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A decision model for selecting sustainable drinking water supply and greywater reuse systems for developing communities with a case study in Cimahi, Indonesia

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ABSTRACT

Capacity Factor Analysis is a decision support system for selection of appropriate technologies for municipal sanitation services in developing communities. Developing communities are those that lack the capability to provide adequate access to one or more essential services, such as water and sanitation, to their residents. This research developed two elements of Capacity Factor Analysis: a capacity factor based classification for technologies using requirements analysis, and a matching policy for choosing technology options. First, requirements analysis is used to develop a ranking for drinking water supply and greywater reuse technologies. Second, using the Capacity Factor Analysis approach, a matching policy is developed to guide decision makers in selecting the appropriate drinking water supply or greywater reuse technology option for their community. Finally, a scenario-based informal hypothesis test is developed to assist in qualitative model validation through case study. Capacity Factor Analysis is then applied in Cimahi Indonesia as a form of validation. The completed Capacity Factor Analysis model will allow developing communities to select drinking water supply and greywater reuse systems that are safe, affordable, able to be built and managed by the community using local resources, and are amenable to expansion as the community's management capacity increases.

1. Introduction: background & research motivation

The state of access to water and improved sanitation is painted with dismal statistics. Eight hundred eighty-four million people are without safe drinking water and 2.5 billion without improved sanitation (WHO and UNICEF, 2008), leading to 1.6 million deaths per year in low-income countries alone (WHO, 2009). Safe and adequate drinking water is essential to human health, is a basic human right (WHO, 2006), and is a necessary condition for disease reduction (Carter et al., 1999). Unimproved sanitation increases risk of exposure to diseases and contributes to environmental degradation (United Nations, 2001).

Improving access to water and sanitation has the potential to prevent 9.1% of the global disease burden and 6.3% of all deaths (Pruss-Ustun et al., 2008), and it is one of the least expensive and most effective means of improving global public health (Montgomery and Elimelech, 2007). The World Health Organization (WHO) estimates that it costs between USD$50 and USD$105 per person to provide access to water in rural and urban environments, respectively (Cotruvo et al., 1999). Using these values, providing complete new access would cost .09% of global GDP.[1]

The Millennium Development Goal Target 7c of Goal 7 is to "halve [the 1990]…proportion of people without sustainable access to safe drinking water and basic sanitation" by 2015 (Pruss-Ustun et al., 2008). Since 1990 there was a 1.8 billion absolute increase of the population served with improved water. This corresponds to a proportional increase of 9.6%, suggesting that the goal for water will likely be met by 2015 (WHO and UNICEF, 2008). However, even if this drinking water goal is met, there will remain an estimated 827 million without improved water by 2015 (see Table 1). Population growth creates a moving target and regional and international inequities. For example, in sub-Saharan Africa current trends indicate that by 2015 the number of people with access to improved drinking water will decrease by 47 million (WHO and UNICEF, 2006).

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[1] Calculated using 2008 gross domestic product (GDP) values from the International Monetary Fund (2009) data and statistics for 182 countries, and unimproved water access values of 743 and 140 million for rural and urban populations respectively from WHO and UNICEF (2008).

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Table 1
Improved drinking water access for 1990, 2008, and projection for 2015 if target is achieved.

	Year		
	1990	2008	2015[a]
World Population (billions)	5.3	6.7	7.3
Total population served with Improved Water (billions)	4.1	5.9	6.5
Total population with Unimproved Water (billions)	1.2	0.88	0.83
Proportion people without access	22.6%	13.1%	11.3%
Proportion of people with access	77.4%	86.9%	88.7%

[a] Values for 2015 are based on meeting Millennium Development Goal 7 of Target 10. Population projection data from the United Nations (2009).

In the case of improved sanitation, there was a 98 million gain[2] in the number of people with access from 1990 to 2004, when accounting for population growth. If current trends continue, the Millennium Development Goal target for access to improved sanitation will be missed by more than 500 million people, with increases by 2015 in the total number without access in Sub-Saharan Africa, Western Asia, and Oceania (WHO and UNICEF, 2004). As with drinking water supply, there are geographic inequities. For example, of the total population without access to improved sanitation, 2 billion live in rural areas (WHO and UNICEF, 2006).

1.1. *Need for holistic approach*

Contributing to the inability to provide sustained access to water and sanitation is the historically high failure rate for water and sanitation intervention, with a 30%–60% critical failure rate of existing water supply systems in developing countries (Davis et al., 1995) that is often attributed to inappropriate technology. In sub-Saharan Africa 35% of all rural water systems are not functioning, with individual African countries experiencing operational failure between 30% and 60% (Harvey and Reed, 2007).

1.1.1. *Capacity factor analysis*

Models are needed to aid decision makers in the systematic selection of appropriate technologies to sustain drinking water and sanitation service in developing communities.[3] Capacity Factor Analysis (CFA) is such a model. Capacity factors are essential categories that affect a community's ability to manage municipal sanitation services (see Fig. 1). The eight factors were developed from a pedagogy similar to methods in risk analysis, including Hierarchical Holographic Modeling, which identifies important sources of risk and captures the multiple aspects and dimensions of a system (Haimes, 2004). Similar to risk analysis and management, CFA focuses on the factors that impact the assessment, evaluation, and management of municipal sanitation service technologies.

The CFA model relies on three components: (1) a community assessment, resulting in a Community Capacity Level (CCL) score of a community, (2) a rating of validated technologies for providing municipal sanitation services, resulting in a Technology Requirement Level (TRL) score of technologies, and (3) a matching policy (see Fig. 2).

Bouabid (2004) developed the community assessment as a quantitative tool that measures the ability of a developing community to manage sustained municipal sanitation services within each capacity factor. Using specific requirements as benchmarks within each capacity factor, the assessment includes drinking

FACTOR	DEFINITION
SERVICE	Supply, delivery, growth
INSTITUTIONAL	Laws, Regulations, Administration, Processes
HUMAN RESOURCES	Professional, Skilled Labor, Unskilled Labor: Literate, Illiterate
TECHNICAL	Supply chain: Spare parts, Supplies, Services
ECONOMIC/FINANCIAL	Markets, Mechanisms, Taxes, Fees, Financial options
ENERGY	Sources, access, utilization, opportunity cost
ENVIRONMENTAL/ NATURAL RESOURCES	Carrying capacity of media; Stock of resources: land, water, soil type, precipitation
SOCIAL/CULTURAL	Housing type, transience rate, caste/class equity, female participation, community organization

Fig. 1. Capacity Factor Definition. Definitions from Louis and Bouabid (2004).

water supply, wastewater and sewage service, and the management of solid waste. Ahmad (2004) proposed a framework for ranking service technologies scored according to requirements in four of the capacity factors: cost, energy, technical, and institutional, called the Technology Requirement Level (TRL). Service technologies were broken up into unit operations, single components that when brought together with other unit operations, leads to the provision of a service. However, its development was incomplete for drinking water supply and did not exist for greywater reuse.

1.2. *Research objectives*

CFA is currently incomplete for drinking water supply (DWS) and for greywater reuse (GWR), as it lacks a capacity-based rating of technologies for providing municipal sanitation services, a matching rule to guide decision makers in selecting the appropriate service

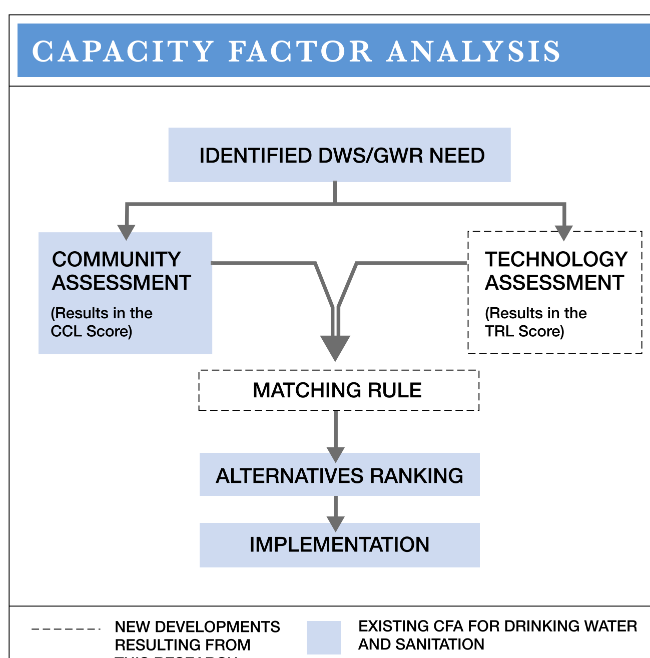

Fig. 2. Capacity Factor Analysis model framework.

[2] According to the WHO and UNICEF (2004), 40% of the world's population lacked access to improved sanitation.

[3] Developing communities are defined as low-income, rural, or indigenous communities that lack the capability to provide adequate access to one or more essential services to their residents (Louis et al., 2008).

Table 2
Requirements in the eight capacity factors for drinking water & greywater.

Capacity factor	Requirement[a]
Service	Production capability or capacity (l/d/c)[b]
Institutional	Scope or scale of installation[c]
Human resource	Technology human input[d]
Technical	Failure rate (%) & required maintenance level[e]
Economical & financial	Service cost (USD$ per capita per year($/c/yr))[f]
Energy	Energy demand of the technology
Environmental	Technological footprint (ft^2)[g]
Social & cultural	Technology complexity[h]

[a] Benchmarks for requirements listed as footnotes.
[b] 40 L per day per capita (l/d/c), water requirement per capita recommended by the WHO (Howard and Bartram, 2003). Requirement suggested by Ahmad (2004).
[c] Bouabid (2004) states that governance is an essential component of water management. Starkl et al. (2009) state that differing levels of governments face challenges to upgrade, extend, or build new infrastructure.
[d] Bouabid (2004) states that according to Lloyd et al. (1991) the number of staff or employees (e.g. human resource) should be proportional to the population served and that of the level of service. Human resource is often cited as a key component of failure of decentralized water systems (Starkl et al., 2009; Massoud et al., 2009).
[e] Carter et al. (1999) state that water supply service in developing communities should not have a system down more then 2% (or 7 days) per year.
[f] Carter et al. (1999) further state that water supply service should cost approximately $40/capita for initial investment, and approximately $4/capita of associated recurrent cost.
[g] The concept of a technological footprint is created from concepts found in Moran et al. (2008); Roth et al. (2000); Heerink et al. (2001).
[h] Complexity of wastewater treatment plants is used by the U.S. EPA to determine licensing and operation requirements (Muga and Mihelcic, 2008). Similarly technology complexity as a measure of the social and cultural requirements of a technology.

technology for their community, and further lacks a validation procedure. The goal of this research was to develop these three essential elements of the CFA. First, requirements analysis was used to develop a ranking, or a capacity-based classification, of DWS and GWR technologies. From this classification, a ranked list of DWS and GWR technologies was produced. Second, rules for an algorithm were developed to guide decision makers in the selection of appropriate DWS or GWR technology options for their community when using CFA. Third, a case study for validation of the CFA model was completed in Cimahi, Indonesia. The inclusion of these elements facilitates the selection of DWS and GWR systems in low-income communities that are safe, affordable, able to be built and managed by the community using local resources, and are amenable to expansion as the community's management capacity increases.

2. Model development

2.1. Developing the technology assessment for DWS & GWR within the eight capacity factors

A new capacity-based classification of DWS and GWR technologies was created using a requirements analysis methodology within the eight capacity factors. Requirements are the detailed list of benchmarks within each of the capacity factors. The requirement attributes, as well as the associated benchmarks, are unambiguous, unique, understandable, concise, design independent, and verifiable. When possible, the requirements and benchmarks are based on international or published standards. To facilitate meaningful comparisons between technology and community scores, and a degree of consistency in units, requirements for the technology assessment were derived from the community assessment. However, the requirements developed for the technology assessment are not strictly a subset of the requirements for the community assessment, as there are requirements for the technology assessment that are not included in the community assessment. Table 2 lists the capacity factors with the associated requirements used to create the technology assessment.

Table 3
Example capacity factor partition into five levels.

Capacity factor (f) with *Requirement* (C)	Level	Partition	Benchmark
Service, production capability	1	<20	40 l/d/c, WHO recommended water requirement per capita (Howard and Bartram, 2003).
	2	20–40	
	3	40–60	
	4	60–80	
	5	>80	

2.1.1. New scoring for technologies and communities

The rubric used to score technologies for the technology assessment was created by partitioning the requirements (Table 2) into levels (1–5) using specific benchmarks as base units. The technology score is the proportional evaluation of a technology to meet benchmarks within each requirement. For example, the World Health Organization states that individuals require a minimum of 40 L of water per day per capita (l/d/c) to avoid negative health impacts (Howard and Bartram, 2003). The value of 40 (l/d/c) is used as the benchmark for the service capacity factor for DWS technologies. Table 3 demonstrates this partitioning. The process to rate either DWS or GWR technologies is the same, hence they are not distinguished in the following process.

The score for a unique technology is defined as a vector (f_{TRL}) of eight values, composed of one value for each capacity factor (f, indexed by i). For a single capacity factor, there may be more than one requirement (C, indexed by j) used to evaluate the technology. Each jth requirement can be weighted (W) on its importance (if there is only a single requirement, then $W = 1$). The value of the ith capacity factor (f_i) for a unique technology is calculated[4] by:

$$f_i = \sum_{j=1}^{n} C_{i,j} W_j \quad \forall \quad i = \{1, 2, \cdots, 8\} \tag{1}$$

where:
$f =$ capacity factor.
$i =$ capacity factor index; $i = \{1,2,\ldots,8\}$
$C =$ requirements in each capacity factor.
$W =$ weight of the requirements in each capacity factor.
$j =$ requirements index; $j = \{1,2,\ldots, N\}$
$f_i =$ value of the ith capacity factor.
$C_{i,j} =$ value of the jth criterion of the ith capacity factor.
$W_j =$ weight of the criterion $C_{i,j}$; value is between $0 < W_j \leq 1$, and $\sum_{j=1}^{n} W_j = 1$.

As an example, consider a technology that is able to produce 50 (l/d/c). Using the partitioned values in Table 3 for service capacity, the requirement of production capability ($C_{1,1}$) is equal to 3. Assuming there is only one requirement, the weights for each are equal, thus W_j is equal to 1. Thus, $f_1 = \sum_{j=1}^{1} C_{1,1} W_1 = 3 \times 1 = 3$.

The above equations will produce a unique vector score for each technology rated (a, indexed by k). The collection of the scored technologies creates a rated technology matrix[5] ($\mathbf{A}$).

$$\mathbf{A} = \left[a_{k,f_i}\right]_{k=1,\cdots,N; f_i=1,\cdots,8}$$

$$\mathbf{A} = \begin{pmatrix} a_{1,f_1} & a_{1,f_2} & \cdots & a_{1,f_8} \\ a_{2,f_1} & a_{2,f_2} & \cdots & a_{2,f_8} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N,f_1} & a_{N,f_2} & \cdots & a_{N,f_8} \end{pmatrix} \tag{2}$$

[4] Calculation equation for the ith capacity factor is the same for the community assessment (Louis and Bouabid, 2004).
[5] This technology matrix was created for the case study by rating a range of technology options (from household to community) for the unit operations procurement, transfer, treatment, disposal, and collection of DWS and GWR.

Table 4
Hypothesis testing with scenarios for CFA model.

Hypothesis	Reject	Accept
Null Hypothesis (H_0): The revised CFA does not predict viable DWS & GWR service options	*Sustained service*: Model Predicts Technology that is currently in use & current service is well managed by the community *Disrupted service*: Disrupted services & H_1–H_3 are accepted	*Sustained service*: Model Predicts Technology that is not currently in use & current service is well managed by the community *Disrupted service*: Model Predicts Technology that is currently in use
Hypothesis 1 (H_1): The developing communities' ability to manage DWS & GWR service options is well described by the CCL scores determined through the capacity factor assessment	*Disrupted service*: CCL scores does not predict the capacity failure occurs in service occurs	*Disrupted service*: CCL scores predicts the capacity factor where failure occurs in service
Hypothesis 2 (H_2): The Enhanced TRL score for DWS & GWR technology options accurately describes the capacity needed to manage the technology	*Disrupted service*: TRL Score is the same or lower then CCL Score	*Sustained service*: TRL Score is the same or lower then CCL Score *Disrupted service*: TRL Score is higher then CCL Score
Hypothesis 3 (H_3): Matching between the TRL & CCL scores within each capacity factor will predict viable DWS & GWR service options.	*Disrupted service*: H_1 & H_2 are true, predicts a higher or equal level technology than is currently in place	*Sustained service*: H_1 & H_2 are true, predicts a equal or lower level technology than is currently in place *Disrupted service*: H_1 & H_2 are true, predicts a lower level technology than is currently in place

where:
$\mathbf{A}$ = rated technology matrix.
a = rated technology.
k = technology index; $k = [1,2,\ldots,n-1,N]$

2.2. New matching rule

This research develops a new matching rule that facilitates the creation of a subset of appropriate and sustainable technologies for each community. This rule guides decision makers in the selection process for their community. With the redevelopment and extension of the technology assessment (see Section 2.1.1), mapping can occur directly between the technology and community scores within each capacity factor. In order to do this, the community assessment score is defined as a vector (f_{CCL}) of eight values, as with the technology assessment. The rule allows for the production of a set of sustainable technology options for the community.

The general matching rule created to produce a subset (T, where $T \subseteq a_k$) of feasible technology options for the community is a conservative rule which states that the capability of the community must be equal to or greater than the management capacity necessary for a given technology. In the case of the capacity factor service (f_1), the reverse of the general rule is the case. The service capacity factor from the community assessment reflects the current level of service in the community, and developing communities by definition have limited to no service. Thus, using the general rule would limit selection to technologies that would not improve the level of service in the community. Of course, the optimal technology choice is one that has the highest production (level of service) and is within the community's capability to manage. As an example, consider a community that does not have any drinking water service. For this community, the general rule would not be able to choose a technology because all technologies provide some level of service. Thus, the combined matching rule is:

$$T = \left\{ t;\ \begin{matrix} f_{i,\,\mathrm{TRL}} \geq f_{i,\,\mathrm{CCL}} & \forall i = [1] \\ f_{i,\,\mathrm{TRL}} \leq f_{i,\,\mathrm{CCL}} & \forall i = [2,\ldots,8] \end{matrix},\quad t \in T \right\} \tag{3}$$

where:
T = set of technology options for a specific community; $T \subseteq a_k$
$f_{i,\mathrm{TRL}}$ = value of the ith capacity factor for specific technology; a_{k,f_i}
$f_{i,\mathrm{CCL}}$ = value of the ith capacity factor for specific community.

The set of possible technologies (T) is ordered ($\mathbf{T}$) from most preferred (e.g. most conservative) to the least preferred by defining a property (x) for each technology (a_k). This property penalizes large differences between the technology ($f_{i,\mathrm{TRL}}$) and community ($f_{i,\mathrm{CCL}}$) scores in each capacity factor, except for the service capacity factor (f_1). In the case of the service capacity factor, it rewards large differences between the technology ($f_{i,\mathrm{TRL}}$) and community ($f_{i,\mathrm{CCL}}$) scores. The vector of technologies ($\mathbf{T}$) is created by ordering the technologies by their property x_{a_k} from the largest to smallest values. This ordering is from most conservative to least conservative. That is to say, that the technology with the largest property (x_{a_k}) is the technology that is closest to the community capability to manage and highest in production capability.

$$x_{a_k} = \left(f_{1,\mathrm{TRL}} - f_{1,\mathrm{CCL}}\right) + \sum_{i=2}^{8}\left(f_{i,\mathrm{CCL}} - f_{i,\mathrm{TRL}}\right) \tag{4}$$

The new matching policy helps ensure a meaningful comparison between the community and technology assessment, provides

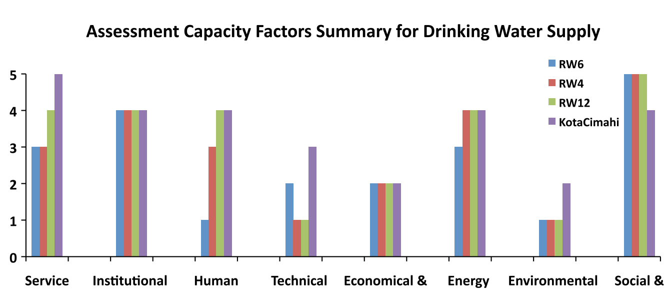

Fig. 3. Drinking water community assessment partitioned scores for Cimahi.

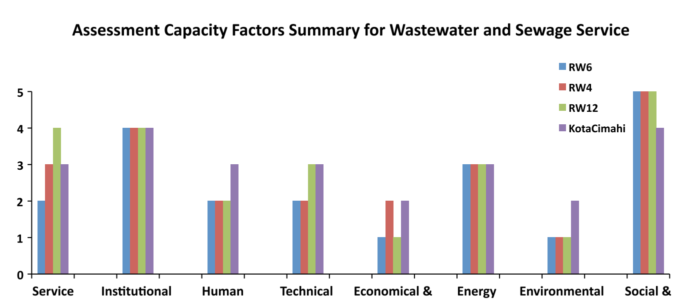

Fig. 4. Wastewater and sanitation community assessment partitioned scores for Cimahi.

Table 5
Technology used in DWS.

	Source	Procurement	Treatment	Storage	Distribution
Kota Cimahi	Drilled well	Motorized Pumps	Traditional Water Treatment Plant	Reservoirs	Piped water (pump)
RW 6, RW 12, & RW 4	Well	Motorized Pumps, Hand Pumps, buckets	Chlorination, Sand Filtration, or none	Tank	Piped water (pump) or none

a higher degree of diagnostic capability to the CFA, and facilitates technology recommendations in communities with low community assessment scores across several capacity factors. The ordering of the technologies by the property defined in Eq. (4) assists experts and decision makers in the final selection when more than one technology option exists.

2.3. CFA model validation process

Model validation is an essential but currently absent aspect of the development of the CFA model. Validation for the CFA model helps ensure that the output (e.g. technology recommendation) is reliable and accurate (e.g. within the community's capability to manage). As the CFA is a hybrid of a social and a physical system model, CFA is faced with unique challenges for validation. Unlike model validation for physical system models, there are no well established procedures to complete model validation for such a hybrid (Macal, 2005). The validation process should be capable of being executed iteratively.

For this validation process, the results of a case study can be used to evaluate underlying hypotheses of the CFA model. By comparing the results to specific scenarios, it is determined whether to accept or reject the hypothesis. In these case studies, the low-income community is assessed using the community assessment. From this assessment, the matching rule is used to produce a set of sustainable technologies for the communities. This set is then compared to the current technologies used for water and sanitation in the community. The scenarios that contribute to accepting or rejecting each underlying hypotheses can be seen in Table 4.

The CFA model is based on at least three hypotheses (H_1, H_2, H_3) and a null hypothesis (H_0). H_1 is the underlying hypothesis of the community assessment, namely, that the community assessment accurately measures the community's capability to manage DWS and GWR services, and that the CCL Score can describe this ability. H2 is the underlying hypothesis of the technology assessment, namely, that the technology assessment accurately describes the necessary capacity needed to manage the technology, and that this is well described by the TRL Score. Finally, H_3 is the underlying hypothesis of the matching rule, namely, that the matching rule will match the technology assessment to the community assessment to predict viable DWS and GWR service options in the community. Validation for a single case occurs when all three hypotheses are true.

3. Applied theory: case study in Cimahi, Indonesia

Cimahi is located in West Java, Indonesia,[6] Indonesia has an estimated population of over 500,000 (2005) and a growth rate that is higher than the national average (Sundana, 2005), causing rapid urbanization. The combined effect of poverty and an increasing population has strained the municipal sanitation service systems in Cimahi, leading to human health hazards and environmental degradation, including the deterioration of the surface and ground water. These challenges are further compounded by Cimahi's designation as the final disposal site (FDS) of solid waste from the neighboring city of Bandung, Indonesia. The FDS is known for inadequate management practices, and in 2005 a landslide of the solid waste resulted in 140 casualties of residents in the FDS surrounding area (NEWS, 2006).

3.1. Materials and methods

The case study conducted in Cimahi allows for the application of the validation process described in Section 2.3 and provides an illustrative use of Capacity Factor Analysis. The research question for the case study was whether the matched CCL and TRL scores produce viable DWS and GWR technology alternatives that are sustainable and appropriate technology options for Cimahi (a low-income community). During an approximately three-month period ranging from December 2007 to March 2008, data was gathered under the supervision of Institut Teknologi Bandung (ITB), a public research university nationally renowned in the engineering sciences. The data collected during the case study was used to complete the community assessment. Methods utilized for data collection during the case study include:

- survey and interview of governmental offices,
- government reports,
- field observations, and
- interview and survey of community members and leaders.

Main data sources for the community assessment information came from the following informal and formal entities and offices[7]

- Bagian Keuangan Program (BKP)[8]
- Dep. Dalam Negeri (DDN)[9]
- Dinas Lingkungan Hidup (DLH)[10]
- Perusahaan Daerah Air Minum (PDAM)[11]
- Dinas Tata Kota (DTK)[12]
- Kelompok Pengguna dan Pemanfaat Air (KP2A)[13]

Formed in 2002, the administrative government is relatively new. Cimahi is divided into three regions called Kecamatan: Cimahi Selatan (South), Cimahi Tengah (Central) and Cimahi Utara (North). Each of the three regions is further divided into regions called Rukun Warga (RW), which are themselves composed of communities or large neighborhoods called Rukun Tetengga (RT). This structure is important, as it illuminates the levels at which the community assessments were completed. Through the interview of

[6] Composed of 17,508 islands, Indonesia is an archipelago between the Indian and Pacific Oceans with a tropical climate. The fourth most populous country in the world (CIA, 2008).

[7] Individual officers or persons interviewed are not listed for the protection of their privacy.
[8] Finances Office, Cimahi.
[9] Internal Department, Cimahi.
[10] Office of Environment, Cimahi.
[11] State-owned Drinking Water Company, Bandung Regency.
[12] Office of Urban Planning, Cimahi.
[13] Water User and Benefiter Community Group, Cimahi North Rukun Warga 6, 12, and 4 (RW 6, 12, 4)-Neighborhood Associations.

Table 6
Final Technology Recommendations for DWS.

	Source	Procurement	Treatment	Storage	Distribution
Kota Cimahi	Spring water capitation [a], Hand dug or drilled well[b]	Bucket, hand pump, rope and bucket	Chlorination, slow sand filter, boiling	Tank/ Barrel	Piped water (gravity)[c], Piped water (pump)

[a] Increase the CFA Community assessment Environmental Capacity Factor score from 2 to 3.
[b] Increase the CFA Community assessment Economic Capacity Factor score from 2 to 4.
[c] Increase the CFA Community assessment Economic Capacity Factor score from 2 to 3.

and sewage service the Environmental capacity factor had the lowest capacity factor scores (Fig. 4).

3.1.2. Technology recommendations based on the revised CFA

Kota Cimahi, and RW 6, 12, and 4 use the DWS service technologies in Table 5. There is often failure of DWS service in Cimahi, as both the quantity and quality of DWS are often inadequate or non-existent, particularly in Leuwigajah. Table 6 outlines the DWS technology recommendation based on an increase of their Financial and Environmental capacity to properly manage the technology. Table 6 shows the technology options that were recommended for Cimahi based on the output of the CFA model. Table 7 shows the GWR technology options generated using the CFA model for Cimahi, Selatan.

Table 7
CFA Recommended GWR Technology for Cimahi.

	Source	Transfer	Treatment	Application
Kota Cimahi	Domestic separated: Kitchen sink[a], washing machines[a], and dishwashers[a], and shower	Bucket[a], hand pump[a]	Coarse filtration with disinfection (bromide or chlorine)	Irrigation
RW 6	Domestic separated: Kitchen sink	Bucket[a]	None	None
RW 12	Domestic separated: Kitchen sink[a], washing machines[a], and dishwashers [a], and shower	Bucket	None	None
RW 4	Domestic separated: Kitchen sink[a]	Bucket[a]	None	None

The colored grey boxes indicate which level of government and which technology should be used for the provision of the GWR service.
[a] Indicates that multiple units of the technology would need to be acquired to achieve service level.

Cimahi's Office of Urban Planning (DTK) and Office of Environment (DHN), it was determined that Cimahi South (Selatan) was the region that has had the most challenges to provide sustained water and sanitation services. Cimahi Selatan has five villages: Cibeber, Leuwigajah, Utama, Cibeureum, and Melong. Of these, Leuwigajah was chosen for the village of focus. In Leuwigajah the communities of RW 6, RW 12, and RW 4 were chosen to apply the CFA.

Following the CFA assessment framework, the community assessment was completed on the scale of the entire city (Kota Cimahi), one city region (Leuwigajah), and communities within the region (RW 6, 12, & 4). The community assessment was completed at these levels of administrative and physical structure because of Cimahi's large population and partially decentralized[14] service provision. This allowed for specific unit operations of DWS and GWR services to be provided by a community in conjunction with the city government.

3.1.1. CFA community assessment for Cimahi Selatan

The assessment scores were calculated using the existing community assessment framework for drinking water supply and for sanitation services. The development of the community assessment is outside the scope of this paper,[15] thus the detailed explanation for each community assessment completed is not included. However, a sample community assessment summary completed for Kota Cimahi can be seen in Fig. A5 in the Appendix. A similar assessment was completed for each level of governmental and community administration to produce a community's scores for both drinking water and greywater reuse.

Fig. 3 and Fig. 4 show the community's capacity factor scores (CCL). As stated previously, the CCL score represents the community's capacity to manage service. As can be seen in Fig. 3 for drinking water supply, the Environmental and Financial capacity factors have several of the lowest values. Similarly, for wastewater

[14] There is a division of responsibility amongst levels of government and community administration for service provision in Cimahi.
[15] Please refer to (Bouabid, 2004) for the development of the CFA community assessment.

3.2. Scenario validation

For the purpose of using scenarios for hypothesis testing, the set of technology produced by CFA model is compared to the technology that is currently in use. If the current technology is failing, the CFA model should predict in what capacity factor the failure is occurring. The validation process described in Section 2.3 could only be used for drinking water supply, as greywater reuse technologies are not currently utilized in Cimahi, Selatan. Table 4 lists the hypothesis and the associated scenarios to be tested in the case study.

H_1 was accepted because DWS service was disrupted, and the CCL community score predicted the capacity factors, Environmental and Financial, that are the contributing factors to the failure. These areas of low capacity are the limiting capacity factors that the CFA Community Assessment predicted. Additionally, they correspond to the reality of the areas that are currently experiencing service failure. PDAM of the Bandung Regency (part of which services Cimahi) received initial monies from the Asian Development Bank. However, as the water treatment plant that services Cimahi has not yet been paid in full, Cimahi has not taken over the financial burden of the plant. An "economic feasibility study" is said to be needed (DTK). This lack of economic capacity is leading to some of the service failure, as Cimahi cannot financially manage the facilities for DWS. As discussed above, the Environmental Capacity Factor is also a constraining factor and is indicative of Cimahi's current scarcity of water resources and its ability to manage service options.

H_2 was accepted because DWS service was disrupted, and the TRL score of the technology that is currently being used by Cimahi (Table 5) represents technology that is higher than the CCL Score of the community (e.g. the community requires a greater capacity to manage it's current technology). Table 6 lists the technologies recommended by the CFA on the condition of increased capacity in specific capacity factors. Without these increases, there were unit operations where the model could not recommend technologies. These null values reflected the unit operations that are currently under strain (e.g. failure) in Cimahi, and correspond to the state of access in Cimahi. Several water leaders and local experts stated that the greatest challenge of Cimahi water access is the water supply (PDAM). Illustrating this point is the original twenty deep wells in Cimahi, where only three are now currently active due to water table depletion over the past 10 years (PDAM). Additionally, the distribution system is an area under strain, as the original piped network was designed for a much smaller population. When the source and distribution technology options are entered into the model, the CFA Model further accurately predicts where the system will fail by indicating the constraining capacity factors. Thus, in order to achieve suitable technological alternatives for the source and distribution, the community must increase their Economic Capacity CCL Score to between 3 or 4 from its current score of 2. Similarly, it would need to increase its Environmental Capacity from its current score of 2–3.

Finally H_3 is accepted. Where there is currently disrupted service, H_1 and H_2 are accepted, as the CFA model predicts lower level technologies that are currently in place. Table 6 shows the recommended technology based on the increase of capacity in environmental and financial capacity factors. Thus, for DWS, the CFA model accepted H_1, H_2, H_3, and rejected H_0.

It should be noted that the four communities assessed in the case study of this research do not provide a sufficient sample size to test the hypotheses with an acceptable level of statistical power (confidence). However, the structure of the hypothesis is illustrative of the process that should be followed as more cases become available. The empirical results obtained from the case studies in this research present consistent qualitative confirmation of the hypotheses tested.

4. Discussion

There are several advantages to the CFA model. One way in which the model is of value in Cimahi is enabling decision makers to objectively and systematically demonstrate their capability to manage the proposed service technologies in all other factors except financial capacity. This would be helpful to Cimahi, for example, if they were seeking funding for their DWS system from governmental sources, non-governmental organizations (NGO), or aid organizations. This systematic articulation of their capability to manage the proposed technologies may assist in securing the funds necessary for the installation and operation of such a system.

Another advantage of the CFA model for a large urban center such as Cimahi is in the ability to systematically assess the capability of different levels of city government and communities. This assessment enables varying levels of administration to handle different aspects of services provisions. For example, the model can demonstrate that a certain unit operation of service must be managed by the highest level of government because of the level of management necessary. Similarly, it may show that certain units are well managed by local community groups. Thus, different levels of city government can provide different unit operations within a specific service.

5. Conclusion

This research contributes to the development of Capacity Factor Analysis for drinking water supply and greywater reuse through three ways. First, it developed a ranking methodology for DWS and GWR technologies using requirements analysis within the eight capacity factors. Second, a new matching rule was developed for the CFA that facilitates a meaningful matching between the community and technology assessments, as well as providing some troubleshooting capabilities. Third, it developed a scenario-based hypothesis testing by case study for a long-term validation plan for continued refinement of CFA, as well as a case study in Cimahi, Indonesia.

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Appendix A. Reference tables & figures

	Capacity Factors	1 - 20	21 - 40	41 - 60	61 - 80	81 - 100	Score
f_1	**Service**						
$C_{1.1}$	Sevice Level	< 20 l/d/c	20- 40 l/d/c	40 - 60 l/d/c	60 - 80 l/d/c	> 80 l/d/c	100
f_1	*Score Service*					$\Sigma C_{i,j} w_j =$	*100*
f_2	**Institutional**						
$C_{2.1}$	Body of legislation	None	Basic	Intermediate	Complete	Advanced	70
$C_{2.2}$	Associated regulation	None	Basic	Intermediate	Complete	Advanced	70
$C_{2.3}$	Administrative agencies	None	National	Regional	State	Local	50
$C_{2.4}$	Administrative processes	None	Basic	Intermediate	Complete	Advanced	60
$C_{2.5}$	Governance	None	National	Regional	State	Local	60
f_2	*Score Institutional*					$\Sigma C_{i,j} w_j =$	*62*
f_3	**Human Resources**						
$C_{3.1}$	Professionals	None	None	Administrative supervisor Health scientist	Administrative manager Health scientist Engineer	Administrative manager Health scientist Engineer Lawyer Public relations manager	81
$C_{3.2}$	Skilled Labor	None	Mechanic	Maintenance technician Laboratory technician Water systems operator	Maintenance technician Laboratory technician Water systems operator Health inspector Administrative assistant Water meter leader	Maintenance technician Laboratory technician Water systems operator Health inspector Administrative assistant Water meter leader IT technician	68
$C_{3.3}$	Unskilled Labor	Craftsman	Clerk Mechanic assistant	Clerk Water meter reader Water systems worker			N/A
$C_{3.4}$	Illiterate	Caretaker	Caretaker				N/A

f_3	Score Human Resources					$\Sigma C_{i,j} W_j =$	74.5
f_4	**Technical**						
$C_{4.1}$	Operations	Water use	Pumping water	Pumping water Control water quality	Monitor water systems Control water quality Control pipes	Monitor water systems Control water quality Monitor pipes network Monitor treatment	75
$C_{4.2}$	Maintenance	None	Clean water systems Minor repair	Check water systems Major repair	Check/Maintain water systems major repair Maintain pipes	Check/Maintain water systems Check/Maintain network Check/Maintain water meter Maintain IT systems	65
$C_{4.3}$	Adaptation	None	Rarely	Occasionally	Usually	Frequently	21
$C_{4.4}$	Supply Chain	None	National supplier	Regional supplier	National manufacturer Regional supplier	National manufacturer Local supplier	61
f_4	Score Technical					$\Sigma C_{i,j} W_j =$	55.5
f_5	**Economical and Financial**						
$C_{5.1}$	Private sector %	None	International	National	Regional	Local	20
$C_{5.2}$	Bonds Rating	None	National	Regional	State	Local	15
$C_{5.3}$	User fees	None	Uniform flat rate	Single block rate	Increasing block rate	Increasing block rate	41
$C_{5.4}$	Budget	None	Basic accounting	Annual	Tracked annually	Tracked quaterly	55
$C_{5.5}$	Asset values	None	Real estate	Real estate Equipment	Real estate Equipment Cash	Real estate Equipment Cash - Stocks	41
$C_{5.6}$	Debt	None	Rating (b)	Rating (bb)	Medium Large Rating	Rating (a-aa)	60
f_5	Score Economical Financial					$\Sigma C_{i,j} W_j =$	38.7
f_6	**Energy**						
$C_{6.1}$	Primary source	None	Non Conventional	Conventional Electricity	Electricity Mid voltage	Electricity High voltage	75
$C_{6.2}$	Back up	None	None	Generator < 10 HP	Generator < 50 HP	Generator > 50 HP	55
$C_{6.3}$	% of Budget	None	Very high	High	Moderate	Low	71
$C_{6.4}$	Rate of outage	None	High	Medium	Low	very low	81
f_6	Score Energy					$\Sigma C_{i,j} W_j =$	70.5
f_7	**Environmental**						
$C_{7.1}$	Quality and Sensitivity:	Very low	Low	Medium	High	Very high	15
$C_{7.2}$	Quantity	Very low	Low	Medium	High	Very high	30
f_7	Score Environmental					$\Sigma C_{i,j} W_j =$	22.5
f_8	**Social & Cultural**						
$C_{8.1}$	Communities	Very low	Low	Intermediate	High	Very high	90
$C_{8.2}$	Stability	Very low	Low	Intermediate	High	Very high	75
$C_{8.3}$	Equity	Very low	Low	Intermediate	High	Very high	50
$C_{8.4}$	Castes	Very high	High	Intermediate	Low	Very low	81
$C_{8.5}$	Participation of Women	Very Low	Low	Intermediate	High	Very High	80
f_8	Score Social Cultural					$\Sigma C_{i,j} W_j =$	75.2

Fig A5. Sample Community Assesment for Kota, Cimahi.

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