 0.27 tonnes of CO_2 (2.7kg CO_2/L) with energy content of 3.84 gigajoules (GJ). Diesel generators consume 0.284 L/kWh and so produce 0.76kg of CO_2/kWh with energy content of 10.9 MJ/kWp.

In addition, due to fuel shortage many municipalities deliver raw sewage to the sea, which has the following negative impacts:

1. Creates serious environmental health problems for residents who use the sea as a recreation area.
2. Decreases the number of residents who use the sea as a recreation area; will impact negatively on tourism and significantly reduce the jobs created from recreation, particularly in summer.
3. Pollution of seawater increases the cost of seawater desalination.

6.3 Technical feasibility

Having completed the data entry phase, the consultant applied a scientific approach to the selection of the most feasible WASH facilities' requirements for installation of a PV solar system. The selection process used multi-criteria analysis, a valuable tool that can be used to make complex decisions with several criteria inputs. It is a logical process that mainly utilizes the analytical hierarchy process (AHP), which has a built-in consistency checking test.

As stated in the methodology chapter, the consultant calculated the feasibility index (FI) for each facility. The following example shows how the consultant computed the FI index for water pump stations.

Example of calculating FI for water pump stations

The consultant collected the facility data from the municipality and CMWU. The basic data collected is listed below in Table 6.13.

Table 6.13 – Water pump station basic data

Data	Value
WPS code	RF.1.WP.06
WPS name (English)	Rafah UNDP P.S (Tel Sultan)
WPS name (Arabic)	رفح الوكالة - تل السلطان
Governorate	Rafah
Municipality	Rafah
Beneficiary	Rafah
WPS capacity (m^3/hr)	520
Construction area m^2	1,604.5
Total electricity consumption (kWh)	100
Generator availability (Yes, No)	Yes
Daily operation electricity (Hr/Day)	4
Daily operation generator (Hr/Day)	2
Required operation (Hr/Day)	6

1. Land availability

To operate a 100 kW facility, we need a 130 kWp PV system.

The required area for generating 130 kWh from a PV system is 1,430m^2.

The available area for a PV system is 1,604.5m^2.

Note: The maximum percentage is not more than 100%.

$$C1 = Min\left(\frac{available\ area}{required\ area}, 100\%\right) \times 10 = \left(\frac{1604.50}{1430}\right) \times 10 = 10$$

2. Hours of facility operation

The total required operation hours of facility is 6 hours.

$$C2 = \frac{6}{24} \times 5 = 1.25$$

3. Operational hours of generator

The total daily operation of the generator is 2 hours, and:

$$C3 = \frac{2}{24} \times 3 = 0.25$$

4. Cost of production

The computed consumption power cost/facility capacity is \$0.03/m^3. Using Table 3.3, the value is between (0.01–0.04), the weight is 0.8:

$$C4 = 0.8 \times 3 = 2.4$$

5. Facility capacity

The capacity of the well is 520m^3/hr. Using Table 3.8, the value ranges between 500 and 650; the weight is 0.8.

$$C4 = 0.8 \times 5 = 4$$

6. Feasibility index

$$\boldsymbol{FI = \frac{10+1.25+0.25+2.4+4}{26} \times 100 = 68.65\%}$$

For each facility the consultant prepared a data sheet presenting the data collected and calculations, with results as shown in Figure 6.1.

OXFAM

Enfra Consultants

Comprehensive Study of Renewable Energy Sources in Gaza's WASH Sector for Public and Private WASH Facilities					
Facility Sheet For Rafah Municipality (Rafah UNDP P.S (Tel Sultan)) Water Pump Station					
Water Pump Station Basic Information					
Municipality	Rafah	WBP Code	RF.1.WP.06	No. of Total WPS in the Municipality	8
Name (Eng)	Rafah UNDP P.S (Tel Sultan)	Name (Ar)	رفح الوكالة - تل السلطان	GOVERNORATE	Rafah
BENEFICIARY	Rafah	CAPACITY (m^3/hr)	520	X-coordinate	78373
Y-coordinate	80355	Construction area (m^2)	1604.5	Total power consumption (kwh)	100
Generator availability	Yes	Daily operation of electricity (hr/day)	4	Daily operation generator (hr/day)	2
No. Available Pumps	3	PUMP_TYPE	Vertical	Total cost electricity (USD/hr)	15.789
Water Pump Station Data Analysis					
Total Cost of Discharge (USD/m^3)	0.030	Production Cost Percentage	80%	Total Daily Operation (hr)	6
Total Daily Operation (%)	60%	Production Capacity Percentage	80%	Gap Shortage Percentage covered by Generator	33%
Proposed System	On grid	Cost (USD/KW)	700	Capacity of the needed PV System (KW)	130
Capacity of the Available Area for PV System (KW)	145	% of the Available Area for PV System (%)	100%	Needed Area (m^2)	1430.00
Shortage of Area (m^2)	-174.500	operational hours of the PV system	5.31	Total energy produced from the PV (KW)	690.30
Capital Cost ($)	$ 91,000.00				
Water Pump Station Feasibility Results					
Land Availability	10.00	Operational Hours of Facility	1.25	Operational Hours of Generator	0.25
Production Cost Score	2.40	Production Capacity Score	4.00	Total Score Feasibility	68.85%
Final Feasibility Score					
The Final Decision result of the feasibility For (Rafah UNDP P.S (Tel Sultan)) Water Pump Station is					Feasible

Figure 6.1 – Facility data sheet

Table 6.14 indicates the FI for each facility. The consultant classified the FI into three categories (40% or less; 40% to 60%; and more than 60%).

Table 6.14 – Summary of feasibility index for each facility

Facility	40% or less	40% to 60%	More than 60%
Water wells	95	128	43
Public desalination plants	15	30	7
Private desalination plants	10	7	4
Wastewater pump stations	10	30	9
Water pump stations	8	19	15
Total	**138**	**214**	**78**

According to Table 6.14 and FI calculations, the FI of 138 facilities is less 40%, there are 214 facilities between 40% and 60%, and 78 facilities score more than 60%. Based on this, 78 WASH facilities are feasible to install a PV system while 214 are moderately feasible and 138 are not feasible to install PV.

The consultant developed an excel data sheet to show the feasibility index for each facility, as shown in Annex 4.1. Annex 6.2 shows the feasible facilities (wells, water pump stations, sewage pump stations, public and private desalination plants). The results are classified by facility type, governorate and municipality.

UN critical facilities

Life-saving services in Gaza currently depend on the UN's delivery of emergency fuel, due to an energy crisis that affects the two million Palestinian residents of Gaza, as grid availability ranges from 25% to 75% per day. Based on the current electricity deficit in Gaza, a minimum of $4.5m (https://www.ochaopt.org/) is required to sustain these essential services until the end of the year.

Without fuel, people will potentially be affected by serious public health concerns as sewage could overflow onto streets. Overall, water and wastewater services are dropping to less than 20% of capacity and water availability is dropping below 50 litres per capita per day, less than half of the minimum requirement according to the WHO. Additionally, some essential infrastructure risks significant damage due to lack of fuel to operate key parts, with potential loss of donor investments as a result (https://www.ochaopt.org/).

Most critical WASH facilities in the Gaza Strip receive fuel from the UN system. In 2018, 186 facilities received about 2.04 million litres of fuel. According to the above technical feasibility calculations on WASH facilities, the consultant found that there are 81 technically feasible and moderately feasible critical WASH facilities to be targeted with solar PV systems. Tables 6.15–6.18 show the critical WASH facilities where installation of a PV system is feasible and moderately feasible.

Table 6.15 – Feasible and moderately feasible critical sewage pump stations

Sewage pump stations					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
GZ.2.SP.09	Sewage PS 7B (Al-Zayton)	Gaza	181	Moderately feasible	162,900
GZ.2.SP.01	Sewage PS5 (Al-Baqqara)	Gaza	136	Moderately feasible	122,400
GZ.2.SP.06	Sewage PS6A (Al-Samr)	Gaza	50	Moderately feasible	45,000
GZ.2.SP.05	Sewage PS1 (Al-Montada)	Gaza	109	Moderately feasible	98,100
MG.1.PS.01	Al Moghragah sewage pump station	Al Moghraqa	63	Moderately feasible	56,700
KH.2.SP.01	Hesbat Elsamak sewage pump station	Khanyounis	81	Moderately feasible	72,900
KH.2.SP.04	Al Maqaber sewage pump station	Khanyounis	13	Moderately feasible	9,100
BJ.2.SP.02	Block 12	Al Buraij	2	Moderately feasible	1,800
BJ.2.SP.01	Block 7	Al Buraij	2	Moderately feasible	1,800
NU.2.SP.02	Al Hasaiyna sewage pump station	Al Nusirat	72	Moderately feasible	64,800
NU.2.SP.01	New Camp PS	Al Nusirat	30	Moderately feasible	24,000
DB.2.SP.02	Al Basa sewage pump station	Dear AlBalah	45	Moderately feasible	40,500
DB.2.SP.01	Al Berka sewage pump station	Dear AlBalah	50	Moderately feasible	35,000
BL.2.SP.05	Aslan 5 sewage pump station	Bait lahia	45	Moderately feasible	31,500
JB.2.SP.01	Abu Rashed PS	Jabalia	260	Feasible	234,000
JB.2.SP.04	Hawaber PS	Jabalia	63	Feasible	56,700
JB.2.SP.06	Mahader PS	Jabalia	40	Moderately	36,000

Sewage pump stations					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
				feasible	
ON.2.SP.01	Um Al Nassir pump satation	Um Al Nasser	36	Moderately feasible	25,200
RF.2.SP.02	Jumizit Al Sabiel PS	Rafah	98	Feasible	88,200
RF.2.SP.04	Tal Al Sultan PS	Rafah	61	Feasible	54,900
RF.2.SP.03	Al Juninah PS	Rafah	59	Feasible	53,100
RF.2.SP.01	Block O PS	Rafah	17	Moderately feasible	13,600
RF.2.SP.05	UNDP PS	Rafah	13	Moderately feasible	10,400
($) Total capital cost					1,338,600

Table 6.16 – Feasible and moderately feasible critical water pump stations

Water pump stations					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
KH.1.WP.01	Al Sa'ada booster	Khanyounis	169	Feasible	152,100
KH.1.WP.03	Al Rahma booster	Khanyounis	72	Moderately feasible	64,800
KH.1.WP.02	Ma'an booster	Khanyounis	78	Feasible	70,200
BS.1.WP.02	Bani Suhaila new booster	Bani Suhaila	45	Moderately feasible	40,500
BS.1.WP.01	Eastern booster station-regional	Bani Suhaila	26	Feasible	23,400
RF.1.WP.05	Rafah ground tank	Rafah	143	Feasible	100,100
				($) Total capital cost	451,100

Table 6.17 – Feasible and moderately feasible critical wells

Wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
GZ.1.PW.01	Al Shajaia 2 water well	Gaza	54	Feasible	105,300
GZ.1.PW.03	Al Shajaia 4 water well	Gaza	30	Moderately feasible	34,300
GZ.1.PW.24	Al Shaekh Ejleen 5 water well	Gaza	45	Feasible	44,100
JB.1.PW.11	Sheikh Radwan water well no. 10w	Gaza	28	Moderately feasible	128,700
GZ.1.PW.82	Sheikh Radwan water well no. 14	Gaza	36	Moderately feasible	64,800
BL.1.PW.01	Sheikh Radwan water well no. 15	Gaza	36	Moderately feasible	171,000
GZ.1.PW.30	Al-Safa water well no. 5 (Zimmo)	Gaza	25	Moderately feasible	171,000

Wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
MG.1.PW.01	Mun. F203	Al Moghraqa	18	Moderately feasible	45,900
MG.1.PW.02	Al Kauthar well F264	Al Moghraqa	71	Feasible	63,900
ZH.1.PW.04	Shoblaq water well	Al Zahra	3	Moderately feasible	10,800
WG.1.PW.01	Wadi Gaza	Wadi Gaza	32	Moderately feasible	28,800
KH.1.PW.08	Al Kewaity water well	Khanyounis	13	Moderately feasible	38,700
KH.1.PW.27	Al Rahma well	Khanyounis	13	Moderately feasible	58,500
KH.1.PW.10	EV2	Khanyounis	22	Moderately feasible	63,900
KH.1.PW.11	EV3	Khanyounis	22	Moderately feasible	88,200
KH.1.PW.01	Eastern well	Khanyounis	81	Moderately feasible	80,100
AN.1.PW.01	Abassan Al Jadida N-04	Abasan Al Jadidah	45	Moderately feasible	45,500
RF.1.PW.12	Al Fukhari	Al Fohkari	22	Moderately feasible	40,500
QR.1.PW.02	Al Matahin	Al Qarara	72	Feasible	64,800
WS.1.PW.01	Wadi Salqa	Wadi Alsalqa	21	Feasible	18,900
MU.1.PW.01	Al Mussadar	Al Musader	31	Moderately feasible	41,400
ZW.1.PW.03	Khalid Ibn Al Walied water well	Al Zawayda	18	Moderately feasible	27,300
ZW.1.PW.01	Al Zohor water well H90	Al Zawayda	20	Moderately feasible	35,100

Wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
BJ.1.PW.01	Miun. S72	Al Buraij	9	Moderately feasible	53,100
MZ.1.PW.04	S-80Mohammed	Al Maghazi	27	Moderately feasible	34,300
MZ.1.PW.03	S-82 Al Buhairi water well	Al Maghazi	45	Moderately feasible	32,200
NU.1.PW.05	Al Faroq F-225	Al Nusirat	18	Moderately feasible	32,400
ZH.1.PW.03	Al Zahra water well F-208	Al Nusirat	2	Moderately feasible	35,700
DB.1.PW.10	Al Sahil4	Dear AlBalah	13	Moderately feasible	19,800
DB.1.PW.12	Al Sahil 5	Dear AlBalah	13	Moderately feasible	33,300
DB.1.PW.02	Abu Marwan water well	Dear AlBalah	26	Feasible	18,200
MZ.1.PW.08	Al Montaza water well	Al Maghazi	27	Moderately feasible	36,900
BH.1.PW.09	Ayda water well	Bait Hanoun	45	Moderately feasible	70,200
BL.1.PW.03	Al Mashrou water well	Bait lahia	90	Feasible	131,400
BL.1.PW.09	Al Shekh Zayed water well	Bait lahia	45	Moderately feasible	88,200
BL.1.PW.06	Al Atatra water well	Bait lahia	45	Moderately feasible	45,000
JB.1.PW.01	Al Khazan water well	Jabalia	27	Moderately feasible	46,800
JB.1.PW.06	Al Zohor water well	Jabalia	23	Feasible	34,200
JB.1.PW.05	Amer water well	Jabalia	36	Moderately	36,900

Wells					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
				feasible	
JB.1.PW.04	Abu Talal water well	Jabalia	8	Moderately feasible	49,500
ON.1.PW.01	Um Al Nassir	Um Al Nasser	13	Moderately feasible	53,100
RF.1.PW.14	Al Nassir 1	Al Nasser	45	Moderately feasible	70,200
RF.1.PW.11	Al Shouka well	Al Shoukah	59	Feasible	53,100
RF.1.PW.31	Al Malizei well	Al Shoukah	59	Feasible	53,100
RF.1.PW.03	Abu Hashem water well P124	Rafah	118	Feasible	106,200
RF.1.PW.09	Abu Zohri water well P138	Rafah	56	Moderately feasible	57,600
RF.1.PW.10	Al Hashash water well P145	Rafah	24	Moderately feasible	51,300
RF.1.PW.07	Al Eskan water well P153	Rafah	66	Feasible	59,400
RF.1.PW.04	Canada P 144	Rafah	24	Feasible	21,600
RF.1.PW.06	PWA well	Rafah	37	Moderately feasible	79,200
($) Total capital cost					2,874,400

Table 6.18 – Feasible and moderately feasible critical public desalination plants

Public desalination plants					
CMWU code	Facility name	Municipality	Proposed PV (kW)	Feasibility	Capital cost ($)
RF.1.DP.02	Al Salam desalination plant	Rafah	72	Moderately feasible	70,200
RF.1.DP.01	Al Shoot desalination plant	Rafah	55	Moderately feasible	49,500
				($) Total capital cost	119,700

7 Conclusions and recommendations

This study, entitled ‘Comprehensive Study of Renewable Energy Sources in Gaza’s WASH Sector for Public and Private WASH Facilities’, obtained significant findings. The following paragraphs present the main findings of the study along with its conclusions and recommendations.

The literature review showed that direct technology to generate electricity is optimally achieved through installing solar PV technologies, and this is also recommended for producing electricity in the Gaza Strip. The study therefore gave this type of technology its full consideration.

OPT has a high solar energy potential because the average solar energy ranges from 2.87 kWh/m^2 per day in December to 8.07 kWh/m^2 per day in June, and the daily average solar radiation intensity on a horizontal surface, peak sunshine hour (PSSH), is 5.31 kWh/m^2 per day.

There are 438 WASH facilities in the Gaza Strip, including 266 water wells, 52 public desalination plants, 21 private desalination plants, 42 water pump stations, 49 wastewater pump stations and 8 wastewater treatment plants. Most public facilities (417 facilities) use generators to bridge the shortage of the public electricity grid. There are 359 diesel generators operating for more than 3 hours per day.

The consultant found that from 2013 to 2017, there were approximately 330 projects installing PV systems for public and private institutions in the Gaza Strip, with a total capacity of about 5,611 kWp.

There are many suppliers of PV technology in the Gaza Strip; all of them are private sector. The local market has a high capacity, and professional knowledge and experience regarding PV systems and installation are developing. Currently, there are some suppliers who have established workshops for repair and maintenance. The available equipment is of high quality and complies with local and international standards. All equipment is imported from well-known manufacturers, including some brand names. The capacity of local suppliers is still limited and capacity building is needed for people working in this sector, such as suppliers, engineers and contractors, etc. Capacity building is also required for energy management.

Existing power resources provide 25–75 % of the daily demand. Therefore, WASH facilities face a serious problem as diesel fuel for generators, usually used during electricity shortage periods, is expensive and not continuously available, due to the political and financial circumstances.

The consultant computed the capital and operational costs of PV systems for 20 years, assuming that the capital cost is $1,200/kWp and the maintenance cost is $60/year (5% of capital cost) for 20 years (the lifetime of the system). The cost of producing 1 kWh from a PV system was found to be 0.3 NIS/kWh for WASH facilities except sewage pump stations, where the cost reached 0.71 NIS/kWh.

The Net Present Value (NPV) of a PV system for WASH facilities except sewage pump stations ranges from $2,209 to $4,582/kWp, with a payback period of 3 to 5 years. The NPV of sewage pump stations ranges from minus $75 to $942/kWpkWp, with a payback period of 7 to 14 years. Implementation of feasible projects will result in 9.75 Mwh of energy savings annually. Feasible and moderately feasible projects will save 29.6 Mwh per year.

The cost of generating electricity from diesel generators ranges from 1.4 to 1.8 NIS/kWh. The consultant estimated an average cost of 1.6 NIS/kWh.

The study showed that installing PV systems would reduce the production of CO_2 by 0.76kg of CO_2/kWh and reduce the energy content by 10.9 MJ/kWp. This is due to the fact that 100 litres of diesel produces 0.27 tonnes of CO_2 (2.7kg CO_2/L), with energy content of 3.84 gigajoules (GJ). Diesel generators consume 0.284 L/kWh and so produce 0.76 kg of CO_2/kWh and energy content of 10.9 MJ/kWp.

Based on the technical feasibility study, 78 WASH facilities are feasible for installing a PV system, while 214 are moderately feasible and 138 are not feasible to install PV. Most critical WASH facilities in the Gaza Strip receive fuel from the UN system; in 2018, 186 facilities received about 2.04 million litres of fuel. Of the critical WASH facilities, 81 are technically feasible and moderately feasible tfor installation of solar PV systems. The cost of implementation of feasible and moderately feasible facilities is about $9m, while the cost of implementation of feasible facilities is about $4.7m.

This study is considered as providing the baseline for further installation of solar energy systems for any WASH facilities. The classification of WASH facilities in this study as feasible, moderately feasible and not feasible can guide all agencies interested in providing WASH facilities with solar energy.

Based on the findings of the study, an action plan for implementing solar energy projects as a priority action should be prepared for WASH facilities throughout the Gaza Strip. It is recommended that this commences with a selected group of facilities (5 to 10 facilities) as a pilot for monitoring over a certain period.

The capacity of the private sector (designers, suppliers and operators) requires enhancement through technical, marketing and managerial capacity-building programmes. This capacity building could be carried out locally, regionally or internationally.

The findings of study can be considered as a roadmap to help identify the necessary next actions, which have to be agreed among the WASH Cluster, PWA and any other stakeholders.

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Annexes

Annex no.	Description	Availability
3.1	Schedule of the conducted field visits	See below
3.2	Collected data of WASH facilities	Excel file available on request: Wassem.Mushtaha@oxfam.org
3.3	Checklist template	See below
3.4	Water quality of water wells	See below
4.1	Proposed PV system and feasibility index for each facility	Excel file available on request:
6.1	Financial analyses of WASH facilities	Excel file available on request
6.2	Feasible WASH facilities	Word file available on request

Annex 3.1 – Schedule of the conducted field visits

Visits plan			
ENFRA team (project manager & water engineers)	Sunday, 21 /10/ 2018	2:00 pm to 3:00 pm	Coastal Municipality Water utility
	Wednesday, 31/10/2018	10:00 am to 11:00 am	PENRA, Gaza
	Wednesday, 31/10/2018	12:00 pm to 1:00 pm	PWA Office, Gaza
ENFRA Team (electrical engineer) with international experts	Tuesday, 06/11/2018	9:00 to 10:00 am	OCHA team
	Tuesday, 06/11/2018	10:00 to 11:30 am	Al Amal Desalination plant
	Tuesday, 06/11/2018	11:30 to 12:00 am	WASH Cluster Coordinator
	Tuesday, 06/11/2018	12:00 am to 12:30 pm	Coastal Municipality Water Utility
	Tuesday, 06/11/2018	12:30 pm to 3:00 pm	some WASH facilities
	Wednesday, 07/11/2018	10:00 to 11:00 am	Palestinian Water Authority staff, Ramallah
	Wednesday, 07/11/2018	11:30 am to 1:00	Two private companies
	Wednesday, 07/11/2018	1:00 pm to 2:00	Abdel Salam Yaseen Company
ENFRA team (project manager & water engineers)	Tuesday, 06/11/2018	12:30 pm to 1:30 pm	Coastal Municipality Water Utility
	Saturday, 10/11/2018	12:00 pm to 1:30 pm	Abdel Salam Yaseen Company
	Sunday 11/11/2018	12:00 pm to 1:00 pm	Action Against Hunger
	Sunday 11/11/2018	1:00 pm to 2:00 pm	PENRA, Gaza

Annex 3.3 – Checklist template

Check List for Comprehensive Study of Renewable Energy Sources in Gaza's WASH Sector for Public and Private Water	
Facility General Information	
Visit Data: Location (Coordinates)	Visit time:
About the operators	
Background Qualification:	Years of experience:
No. of operators:	
Facility technical information	
Unit type: ☐ Wells ☐ Public Desalination plants (brackish) ☐ Private Desalination plants (brackish) ☐ Water Pump Stations ☐ sewage Pumping Station ☐ Wastewater Treatment plants	Capacity: ☐
Source of Power ☐ GRID , Subscription rate ☐ ☐ PV System, Type of PV System ☐ ☐ Generators, No of Generators ☐ , Generators rates ☐ ☐ Other	
Power needed \ KW \ HP ☐ Pumping ☐ Desalination Units ☐ Other	
Power consumption ………	
Running Operating ……………hours\day …………Day /Night Total Area available: ……… Roofs: ……….. Land:……… Is There an Obstacles toward south yes / no	
Statues Current statues: ☐ Active ☐ Stop Parts need maintenance:	

Annex 3.4 – Water quality of water wells

Table 1 – Gaza governorate water well nitrate concentrations

Range	WW nitrate concentration		Weight
From – to	85 or less		5
	>85	=1,500	4
	>1,500	=3,000	3
	>3,000	=4,700	2
	>4,700	=5,900	1
	More than 5,900		0

Table 2 – Gaza governorate water well chloride concentrations

Range	WW chloride concentration		Weight
From – to	40 or less		5
	>40	=90	4
	>90	=120	3
	>120	=160	2
	>160	=200	1
	More than 200		0

Table 3 – North governorate water well nitrate concentrations

Range	WBP Flow rate (m^3/hr)		weight
From – to	100 or less		0
	>100	=200	0.2
	>200	=350	0.4
	>350	=500	0.6
	>500	=650	0.8
	> 650	=800	1

Table 4 – North governorate water well chloride concentrations

Range	WW chloride concentration		Weight
From – to	250 or less		5
	>250	=600	4
	>600	=1,000	3
	>1,000	=1,500	2
	>1,500	=2,000	1
	More than 2,000		0

Table 5 – Middle Area governorate water well nitrate concentrations

Range	WW nitrate concentration		Weight
From – to	10 or less		5
	>10	=100	4
	>100	=150	3
	>150	=200	2
	>200	=300	1
	More than 300		0

Table 6 – Middle Area governorate water well chloride concentrations

Range	WW chloride concentration		Weight
From – to	65 or less		5
	>65	=500	4
	>500	=1,000	3
	>1,000	=1,500	2
	>1,500	=2,050	1
	More than 2,050		0

Table 7 – Khanyounis governorate water well nitrate concentrations

Range	WW nitrate concentration		Weight
From – to	50 or less		5
	>50	=100	4
	>100	=150	3
	>150	=220	2
	>220	=380	1
	More than 380		0

Table 8 – Khanyounis governorate water well nitrate concentrations

Range	WW chloride concentration		Weight
From – to	100 or less		5
	>100	=600	4
	>600	=1,000	3
	>1,000	=1,500	2
	>1,500	=2,100	1
	More than 2,100		0

Table 9 – Rafah governorate water well nitrate concentrations

Range	WW nitrate concentration		Weight
From – to	15 or less		5
	>15	=100	4
	>100	=150	3
	>150	=200	2
	>200	=300	1
	More than 300		0

Table 10 – Rafah governorate water well chloride concentrations

Range	WW chloride concentration		Weight
From – to	120 or less		5
	>120	=300	4
	>300	=500	3
	>500	=800	2
	>800	=1,000	1
	More than 1,000		**0**

For further information on the issues raised in this paper please email Wassem Mushtaha (WASH Programme Manager) Wassem.Mushtaha@oxfam.org)

Published by Oxfam GB for Oxfam International under
ISBN 978-1-78748-466-5 in July 2019. DOI: 10.21201/2019.4665
Oxfam GB, Oxfam House, John Smith Drive, Cowley, Oxford, OX4 2JY, UK.

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