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TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Numerical modelling to better understand urban water systems

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Humanitarian response to the Syria crisis lacked means to define deficiencies of urban water services/systems. Suitable numerical models were developed to better understand sector performance, analyse the different components of the dynamic systems and measure the impact of repairs and rehabilitation works. Indicators were used to define performance levels of the main components, which are in turn converted into various composite indicators defining the Adequacy, Efficiency and Dependability of water systems. Collected data was used to analyse the performance of systems and highlight bottlenecks and shortcomings to better address their needs. The numerical models could systematically measure repair/rehabilitate effects. Models could also be used for setting priorities and allocating budgets to suit different priority perspectives. These uses made it possible to adapt a systematic approach to set priorities and to planning in general and understand the effects of humanitarian and/or early recovery works in this domain.

Introduction

Urban water systems in Syria, like many of those across the Middle East and North Africa region, are characterized as being dynamic and complex in the way they operate. Systems in Syria are state-owned and managed, and required high operational costs as well as a mix of qualified human resources. Prior to the start of the civil war, Syria had achieved high water coverage rates and provided high quality water services. However, since 2011, the conflict has led to fast deterioration in these systems due to a sharp decline in the availability of mentioned resources and also as a result of the partial collapse of the electricity sector. The humanitarian response to the crisis lacked the scope and the means to adequately address water service needs of this level of sophistication. Support was patchy and unregulated; only focusing on hardware components, though to its credit, prevented a faster deterioration of the sector. Defining the impact of the humanitarian work, which is key to attract donors' attention, presented another difficulty due to the absence of a measurement tool. UNICEF, with the WASH Cluster decided to pursue a suitable methodology that could help demystify this complexity through the systemization of this intricacy. Numerical modelling was identified as best suited for this purpose.

Methodology

A sustainably functional urban water supply system requires a harmonious interaction between its four (4) main cornerstones, namely, Infrastructure, recurrent operations and maintenance O&M works, Human resources, and Cash/Financial resources. These cornerstones are composed of different components that are simulated into indicators with values mainly defining how efficient and/or sufficient they were in providing the intended services and whether these services were dependable.

The numerical model was designed to define the characteristic of the modern, dynamic and complex water systems in Syria through indicators simulating the various components/stages of water systems and composite indicators defining Adequacy of service (e.g. service coverage and daily water per capita share), Efficiency of performance (how civil and electro-mechanical components are delivering up to their full potential), Dependability of the design configuration (e.g. is siting correct to minimize contamination risks, standby equipment are in place to minimize shutdown risk) and operation and maintenance (O&M) activities (availability of treatment chemicals, spare parts, treatment chemicals, etc), and the cadre (in numbers and knowledge/experience) that manages and operates these systems.

A composite indicator represents a combination of indicators for a set of components that collectively contribute to a similar cause or deliver a certain duty for water service, such as the Infrastructure efficiency composite indicator. In the formation of the composite indicator, each single indicator was assigned a weight. This weight is reflective of the component's impact on the system's efficient performance as well as its cost. Assigning weights to different components were agreed upon following an empirical debate by sector professionals and engineers. Table 1 shows an example of components/indicators and weights of a Well/Spring water station. Ultimately, the efficiency (or efficient performance) of an individual water infrastructure could be compared to others using a number/percentage that defines how good or bad this infrastructure is against an ideal efficiency level of 100%; e.g. simply, a water station with an Infrastructure Efficiency composite indicator of 85% is able to better perform, from an infrastructure angle, than another with an indicator of 50%. Furthermore, several composite indicators could be combined to define a perspective of the system's overall performance; e.g. infrastructure efficiency, O&M dependability, power efficiency, etc. Assigning different weights to a group of indicators and composite indicators, to form an overall composite indicator, avail a certain perspective from which a planner wishes to evaluate the performance of a system. For example, forming an overall composite indicator for investment plans and subsequent budgetary allocations aiming at improved infrastructure would be different from an investment plan aiming at improved operations and maintenance quality or increased per capita share. All systems' indicators are further weighed to take scale into account using numbers of population they serve.

Table 1. Infrastructure efficiency indicators

Station component/indicator	Weight
Water tank/s structural condition	10%
Condition of well submersible pumps	16%
Condition of highlift pumps	13%
Condition of water hammer	5%
Wells/casing condition	10%
Central control panel condition	8%
Power cable(s) condition	5%
High and low tension transformers condition	10%
Chlorination system condition	8%
Valves and piping system condition	8%
Structural integrity of civil works	7%
Total	**100%**

For a more holistic understanding of how efficient a water station infrastructure is, a composite indicator is formed comprising of all the individual components/indicators (Table 1) to represent "Infrastructure efficiency composite indicator" using the following equation:

$I_C = (W_1 \times I_1 + W_2 \times I_2 + W_3 \times I_3 + \ldots + W_N \times I_N)/\Sigma\, W_{1\text{–}N}$, where W_N is weight of the N^{th} component's efficiency indicator (I_N), rated against a scale of 0 (the component is out-of-order) to 10 (perfect operational status), I_C is the infrastructure efficiency composite indicator and $W_1 + W_2 + W_3 + \ldots + W_N = 100\%$.

The definition of the various indicators/composite indicators is presented in the following:

- **Efficiency indicators:** Aimed at measuring the operational (performance) status of the different components of the infrastructure, individually and as a group. Indicators were rated and weighed as explained above.
- **Dependability indicators:** The model adapted two (2) sets of indicators. The first aimed for measuring system's dependability to deliver sustained service as a result of its design/configuration and location including exposure to risks. The second aimed at measuring system's dependability to deliver sustained service as a result of availability of qualified cadre, operations and maintenance plans, spare part, consumables and cash.
- **Adequacy indicators:** Aimed to quantify the service received at the location served by the system(s). The model measures two (2) types of indicators in an indirect manner using census-type population figures. The first is water coverage; to identify percentage of served population (was not measured due to the absence of total population figures), while the second is the estimated per capita share of water.

Tables 2–5 below, show components/indicators and weights for different composite indicators.

Table 2. Design/configuration dependability indicators

Components/indicator	Weight
Network design sufficiency	15%
Standby submersible pumps	20%
Standby horizontal pumps	20%
Standby chlorinators	10%
Backup generator	15%
Water quality	11%
Wastewater effluent close to wells	4%
Safety measures	5%
Total	**100%**

Table 3. O&M dependability indicators

Components/indicator	Weight			
	Total	Station (75%)	Market (25%)	General
Availability of purification chemicals	20%	15%	5%	
Availability of running spare parts and tools	16%	12%	4%	
Availability of fuel and oil for generators	25%	18.75%	6.25%	
Availability of Cash	18%			18%
O&M plan of action	13%			13%
Mobility of maintenance team	8%			8%
Total	**100%**	**45.75%**	**15.25%**	**39%**

Table 4. Human resources indicators									
Weight									
HR category	**Category weight**	**Number of members adequacy indicator**	**20%**	**Experience indicator**	**30%**	**Skills indicator**	**40%**	**Need for training indicator**	**10%**
Engineer	15%								
Technician	35%	Non-existent	0%	Poor	20%	Poor	20%	Comprehensive training	90%
Operator	30%	Inadequate	40%	Moderate	50%	Moderate	50%	Training in some of the core themes	50%
Admin	10%	Adequate	100 %	Good	80%	Good	80%	Only refresher courses	10%
Storekeeper	10%								

Table 5. Electrical power efficiency indicators		
Power indicator		
Average power supply from the national grid (hours/day)		
Standby power generator available in the station?	☐ Yes	☐ No
Average power supply by the generator (hours/day)		
Percentage (%) of station production capacity covered by generator power supply		

Results

Three (3) models were developed to collect and process data from three (3) types of water facilities—Well/Spring Pumping Stations using underground water; Water Treatment Stations using surface water bodies; and Boosting Stations, usually used to add pumping pressure to water delivered to remote or elevated areas. Models also aimed at collecting some identity parameters and other individual indicators such as names, locations, served areas, depths of pumps, design capacities, among others.

Indicators were used to to analyse the situation of the water sector and highlight some sectoral bottlenecks and shortcomings that negatively affected water supply services to population, as follows:

The table below displays an empirical methodology to show the effects of the efficiencies of the different factors on the maximum production capacity. The production capacity will be factored using indicators/ composite indicators on infrastructure efficiency, electrical power supply efficiency and network efficiency. The variation of the referenced indicators in the different governorates give a numeric status comparison between the different aspects of water systems. Comparisons here are made between different governorates but could be applied to any geographic unit. For planning purposes, lower efficiencies (individually or collectively) could be used to prioritize interventions. It's clear from the results that electrical power efficiency alone is just above one third of how it should be while the infrastructure in less than 50% of its efficiency.

Table 6. Infrastructure, electricity and water network efficiency			
Governorate	**Infrastructure efficiency composite indicator**	**Power efficiency indicator**	**Water network efficiency**
Aleppo	58.9%	38.7%	71.2%
Al-Hasakeh	56.4%	71.2%	77.1%
Ar-Raqqa	27.3%	16.9%	71.4%
Dar'a	65.2%	47.6%	53.9%
Deir-ez-Zor	52.1%	12.1%	51.6%
Hama	51.8%	41.1%	65.0%
Homs	44.5%	41.9%	72.9%
Idleb	57.9%	37.3%	67.7%
Quneitra	43.7%	26.8%	57.9%
Rural Damascus	42.5%	4.1%	70.1%
Total	**48.8%**	**38.5%**	**67.8%**

Table 7. Operations and Maintenance dependability				
Governorate	**O&M indicator**	**Human resources indicator**	**Cash availability**	**Spare parts availability**
Aleppo	23%	35%	28%	10%
Al-Hasakeh	33%	49%	45%	27%
Ar-Raqqa	9%	23%	5%	2%
Dar'a	13%	41%	7%	1%
Deir-ez-Zor	13%	14%	7%	25%
Hama	16%	36%	16%	6%
Homs	24%	26%	34%	23%
Idleb	25%	47%	16%	9%
Quneitra	20%	19%	38%	1%
Rural Damascus	7%	46%	9%	12%
Total	**19%**	**37%**	**18%**	**12%**

Other indicators on O&M dependability, human resources and availability of cash and spare parts are also shown in Table 7. As could clearly be seen, all elements that contribute to proper daily operations and maintenance of water systems are of low dependability levels.

One of the important indicators is the adequacy indicator used to evaluate the level of water service. The daily per capita share of water measured in litres/day was used. The per capita share was calculated through a proxy process using the maximum production capacity per facility, factored using the following indicators:

The infrastructure efficiency indicator, The power factor indicator, The network efficiency and calculated using the Number of population benefiting from each facility.

Accordingly, the per capita share at any geographic level was calculated as follows:
PCS = MPC × IE × PE × NE × 1,000 / P
Where,
PCS =Per capita share in litres/day
MPC = Maximum production capacity of the facility in m^3/day
IE = Infrastructure efficiency composite indicator (%)
PE = Power efficiency taking into account national grid and standby power generation (%)
NE = Estimated water network efficiency (%)
P = Number of served population at any given geographic level

Calculations were made at community level and the following results obtained for numbers of people and their respective service levels.

Table 8. Daily per capita share of water

Governorate	Number of beneficiaries	Average per capita share (litres/day)	Dangerously critical (< 5 l/day)	Critical (5–20 l/day)	Barely sufficient (20–30 l/day)	Sufficient (30–40 l/day)	Comfortable (> 40 l/day)
Aleppo	1,282,691	20	656,235	269,090	76,060	94,450	186,856
Al-Hasakeh	856,909	126	37,339	27,730	240,660	11,980	539,200
Ar-Raqqa	805,377	15	520,455	125,132	8,220	15,810	135,760
Dar'a	664,310	56	150,790	91,700	185,100	64,500	172,220
Deir-ez-Zor	736,760	11	424,445	166,845	111,820	320	33,330
Hama	211,035	40	75,195	29,500	26,700	9,900	69,740
Homs	290,180	18	67,350	139,250	62,100	5,600	15,880
Idleb	1,683,605	38	460,304	362,805	142,305	180,965	537,226
Quneitra	133,315	5	94,500	33,395	240	2,330	2,850
Rural Damascus	353,440	6	320,440	0	0	0	33,000
Total	**7,017,622**	**39**	**2,807,053**	**1,245,447**	**853,205**	**385,855**	**1,726,062**

Examples on how to use numerical models results for planning purposes.

1. **Measuring Impact:** Table 9 represents a comparison of selected indicators for a UNICEF-supported water system, where rehabilitation and O&M support were provided. It could be noted how an impact on a coplex system could be demonstrated using the language of numbers; a rather easy way to explain results especially to lay people.

Table 9. Measuring impact of rehabilitation and O&M support

Kafr Naseh Station	Max. product Capacity (m^3/day)	Max # of daily working hours	Infra-structure efficiency	National power available	Genset power available	Power factor Infra-indicator	Network losses	Design dependability Indicator	O&M dependability Indicator	Number of beneficiaries
Before rehabilitation	600	20.0	38%	0%	0%	0%	23%	34%	32%	7,000
After rehabilitation	600	20.0	81%	0%	25%	20%	18%	50%	72%	7,000

2. **Resource Allocation:** Let's assume that a donor wishes to allocate 60M to 10 governorates. The donor has set a criteria whereby more weight is given to improve the efficiency of the infrastructure (say 70%) while 30% is given to enhance the status of the O&M activities for sustainability purposes.

   Accordingly, a new composite indicator will be created to factor in the criteria components (more components could be added as deemed necessary). Indicators will be used to calculate coefficients which, in turn, will be used to calculate a new composite indicator representing a "level of need" for each beneficiary in the respective governorates. In the case of infrastructure efficiency for example, the lowest Infrastructure efficiency indicator will secure a maximum coefficient value of 70% (Ar-Raqqa in this case). The same for the O&M indicator, which will secure a maximum coefficient value of 30% for Rural Damascus which has the lowest O&M efficiency value. The resulting level of need (the resulting sum of infrastructure and O&M coefficients) for the governorates along with the corresponding budget allocation is as shown. Needless to say, any number of governorates could be selected. Also, allocation could be made to smaller geographic units within one governorate using the same logic.

Table 10. Allocation of financial resources

Governorate	No. of beneficiaries	Infrastructure efficiency	O&M dependability Indicator	Infrastructure coefficient	O&M coefficient	Level of need	Budget allocation
Aleppo	1,282,691	58.9%	22.7%	39.5%	24.9%	64.5%	9.91 M
Al-Hasakeh	856,909	56.4%	32.9%	42.0%	21.6%	63.6%	6.53 M
Ar-Raqqa	805,377	27.3%	9.5%	70.0%	29.2%	99.2%	9.57 M
Dar'a	664,310	65.2%	13.0%	33.5%	28.1%	61.5%	4.90 M
Deir-ez-Zor	736,760	52.1%	13.5%	46.1%	27.9%	74.0%	6.53 M
Hama	211,035	51.8%	15.6%	46.4%	27.2%	73.6%	1.86 M
Homs	290,180	44.5%	23.6%	53.4%	24.6%	78.0%	2.71 M
Idleb	1,683,605	57.9%	24.7%	40.5%	24.3%	64.8%	13.08 M
Quneitra	133,315	43.7%	19.5%	54.2%	25.9%	80.1%	1.28 M
Rural Damascus	353,440	42.5%	6.9%	55.3%	30.0%	85.3%	3.62 M
Total	**7,017,622**						**60.00 M**

(Just straight away present your findings, then can give the example for illustration)

Lessons learnt

1. Using numerical models with indicators that define the efficiency and dependability of the water systems provides a systematic and simple, yet effective means of understanding the performance of water systems, define patterns of problems and to optimal use of resources to provide solutions.
2. Developing numerical models to cover more sub-sectors such as sewerage disposal and treatment, and solid waste disposal should be considered for the same reasons mentioned above.
3. The frequency of information updates should be sustained, to keep the information alive and relevant.
4. Further elaboration to capture finer sector details should always be considered when possible since it allows for finer analysis and better use of resources for more precise solutions to sector problems.
5. Correlating the data to water quality and water related disease indicators would add another layer of detail to the results
6. The use and integration of other sectors' indicators along with those of WASH to formulate composite Humanitarian and/or Development indicators would expand the use of this systematic approach.

Conclusion

A numerical model is the starting point for a systematic planning approach in the water sector and WASH at large. The methodology can systematically demonstrates the deficiencies in the water sector (or any related sector), using the simple power of numbers and in a way that is easily understood by laypeople. The survey database was used as a platform for measuring the impact resulting from any intervention to repair and/or rehabilitate the water systems by sector stakeholders and correlating financial inputs to efficiency, dependability and adequacy improvements. It is also being used by donors to justify their resource allocation strategies. This represents a systematic approach to planning, prioritization and resource allocation for reconstruction and/or development works.

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