BORDA

# Communal Wastewater Characteristics in Developing Countries

## Desk Study to inform Sanitation System Design

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# Content

## List of Abbreviations

| | |
|---|---|
| BGD | biogas digester |
| BOD | biochemical oxygen demand |
| BORDA | Bremen Overseas Research and Development Association |
| BW | black water |
| cap. | capita |
| CDF | Cumulative distribution function |
| COD | chemical oxygen demand |
| CSC | community sanitation centre |
| CU | commercial utility |
| EAP | East Asia and Pacific |
| ECA | Eastern Europe and Central Asia |
| GNI | gross national income |
| GW | grey water |
| HH | household |
| HI | high income |
| inhab | inhabitants |
| JMP | Joint Monitoring Programme |
| LAC | Latin America and Caribbean |
| LI | low income |
| LMI | lower middle income |
| ltd | limited |
| MAP | mean annual precipitation |
| MNA | Middle East and North Africa |
| N | Nitrogen |
| NAC | North America |
| P | Phosphorus |
| p.a. | per annum (per year) |
| PDF | Probability density function |
| pop | population |
| PRG | Pollution Research Group |
| SAS | South Asia |
| SBS | school-based sanitation |
| SSA | Sub-Sahara Africa |
| SSS | small sewer system |
| UCT | University of Cape Town |
| UI | user interface |
| UKZN | University of KwaZulu Natal |
| UMI | upper middle income |
| UNICEF | United Nations International Children’s Emergency Fund |

| | |
|---|---|
| unltd | unlimited |
| TSS | total suspended solids |
| WCE | Western and Central Europe |
| WHO | World Health Organization |
| WRC | Water Research Commission |
| WW | wastewater |
| WWTP | wastewater treatment plant |

## List of Formula Symbols

| Formula Symbol | Unit | Description |
|---|---|---|
| $BOD_5$ | $\frac{g}{cap \cdot d}$ | per capita daily 5-day biochemical oxygen demand |
| COD | $\frac{g}{cap \cdot d}$ | per capita daily chemical oxygen demand |
| $K_1$ | - | daily peak flow factor |
| $K_2$ | - | diurnal peak flow factor |
| m | - | mode of a log-normal distribution |
| med | - | median of a log-normal distribution |
| $med^*$ | - | median of log-normal distribution of values calculated with factors |
| Max | - | maximum value |
| $Max^*$ | - | maximum value of values calculated with factors |
| Min | - | minimum value |
| $Min^*$ | - | minimum value of values calculated with factors |
| PFF | - | peak flow factor |
| t | - | t-value of the student distribution |
| $t^*$ | - | t-value of sample size for factor calculations |
| TKN | $\frac{g}{cap \cdot d}$ | Total Kjeldahl Nitrogen |
| TP | $\frac{g}{cap \cdot d}$ | Total Phosphorus |
| s | - | standard deviation of a discrete sample |
| TSS | $\frac{g}{cap \cdot d}$ | per capita daily total suspended solids |
| $W_{cons}$ | $\frac{L}{cap \cdot d}$ | per capita daily water consumption |
| WRC | - | water return coefficient |
| $WW_{prod}$ | $\frac{L}{cap \cdot d}$ | per capita daily wastewater production |
| $\bar{x}$ | - | arithmetic mean of discrete sample |
| z | - | z-value of the standard normal distribution |
| $\mu$ | - | mean of a log-normal distribution |
| $\sigma$ | - | standard deviation of a log-normal distribution |
| $\Phi$ | - | $\Phi$-function of the standard normal distribution (probability) |

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# 1 Introduction

The main design parameters for DEWATS design are the daily per capita (or applicable units for institutional, commercial and industrial setups) wastewater production, organic and to a limited extend nutrient loads and the peak flow factor. However, these parameters highly depend on income, water availability, supply and demand, climate, culture and cultural habits (Pescod, 1992; Reynaud, 2014).

Reliable wastewater characteristics are commonly available for industrialised countries, where population equivalents have been established over the course of decades, whereas engineers in developing countries are forced to use and adjust these values in the absence of more suitable estimates, which may lead to oversized systems and resource wastage or in the opposite situation underdesign can occur, leading to process failure due to overloading (Campos and von Sperling, 1996; Reynaud, 2014).

Wastewater characteristics for developing countries are usually either very generalising, outdated or only applicable in a limited context under specific circumstances.

## 1.1 Objectives of this Study

The goal of this assignment is to review and collate accessible data on DEWATS design parameters in developing countries and where possible to classify it depending on country and income group in order to

- identify knowledge gaps which will guide future BORDA R&D efforts
- form the basis for improved DEWATS design procedures

The systems and setups under investigation are communal systems (small sewer systems, community sanitation centres and combinations of the two), institutional and commercial setups, i.e. schools, offices, hospitals, hotels/lodges, and industrial systems (limited to agricultural systems and systems from industries dealing with predominantly organic products such as food processing, pulp and paper and abattoirs). The wastewaters under investigations are blackwater, greywater and mixed black and greywater as far as human activities are the source of the waste.

## 1.2 Research Questions

Following questions shall guide the research on this topic. Answering these questions provides the baseline database set for appropriate DEWATS design:

1. How can sampling and testing of population equivalents with a small sample size be applied on a macro scale (country/region level)?
2. How can society groups in a specific country/region be classified and differentiated?
3. Which is the most suitable classification criteria for population equivalents?
4. What are the key determining, quantifiable parameters on population equivalents? Following parameters are to be considered, but not limited to:
    a. Macro-parameters (e.g. average country income, climate, country/region)
    b. Micro-parameters (e.g. household income, water supply, sanitation interface, wastewater composition)
5. Is there a direct relation between water consumption and wastewater generation? How can it be quantified?
6. What are relevant and realistic parameter options (mean) and ranges (min/max) per parameter?
    a. Wastewater production
    b. Organic load per capita (COD, BOD)
    c. Nutrient load per capita (Nitrogen, Phosphorus)
    d. Peak flow factor
7. For which DEWATS set ups can population equivalents be determined (e.g. SSS, CSC, Hybrid, SBS)?

## 1.3 Definitions

Within the study certain terminologies are used to explain the methodologies used. Terminologies that could be misinterpreted are defined and explained in this chapter.

<u>Classification criteria & distinctive feature:</u>

Literature values refer to a certain context and are provided for a widely differing level of detail, between very general (e.g. 'developing countries') and very context specific (e.g. sampling results from M&E missions). However, the criteria applied are not standardised and also the differentiation within a criterion differs from source to source. Therefore, standardised criteria are defined, called "classification criteria", the different values used within one criteria are called "distinctive features". In this report the terms "criteria" and "feature" are used as short forms for these terms. An example is provided below:

**Table 1: Distinctive features for the classification criteria 'Income'**

| **Classification criteria** | **Income** |
|---|---|
| **Distinctive features** | Low income |
| | Lower middle income |
| | Upper middle income |
| | High income |

Parameter, parameter range & parameter set:

A parameter set in this study refers to one row of data including distinctive features for the classification criterion and values for each parameter available (red boarders in Table 2). A parameter refers to one specific value within one parameter set (green shaded cell in Table 2), a parameter range refers to a min/max range for a given parameter (yellow shaded cell in Table 2).

Table 2: Simplified extract of raw database

| Country | Income | Water consumption [L/(cap * d)] | BOD [g/(cap * d)] |
|---|---|---|---|
| **Zambia** | LMI | 120 | 36 - 44 |

System types (BORDA, 2017):

- SSS: DEWATS treating the grey- and/ or blackwater of several private households, connected via a small sewer system
- CSC: DEWATS treating the grey- and/ or blackwater of a community sanitation centre
- Hybrid: DEWATS connected to a small sewer system and a community sanitation centre, a combination between SSS and CSC

Global w/o industrialised countries:

Wastewater characteristics from countries/regions, which are not considered as industrialised countries. These values are used as global references for parameter ranges for DEWATS application.

Residential vs. Domestic vs. Communal:

Domestic in this study refers to activities on the household level whereas residential includes all human activities in residential areas such as wastes generated from public and private institutions (e.g. schools, offices, businesses). Communal is used to refer to either domestic or residential setups as generic term.

# 2 Methodology for Data Collection and Preparation

## 2.1 Data Collection

Values for wastewater characteristics were collected from various literature sources. Data was obtained by web and library-based searches and through contacting experts in the sector. Following experts contributed through their communication to the data collection of this work:

Table 3: Experts from the sanitation sector contacted to obtain data on wastewater characteristics

| No. | Name | Organisation | Response | Relevant data input |
|---|---|---|---|---|
| 1 | Andreas Schmidt | BORDA e.V. | Yes | Yes |
| 2 | Aubrey Simwambi | BORDA Zambia | Yes | Yes |
| 3 | Björn Pietruschka | BORDA South Africa / PRG (UKZN) | Yes | Yes |
| 4 | Chris Buckley | PRG (UKZN) | Yes | Yes |
| 5 | David Ikumi | UCT | No | No |
| 6 | Elisabeth Münch | SuSanA | Yes | Yes |
| 7 | Elizabeth Tilley | University of Malawi | Yes | No |
| 8 | Godlove Ngoda | BORDA Tanzania | Yes | Yes |
| 9 | Hendra Gupta | BORDA Thailand | Yes | Yes |
| 10 | Jeannette Laramee | Stanford University / BORDA e.V. | Yes | Yes |
| 11 | Jorge Bachur | ENRESS Santa Fe, via SuSanA | Yes | Yes |
| 12 | Nicolas Reynaud | BORDA Indonesia | Yes | Yes |
| 13 | Phillippe Reymonde | EAWAG | Yes | Yes |
| 14 | Sudhir Pillay | WRC | Yes | Yes |

The digital search was done by searching for relevant key-words in university library catalogues and search engines. The key words were assessed according to the number of total hits, their relevance and the number of relevant documents obtained. The relevance is rated according the title and abstract of the documents and based on that the likelihood to find per capita wastewater characteristics:

Table 4: List of key searches from library catalogues

| No. | Search word | Hits | Relevance | Relevant hits |
|---|---|---|---|---|
| 1 | Waste water | High | Medium | 2 |
| 2 | Wastewater | High | High | 5 |
| 3 | Wastewater characteristic | High | High | 3 |
| 4 | Waste water characteristic | High | Low | 0 |
| 5 | Population equivalent | Low | Low | 0 |
| 6 | Population equivalent wastewater | Low | Low | 0 |
| 7 | DEWATS | Medium | High | 3 |
| 8 | On-site sanitation | Low | Low | 1 |
| 9 | Waste characteristic | High | Low | 0 |

The library search did not result in a high number of relevant documents found due to the fact that many sources do not define per capita values, but rather concentrations of pollutants and very general values for water consumption and wastewater production without detailed definition of the local context and the actual water and wastewater sources. The majority of relevant documents were obtained through direct contact with experts in the field and from the bibliography of relevant documents.

## 2.2 Literature Overview

109 documents have been obtained and studied during the literature review and values from 82 sources were derived and analysed. A number of research papers and books were already classified as not relevant after the study of the abstract and therefore not obtained and are not included in the literature lists provided in this report.

A total number of 487 parameter sets with a total of 2395 data points were obtained from the literature. A parameter set refers to one row of raw data consisting of classification criteria and data points for the available wastewater characteristics. Hence, each parameter set consists of an average of approximately 5 data points.

The literature deemed to be relevant for this study is listed in the bibliography in Chapter 10. Literature that was reviewed and deemed to be not relevant is listed below, so that these documents do not need to be studied for future per capita wastewater characteristics investigations. Main reason for the documents being of no relevance for these investigations being the lack of per capita values, but wastewater characteristics stated in concentrations.

List of reviewed literature deemed to be not relevant:

1) Bodkhe, S. Y. (2009) 'A modified anaerobic baffled reactor for municipal wastewater treatment', Journal of Environmental Management. Elsevier Ltd, 90(8), pp. 2488–2493. doi: 10.1016/j.jenvman.2009.01.007.
2) Buckley, C., Pietruschka, B. and Pillay, S. (2014) 'DEWATS Process for Decentralised Wastewater Treatment - Technical Lessons From eThekwini Municipality', WIN-SA Lesson Series, (June), pp. 1–12.
3) Choukr-Allah, R. (2005) 'Wastewater Treatment and Reuse in Morocco - Situation and Perspectives', Non-conventional water use: WASAMED project, pp. 271–287.
4) Deng, W., Cheng, S.-F., Chen, J.-W., Yen, H.-M., Kao, C.-M., Tu, Y.-T., Huang, C.-Y. and Chen, J.-R. (2012) 'The Characteristics of Taiwan Domestic Wastewater Sludge and the Feasibility of Reusing for Growing Edible Crops', in AASRI Conference on Modeling, Identification and Control. Elsevier B.V., pp. 307–312. doi: http://dx.doi.org/10.1016/j.aasri.2012.11.049.
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13) Oliveira, S. C. and Von Sperling, M. (2008) 'Elements for setting up discharge standards in developing countries based on actual wastewater treatment plant performance', Water Science and Technology, 58(10), pp. 2001–2008. doi: 10.2166/wst.2008.756.
14) Pasztor, I., Thury, P. and Pulai, J. (2008) 'Chemical oxygen demand fractions of municipal wastewater for modeling of wastewater treatment', International Journal of Environmental Science & Technology, 6(1), pp. 51–56. doi: 10.1007/BF03326059.

15) Pillay, S., Foxon, K. M. and Buckley, C. A. (2008) 'An anaerobic baffled reactor/membrane bioreactor (ABR/MBR) for on-site sanitation in low income areas', Desalination, 231(1–3), pp. 91–98. doi: 10.1016/j.desal.2007.10.023.
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22) Roma, E. (2010) Case study of sustainable sanitation projects - Community ablution blocks with sewers or infiltration - eThekwini (Durban), South Africa.
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## 2.3 Data Collation

Each parameter set is classified based on the context and information provided in the literature. All available information of the context of the respective studies were included in the raw database, because the specific classification criteria and their distinctive features were not known, by the time the data was collated. Criteria and features were standardised in the data preparation to enable comparison of parameter sets. Main objective of this is to determine the main influencing factors on wastewater characteristics.

## 2.4 Data Preparation

Literature values refer to a certain context and are provided for a widely differing level of detail, between very general (e.g. ‘developing countries’) and very context specific (e.g. sampling results from M&E missions). However, the criteria applied are not standardised and also the differentiation within a criterion differs from source to source. Therefore, standardised classification criteria and distinctive features are defined. The parameter sets from the raw data are associated to these features according to the context provided in the literature to enable clustering and comparability of the parameter sets. Criteria and their features and their respective definition are provided in this section. Not all specified criteria and features are applicable to the objective of the study. Thus, the data preparation is also used to remove the non-applicable parameter sets from the data analysis.

### 2.4.1 Classification Criteria for Parameters

Table 5: Overview of standardised classification criteria and distinctive features

| Classification criteria | Macro classification | Region/ Country | Income (global / local) | Climate | Urban/ Rural | WWTP Size | Water Access | Sanitation Interface | Wastewater Source |
|---|---|---|---|---|---|---|---|---|---|
| **Distinctive features** | Global | East Asia & Pacific: Bangladesh, Cambodia, China, Fiji, Indonesia, Lao, Philippines, South Korea, Thailand, Vietnam | LI | Arid | Urban | ≤ 100 cap. | In house | Private – full flush | Domestic |
| | Global w/o Industrialised Countries | Eastern Europe & Central Asia: Turkey | LMI | Moderate | Rural | > 100 – 1,000 cap. | Yard tap | Private – pour flush | Residential |
| | Developing Countries | Latin America & Caribbean: Brazil, Mexico | UMI | Tropical | Semi-urban | > 1,000 – 10,000 cap. | Public – unltd | Shared – full flush | Blackwater (total, faeces, urine, anal cleansing water) |
| | Emerging Countries | Middle East & North Africa: Algeria, Egypt, Iran, Jordan, Morocco, Palestine, Syria, Tunisia, Yemen | HI | Diverse | | > 10,000 – 100,000 cap. | Public - ltd | Shared – pour flush | Greywater (total, shower & bath, kitchen, laundry) |
| | Industrialised Countries | North America: USA | | | | > 100,000 cap. | | Dry | Urban storm water |
| | | South Asia: Afghanistan, India, Pakistan | | | | | | | |
| | | Sub-Sahara Africa: Botswana, Kenya, Lesotho, Mali, Nigeria, South Africa, Tanzania, Uganda, Zambia | | | | | | | |
| | | West & Central Europe: Denmark, England, Germany, Italy, Sweden | | | | | | | |

Household size:

It is necessary in this study to convert the number of households into number of inhabitants to determine per capita income based on household income values and to determine the number of connected users, if the number of connected households is stated in a data source. Based on investigations on average household sizes in developing countries and the necessity of a simple, universal factor for easy conversion a value of 5 inhabitants per household is found to be suitable as it a realistic value and allows easy conversion (Bongaarts, 2001).

Macro classification:

Most general differentiation criteria. The values for the distinctive feature “Global” consist of all available parameter sets as global average. The feature “Global w/o Industrialised Countries” consists of all values except the values specifically for industrialised countries. These values serve as benchmark values, as this study focusses on design parameter values for DEWATS systems in developing countries. The feature “Emerging Countries” is defined based on a modified definition of BRICS and N-11 countries (Euromonitor International, 2017). This is done to cater for the widely ranging level of development in non-industrialised countries. Countries falling into this definition are

- Brazil
- China
- Egypt
- India
- Mexico
- South Africa
- Thailand

Industrialised countries are members of the OECD. Developing countries are all countries, for which parameter sets are listed and not falling into the above-mentioned definition.

Region/Country:

Countries within the focus of BORDA’s activities were prioritised for data collection. Nonetheless, when data was obtained from countries to be used as references, these were also included in the database.

The regions are differentiated according to the geographic regions as defined by the World Bank (The World Bank, 2017a) with one exception: The region “Europe and Central Asia” is subdivided into “Eastern Europe and Central Asia” and “West and Central Europe” with the boundary being the eastern border of the European Union to account for the wide range of different countries within the region.

Income – global/local context:

Each country is classified into one of four income classes as per World Bank definition (The World Bank, 2017c) (The World Bank, 2017b). The basis of this classification is the per capita GNI according to the Atlas Methodology. Following thresholds are applicable for the fiscal year 2017 (The World Bank, 2017c):

- Low income (LI) <= 1,025 US$ p.a. (≈ 427 US$/HH*month)
- Lower middle income (LMI) 1,026 – 4,035 US$ p.a. (≈ 428 – 1,681 US$/HH*month)
- Upper middle income (UMI) 4,036 – 12,475 US$ p.a. (≈ 1,682 – 5,198 US$/HH*month)
- High income (HI) > 12,475 US$ p.a. (≈ 5,199 US$/HH*month)

Monthly household income values are calculated with an average household size of 5 as stated above. If the average per capita or household income is given in the literature for a specific parameter set, these values are put in the local context, by assessing the classification and definition provided in the data source and comparing it with the definition above. If the year of data collection is stated, historical values as per World Bank definition are used (The World Bank, 2017b).

Climate – Macro/local context:

The climate of each country is defined using the Köppen-Geiger climate classification (M. C. Peel, Finlayson and McMahon, 2007b). As a measure of simplification, the features are limited to arid, moderate and tropical climate, whereas each category consists of following Köppen-Geiger classes:

- Arid: B
- Moderate: C & D
- Tropical: A
- Diverse: diverse climate with no prevalence of a single climate classes

The prevailing climate of a country and region is determined through visual assessment of a global Köppen-Geiger map (M. Peel, Finlayson and McMahon, 2007).

If different classes exist in a specific country the most prevailing climate is chosen (e.g. Kenya: arid and tropical areas, but arid areas outbalance tropical areas). Nonetheless, several large countries cannot be assigned to a single climate classification (e.g. China, India). In these cases, the climate is stated as diverse and this parameter cannot be used in further investigation on the respective country.

The local climate is considered where the literature states a significant difference for areas with different temperatures and precipitations or if data from different seasons is available.

Climate classes for the regions are adopted from the predominant class of the countries within the region, where applicable and defined as diverse otherwise.

Urban/Rural:

A number of sources, such as state particular values for certain cities, urban and sub-urban areas as well as for rural areas (CPHEEO, 1993) (Salama *et al.*, 2014) (UNEP, 2000) (von Sperling, 2008). Several sources also state that water consumption and wastewater generation per capita are higher in urban areas, because of the higher amount of institutions and commercial setups contributing to the water and wastewater streams on one side and different lifestyles and user habits on the other (Montangero, 2007b) (Fourie and van Reyneveld, 1993) (Von Sperling and Lemos Chernicharo, 2005). This criterion is related to the criterion “Wastewater source”.

Wastewater treatment plant (WWTP) size:

This criterion refers to the number of connected users of a WWTP. If only the number of connected households is specified and the average number of persons per household is not specified, the above mentioned average household size (1 HH = 5 cap.) is used to calculate the number of people. This criterion is only relevant for the determination of peak flow factors as the treatment plant does not influence the user habits and patterns.

Water access:

The definition and classification of water access differs widely in the literature. The chosen standardised classes are based on the definition from the Joint Monitoring Programme (JMP) by UNICEF and WHO (WHO and UNICEF, 2015) and adjusted according to field investigations on public water points and community ablution blocks in informal settlements in South Africa (Crous, 2014). A public water access is considered unlimited, if the distance to the water access point is closer than 200 m from the household and limited for further distances. Water kiosks, wells and handpumps are generally classified as limited access. The classes for water access are closely related to the classes in the criterion “Sanitation Interface”. Following features are defined:

- In house
- Yard tap
- Public – unltd (e.g. public standpipe < 200 m, CSC)
- Public – ltd (e.g. public standpipe > 200 m, water kiosk, handpump, well)

Sanitation interface:

The criterion sanitation interface consists of five features, of which the category “dry” is only relevant for organic and nutrient loads, but not for water usage values, because of their irrelevance for DEWATS systems. The other features specify whether a sanitation interface is private or shared (community sanitation centres or community ablution blocks) and full flush or pour flush toilets.

Wastewater source:

This criterion consists of a high number of distinctive features to consider values for different types of wastewater (domestic vs. residential, blackwater vs. greywater) and subdivides blackwater and greywater into their main constituents. Domestic wastewater refers to wastewater strictly from households, residential wastewater consists of wastewater from households plus commercial and institutional buildings within residential areas (e.g. schools, religious centres, offices). Although the latter are not relevant for communal DEWATS design, it is assumed that values from urban areas include a significant proportion of water, organic and nutrient loads from commercial/institutional establishments, which has to be considered when deriving realistic parameter ranges.

### 2.4.2 Elimination of Duplicates and Extreme Values

Values that were observed to be far out of the typical range or did not fit in the classification criteria of this study were excluded from the raw database. An example is a per capita water consumption of 3,588 L/cap*d at public water points in Vietnam, obtained from the IBNET database, which must be subject to wrong calculations and/or data collection (IBNET, 2017). Wastewater production values which were calculated based on water consumption and an estimated water return coefficient are excluded from the database, as they are based on assumptions and pretend a false level of accuracy. Furthermore, data duplicates cited from different secondary sources, but originating from the same primary source were eliminated to avoid over-weighing of single parameters.

The eliminated values are marked with an asterisk (‘*’), so that the values are still shown in the database, but are not taken into consideration for further calculations.

Both, the elimination of duplicates and extreme values were executed manually. Therefore, despite care was taken when analysing the parameter sets, it cannot be guaranteed, that duplicates do not exist in the database.

After the elimination of values, a total number of 2151 data points remained which were used as data input for the parameter analysis.

### 2.4.3 Conversion of Standard Deviation into Minimum/Maximum Values

Parameter ranges from the literature are either stated as min/max ranges (e.g. 80 – 120 L/cap*d) or as mean values with standard deviations (e.g. 100 ± 10 L/cap*d), assuming that the parameters are normal distributed. It is decided here to express parameter ranges in the form of min./max. ranges, because it cannot be expected that every practitioner is able to interpret standard deviations correctly to derive actual quantified parameter ranges as design values; additionally, the notation as mean and standard deviation can only express symmetric distributions, such as normal distributions and cannot display skewed distributions with non-symmetric mean values, unless the hypothesised distribution function is defined. However, skewed distributions are better suitable to describe the distribution of naturally positive values such as wastewater characteristics (Montangero, 2007a).

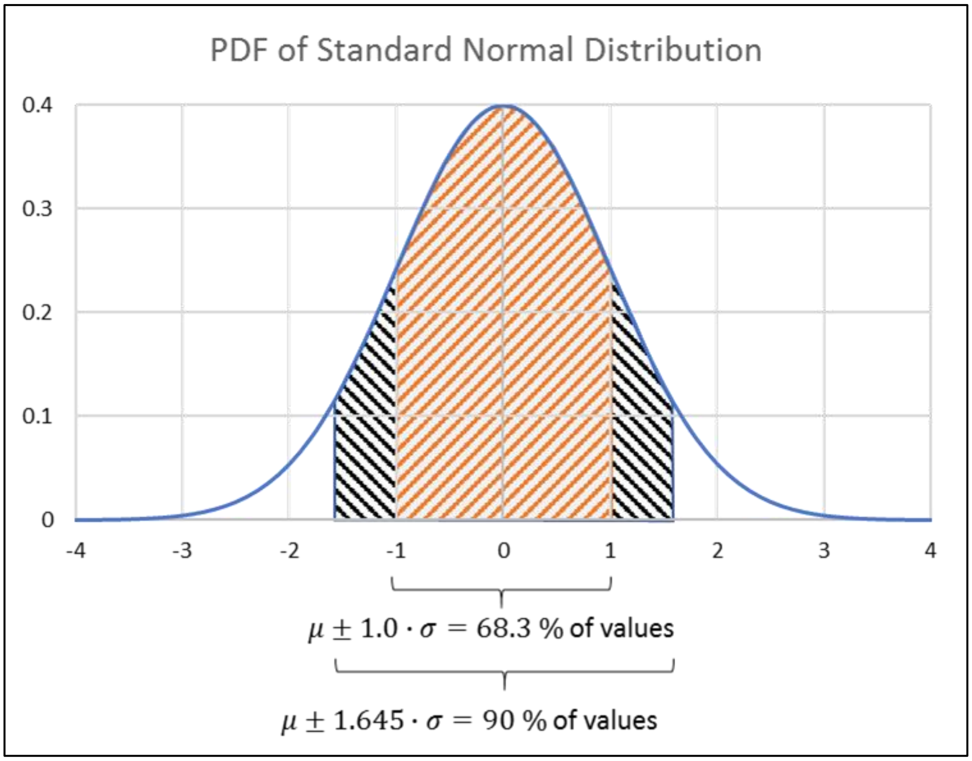



Figure 1: Probability density function with characteristic Φ(z)-values of standard normal distribution

To allow comparison of these two notations a conversion rule has to be defined. It is hypothesised that min/max ranges show a two-sided confidence level of 90% (unless stated otherwise in the source), meaning that 90% are included in the range so that 5% smallest and largest values are not represented. In reverse, the mean value plus-minus standard deviation represents 68.3% of all values for normal distributions. This can be calculated using the probability density function (PDF) and the cumulative distribution function (CDF), also known as Φ(z)-function of the standard normal distribution and is shown in Figure 1. The CDF of 0.95 (right-sided confidence level) calculates to 1.645 (Φ(1.645) = 0.95), which is used as conversion factor between the two notations. The mean value for a given min/max range is calculated as arithmetic mean of min and max values. An example of how min/max ranges are calculated for given mean and standard deviation values is shown in Table 6:

Table 6: Conversion of min/max ranges and mean ± SD values

| | min | max | mean | SD |
|---|---|---|---|---|
| **Given: mean and SD** | $\mathrm{mean} - 1.645 \cdot \mathrm{SD} = 84$ | $\mathrm{mean} + 1.645 \cdot \mathrm{SD} = 116$ | 100 | 10 |

## 2.5 Structure, Computation and Update of the Wastewater Characteristics Databases

Within the scope of this study two Excel databases have been created: a research database and a design database. The research database contains all relevant datasets and analysis based thereupon. It consists of four main sheets, namely:

1. **Database – raw:**
   Lists all parameter sets and data points obtained from the literature including classification information on the context and the sources. The sheet is designed in a manner that new values can be added if further parameter sets are gathered (see Chapter 2.5.2).
2. **Database – clean:**
   Statistical analysis of the data points and generation of factors depending on major influencing factors according to the provided context
3. **Database – output:**
   Simplified summary of processed factors and preparation of factors to be used for the parameter design interface.
4. **Design parameter – UI[1]:**
   User interface for DEWATS parameter design based on developed factors. Design engineers receive guidance in form of parameter ranges and mean values for each design parameters and can select appropriate parameters manually or adopt suggested parameters as a quick pre-design option.

Furthermore, the database consists of auxiliary sheets with dropdown parameters and bibliography, which are not explained further here.

Because of the tremendous computing time for changes to be applied in the research database a second, simplified design database is generated. This database is decoupled from the research database and only contains the sheets 3 and 4 of the research database. Formula links are broken up so that only the values of the developed factors are included to increase the computing performance of this database. Hence, if the research database is updated and a new version generated, the sheet "Database – output" of the design database has to be updated manually (see Chapter 2.5.3).

### 2.5.1 Spreadsheet Calculation Settings

Because of the tremendous computing time for the spreadsheet calculation, induced by the computationally intensive matrix formulas applied to compute the factors for the influencing parameters, the sheet computation has to be switched to manual calculation, which can be executed by changing the calculation options switch to *Formulas → Calculation → Calculation Options → Manual*[2] (see Figure 2). This is only necessary for the research database and not for the design database. Formulas are not automatically calculated when this option is activated, which drastically increases the performance of this spreadsheet. Single formulas can be computed by activating

[1] UI = user interface

[2] Applies to Microsoft Excel 2016

the respective cell and confirming with *Enter.* The whole spreadsheet can be calculated by using the *Calculate Now* option in the same sub-menu. Note: The calculation of the spreadsheet can take up to a few minutes depending on the computer's performance.

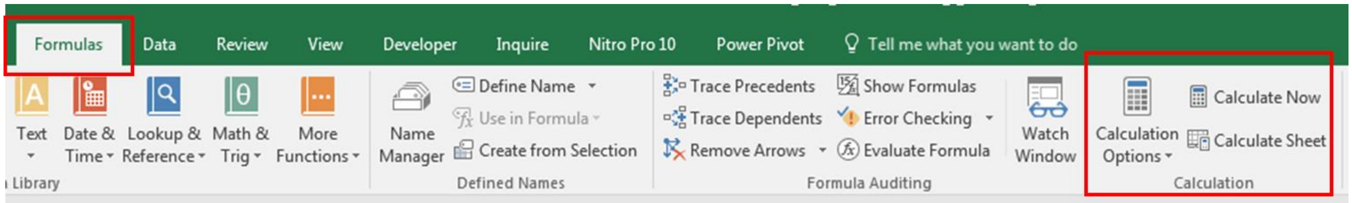



Figure 2: Switch to turn on manual sheet calculation

## 2.5.2 Addition of Values into the Research Database

The database is designed in a way that additional values can be added and automatically considered for the data analysis and calculation of factors. To reduce the computing time of the matrix formulas applied to derive factors for the main influencing parameters, the number of rows in the sheet "Database – raw" is readout. Therefore, a hint is given below the last row in column A of the aforementioned sheet: "DO NOT ENTER DATA BELOW HERE! (insert cells above!)" (Figure 3). Instead, new rows need to be inserted at any position in the database above the last row. New columns shall not be included to prevent reference errors through relative references in the computation algorithms of the factors.

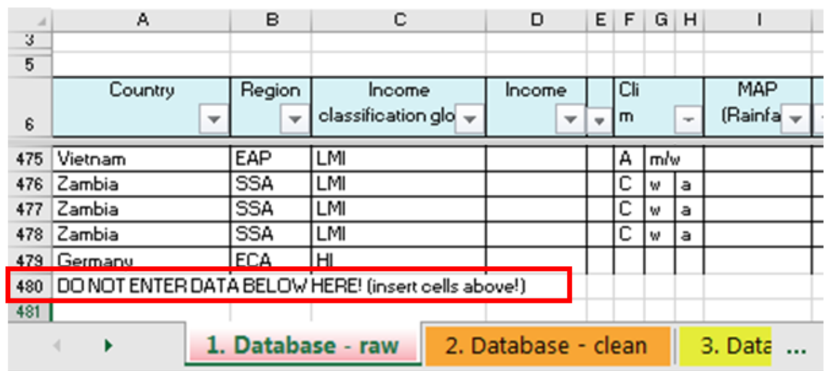



Figure 3: Hint in sheet "Database - raw" of the research database to not add new values below the last parameter set (row)

The columns to be filled with information about the context of the parameter are columns T to W for institutional and industrial systems and columns AC to AO for information about the defined classification criteria. These columns are shaded in light grey. Note: Columns AC, AE, AG and AH contain formulas to classify the respective country according to income and climate (further elaborated in Chapter 3.7), which have to be copied manually.

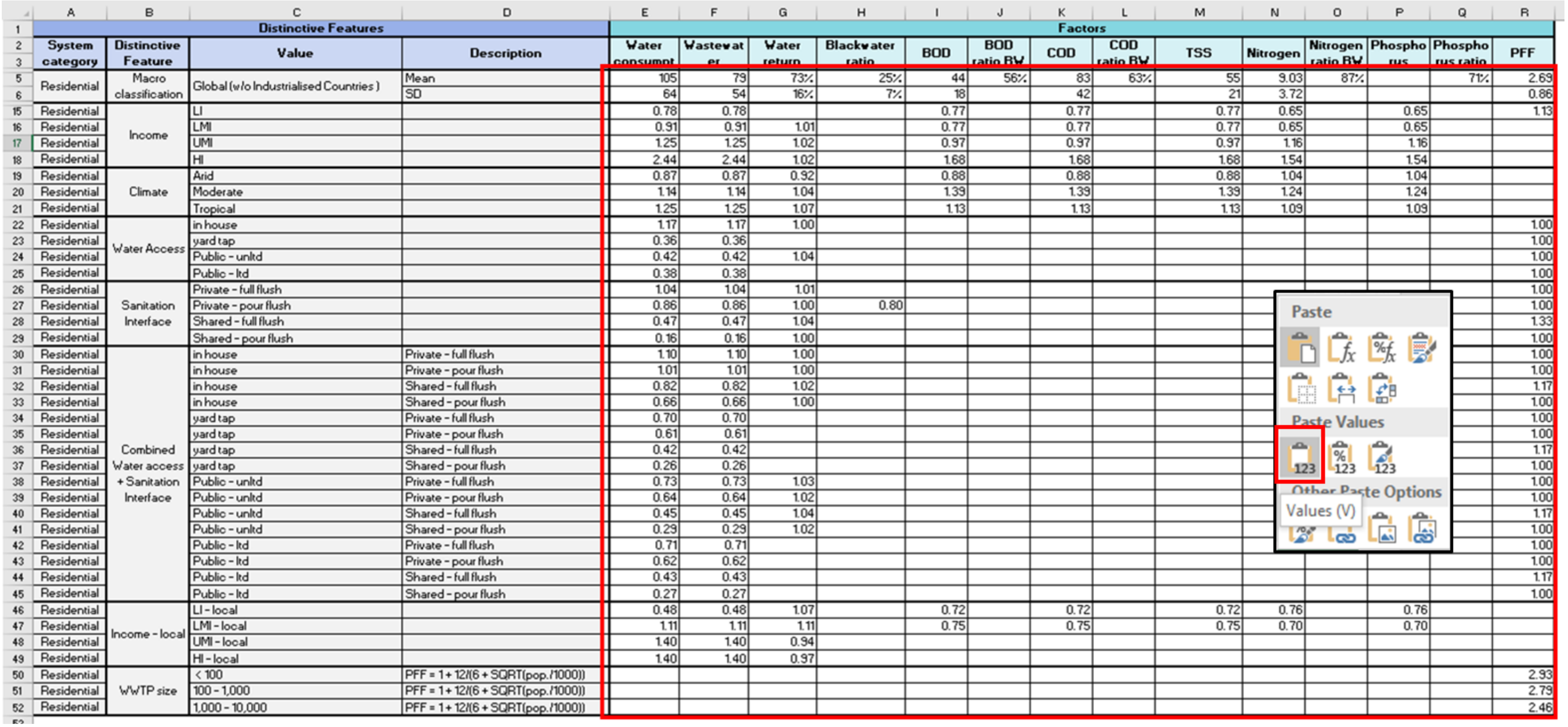
Individual comments shall be provided in column AQ and the data source shall be mentioned in columns AR to AU. Values are inserted in columns AW to PF for respective parameters. Following this procedure new values are automatically considered for the computation of the factors in the successive sheets.

| AC<br>System category | AD<br>Macro classification | AE<br>Region | AF<br>Country | AG<br>Income – Macro | AH<br>Climate – Macro | AI<br>Income – Local | AJ<br>Climate – Local | AK<br>Urban/ Rural |
|---|---|---|---|---|---|---|---|---|
| Residential | Global | | | | Diverse | | | |
| Residential | Developing Countrie | EAP | Indonesia | LMI | Tropical | | | |
| Commercial/Institutional | | EAP | | LMI | Tropical | | | |
| Commercial/Institutional | | EAP | | LMI | Tropical | | | |

Figure 4: Extract from the sheet "Database - raw" showing a selection of classification parameters

### 2.5.3 Update of Design Database

To update the factors relevant for the design parameter user interface (sheet "4. Design parameter – UI") the values from the sheet "3. Database – output" of the research database have to be copied into the sheet "1. Database – output" of the design database. Therefore, the range E5:R52 has to be copied and the option *Paste* → *Paste Values* → *Values* of the pasting context menu has to be selected as shown in Figure 5.




| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Distinctive Features | | | | Factors | | | | | | | | | | | | | |
| 2<br>3 | System category | Distinctive Feature | Value | Description | Water consumpt | Wastewat er | Water return | Blackwater ratio | BOD | BOD ratio BW | COD | COD ratio BW | TSS | Nitrogen | Nitrogen ratio BW | Phospho rus | Phospho rus ratio | PFF |
| 5 | Residential | Macro classification | Global (w/o Industrialised Countries ) | Mean | 105 | 79 | 73% | 25% | 44 | 56% | 83 | 63% | 55 | 9.03 | 87% | | 71% | 2.69 |
| 6 | | | | SD | 64 | 54 | 16% | 7% | 18 | | 42 | | 21 | 3.72 | | | | 0.86 |
| 15 | Residential | Income | LI | | 0.78 | 0.78 | | | 0.77 | | 0.77 | | 0.77 | 0.65 | | 0.65 | | 1.13 |
| 16 | Residential | | LMI | | 0.91 | 0.91 | 1.01 | | 0.77 | | 0.77 | | 0.77 | 0.65 | | 0.65 | | |
| 17 | Residential | | UMI | | 1.25 | 1.25 | 1.02 | | 0.97 | | 0.97 | | 0.97 | 1.16 | | 1.16 | | |
| 18 | Residential | | HI | | 2.44 | 2.44 | 1.02 | | 1.68 | | 1.68 | | 1.68 | 1.54 | | 1.54 | | |
| 19 | Residential | Climate | Arid | | 0.87 | 0.87 | 0.92 | | 0.88 | | 0.88 | | 0.88 | 1.04 | | 1.04 | | |
| 20 | Residential | | Moderate | | 1.14 | 1.14 | 1.04 | | 1.39 | | 1.39 | | 1.39 | 1.24 | | 1.24 | | |
| 21 | Residential | | Tropical | | 1.25 | 1.25 | 1.07 | | 1.13 | | 1.13 | | 1.13 | 1.09 | | 1.09 | | |
| 22 | Residential | Water Access | in house | | 1.17 | 1.17 | 1.00 | | | | | | | | | | | 1.00 |
| 23 | Residential | | yard tap | | 0.36 | 0.36 | | | | | | | | | | | | 1.00 |
| 24 | Residential | | Public - unltd | | 0.42 | 0.42 | 1.04 | | | | | | | | | | | 1.00 |
| 25 | Residential | | Public - ltd | | 0.38 | 0.38 | | | | | | | | | | | | 1.00 |
| 26 | Residential | Sanitation Interface | Private - full flush | | 1.04 | 1.04 | 1.01 | | | | | | | | | | | 1.00 |
| 27 | Residential | | Private - pour flush | | 0.86 | 0.86 | 1.00 | 0.80 | | | | | | | | | | 1.00 |
| 28 | Residential | | Shared - full flush | | 0.47 | 0.47 | 1.04 | | | | | | | | | | | 1.33 |
| 29 | Residential | | Shared - pour flush | | 0.16 | 0.16 | 1.00 | | | | | | | | | | | 1.00 |
| 30 | Residential | Combined Water access + Sanitation Interface | in house | Private - full flush | 1.10 | 1.10 | 1.00 | | | | | | | | | | | 1.00 |
| 31 | Residential | | in house | Private - pour flush | 1.01 | 1.01 | 1.00 | | | | | | | | | | | 1.00 |
| 32 | Residential | | in house | Shared - full flush | 0.82 | 0.82 | 1.02 | | | | | | | | | | | 1.17 |
| 33 | Residential | | in house | Shared - pour flush | 0.66 | 0.66 | 1.00 | | | | | | | | | | | 1.00 |
| 34 | Residential | | yard tap | Private - full flush | 0.70 | 0.70 | | | | | | | | | | | | 1.00 |
| 35 | Residential | | yard tap | Private - pour flush | 0.61 | 0.61 | | | | | | | | | | | | 1.00 |
| 36 | Residential | | yard tap | Shared - full flush | 0.42 | 0.42 | | | | | | | | | | | | 1.17 |
| 37 | Residential | | yard tap | Shared - pour flush | 0.26 | 0.26 | | | | | | | | | | | | 1.00 |
| 38 | Residential | | Public - unltd | Private - full flush | 0.73 | 0.73 | 1.03 | | | | | | | | | | | 1.00 |
| 39 | Residential | | Public - unltd | Private - pour flush | 0.64 | 0.64 | 1.02 | | | | | | | | | | | 1.00 |
| 40 | Residential | | Public - unltd | Shared - full flush | 0.45 | 0.45 | 1.04 | | | | | | | | | | | 1.17 |
| 41 | Residential | | Public - unltd | Shared - pour flush | 0.29 | 0.29 | 1.02 | | | | | | | | | | | 1.00 |
| 42 | Residential | | Public - ltd | Private - full flush | 0.71 | 0.71 | | | | | | | | | | | | 1.00 |
| 43 | Residential | | Public - ltd | Private - pour flush | 0.62 | 0.62 | | | | | | | | | | | | 1.00 |
| 44 | Residential | | Public - ltd | Shared - full flush | 0.43 | 0.43 | | | | | | | | | | | | 1.17 |
| 45 | Residential | | Public - ltd | Shared - pour flush | 0.27 | 0.27 | | | | | | | | | | | | 1.00 |
| 46 | Residential | Income - local | LI - local | | 0.48 | 0.48 | 1.07 | | 0.72 | | 0.72 | | 0.72 | 0.76 | | 0.76 | | |
| 47 | Residential | | LMI - local | | 1.11 | 1.11 | 1.11 | | 0.75 | | 0.75 | | 0.75 | 0.70 | | 0.70 | | |
| 48 | Residential | | UMI - local | | 1.40 | 1.40 | 0.94 | | | | | | | | | | | |
| 49 | Residential | | HI - local | | 1.40 | 1.40 | 0.97 | | | | | | | | | | | |
| 50 | Residential | WWTP size | < 100 | PFF = 1 + 12/(6 + SQRT(pop./1000)) | | | | | | | | | | | | | | 2.93 |
| 51 | Residential | | 100 - 1,000 | PFF = 1 + 12/(6 + SQRT(pop./1000)) | | | | | | | | | | | | | | 2.79 |
| 52 | Residential | | 1,000 - 10,000 | PFF = 1 + 12/(6 + SQRT(pop./1000)) | | | | | | | | | | | | | | 2.46 |

**Figure 5: Pasting updated values from the research database into the design database**

### 2.5.4 Viewing, Grouping and Filtering of Data in the Database

Because of the large size of the sheet "*1. Database raw*", several tools were integrated to view, group and filter the raw data for improved transparency and traceability of parameter sets and data points:

**Grouping:**

Columns are grouped in four hierarchy levels according to categories to show or hide certain columns to increase or decrease the number of columns that are displayed.

**Split Screen:**

The split option is activated to enable scrolling through the database on a sub-screen and keeping important information locked on another sub-screen. The split positions can be adjusted by the user according to the needs.

**Filter:**

Data filters are applied to show and hide parameters meeting certain requirements. Group filters for the filtering of main parameters (i.e. all parameter sets that contain nutrient and pollutant data - BOD, COD, TKN, TP), are provided in columns Z:AB. Parameter sets containing at least one of the respective data points are labelled with "*1*". By disabling the values "*0*" in the filter only shows parameter sets that contain data on the respective parameter Figure 6.

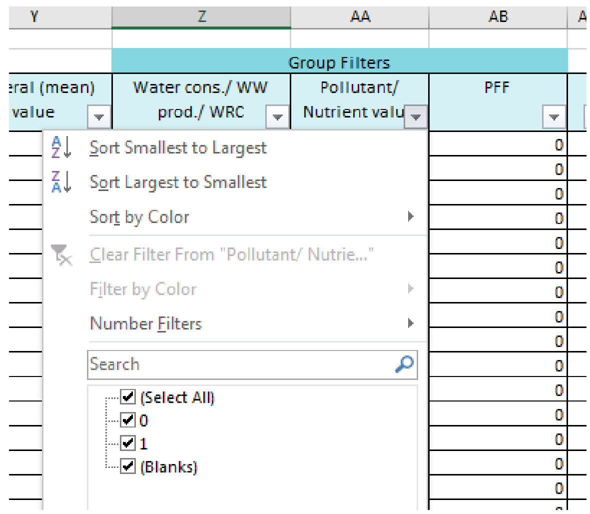



Figure 6: Filtering the database using provided group filters

# 3 Methodology for Quantitative Data Analysis

According to the study's objective to form the basis for improved DEWATS design procedures, the data analysis aims to determine main influencing factors on relevant per capita wastewater characteristic's parameter to identify whether correlations exist and how they can be quantified. Despite a number of parameter sets for institutional/commercial, agricultural and industrial setups being obtained from the literature, this analysis is limited to communal systems (SSS, CSC or hybrid) treating domestic wastewaters, because the amount of available data is insufficient for a detailed data analysis of non-communal systems. Hence, design engineers need to refer to the tabularised values summarised in Chapter 4.2 and 4.3 for the design of institutional/commercial and industrial systems.

Only few of such studies have been carried out, for example by Campos and von Sperling (1996), assessing the influence of socio-economic variables on per capita wastewater characteristics in the city of Belo Horizonte, which is said that "*the general principles can be extrapolated to other cities in Brazil, since they have approximately the same living standards and patterns as those from Belo Horizonte*" (Campos and von Sperling, 1996, p. 7). Sperling *et al.* (2002) furthermore assessed the combined influence of mean annual precipitation (MAP), average household income and municipality's population on the water consumption, resulting in higher consumption for higher income, MAP and more populous municipalities. A study carried out by the sanitation service regulator (ENRESS) in the province of Santa Fe, Argentina assessed the per capita water supply and organic pollutant loads based on community size and socio-economic status, using the level of satisfied basic needs as benchmark parameter (Bachur and Ferrer, 2013). The results show significantly higher water supply and slightly higher per capita BOD loads for bigger communities and higher socio-economic level of the community. The report explicitly encourages other provinces in Argentina to carry out similar studies to serve as reliable design basis for new treatment plants. Moreover, Mara (2004) addresses the usefulness of "the derivation of similar equations [as developed by Campos and von Sperling (1996)] for African and Asian developing countries […]." However, Reynaud (2014) did not find significant correlation between average household income and wastewater production in 11 DEWATS system in Indonesia, reasoning this observation with the readily availability of freshwater from shallow wells.

From the studies quoted above it becomes apparent that the general applicability and transferability is limited. Therefore, the identified main influencing parameters (average household income, climate, community size, satisfied basic needs) are taken into account, but a more general approach is taken to derive more general correlations. Benchmark values are calculated using all available and relevant values for each wastewater characteristic to determine a global mean value, which is used to calculate factors for selected configurations.

Based on the parameter sets obtained, distribution parameters, such as mean values, standard deviation and a range of minimum and maximum values are calculated, to provide design engineers not only with an average value, but with a parameter range to represent the whole spectrum of realistic parameters for a given configuration.

## 3.1 Calculation of Arithmetic Mean and Standard Deviation

For the calculation of arithmetic mean $\bar{x}$ and standard deviation $s$ of each wastewater characteristic, not only the mean value of each parameter set is considered, but also the min and max values, if a range is given in the literature. This has the advantage of significantly increasing the amount of data points through consideration of min and max values and thereby weighing parameter sets, consisting of min, max and mean values three times as high as parameter sets that only provide a mean value. Furthermore, some parameter sets explicitly only state maximum values, which would be neglected, if only mean values were considered. This procedure is highlighted in a simple example in Table 7. Result 1 only takes mean values into account, calculating a mean value of $\bar{x}$ = 112 with n = 3 data points and a standard deviation of s = 10.4. Result 2 considers all data points available resulting in a mean value of $\bar{x}$ = 114 with n = 8 data points and a standard deviation of s = 23.8. The same mean value would be calculated if the mean value of the parameter sets containing ranges was multiplied by 3 and the remaining values considered with a weight of 1:

$$[1]\ \bar{x}_{Result\ 2} = \frac{100 \cdot 3 + 120 + 150 + 115 \cdot 3}{8} = 114$$

In conclusion, this methodology enables the consideration of all available parameters and a higher rating of parameter sets containing ranges. It causes a bias towards values with min and max ranges and significantly higher standard deviations leading to wider parameter ranges, which has to be considered in the interpretation of the results. However, this bias is towards parameter sets with presumably better reliability, because a sampling series is necessary to define minimum and maximum values.

**Table 7: Example calculation of mean values of wastewater characteristics considering only mean values of parameter sets vs. considering min, max and mean values**

| Parameter set | Min | Max | Mean |
|---|---|---|---|
| Parameter set 1 | 80 | 120 | 100 |
| Parameter set 2 | | | 120 |
| Parameter set 3 | | 150 | |
| Parameter set 4 | 90 | 140 | 115 |
| **Result 1 (considering only mean values)** | **n = 3**<br>**$\bar{x}$ = 112**<br>**s = 10.4** | | |
| **Result 2 (considering all values)** | **n = 8**<br>**$\bar{x}$ = 114**<br>**s = 23.8** | | |

## 3.2 Distribution Function: Log-Normal Distribution

The normal distribution is commonly used to represent real-valued random variables whose distribution are not known. Particularly randomly distributed values of several independent variables, which are intrinsically positive are commonly expressed as logarithmic normal distribution (Eckhardt Limpert, Werner A. Stahel and Markus Abbt, 2001). In contrast to the normal distribution, the log-normal distribution has the crucial characteristic that values are always positive, independent from the magnitude of the standard deviation (Brodsky, 2015). With its characteristic of being asymmetric, it is also able to reproduce disparities rooted in inequalities due to its skewness factor (Montangero, 2007a). However, certain parameters, i.e. the WRC, are expected to not follow a log-normal distribution. This is primarily due to the fact that this parameter is rather expected to show a negative skewed (left-skewed) distribution, whereas log-normal distributions can only represent positive skewed distributions. Since this is likely to be the exception, log-normal distributions are used for all distribution functions, for uniform and consistent calculations, also because log-normal distributions can approximate normal distributions with sufficient accuracy (Brodsky, 2015).

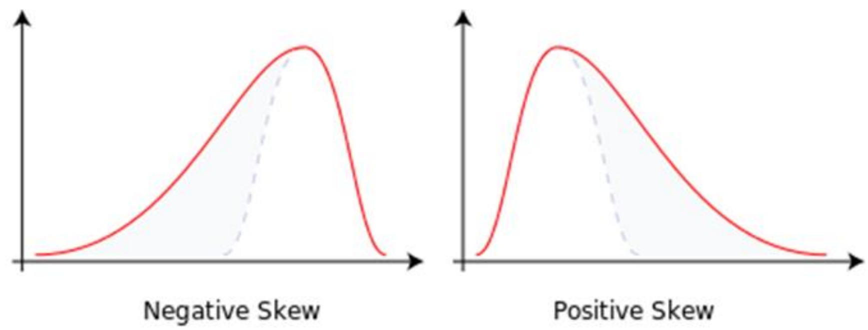



**Figure 7: Distribution functions with negative skewness (left) and positive skewness (right)**

The mean μ and standard deviation σ of a lognormal distribution can be calculated by using the arithmetic mean $\bar{x}$ and the standard deviation s of a sample (Johnson, Kotz and Balakrishnan, 1994). These functions describe the mathematical function with which the discrete sample values are idealised:

[2] $\mu = ln\left(\frac{\bar{x}^2}{\sqrt{s^2+\bar{x}^2}}\right)$

[3] $\sigma = \sqrt{ln\left(1+\frac{s^2}{\bar{x}^2}\right)}$

The mode *mode* and the median *med* of a log-normal distribution represent the global maximum, representing the value with the highest discrete probability and the value for which the cumulative density function is 0.5, meaning that 50 % of values are smaller and 50 % of values are bigger than the median. Mode and median are calculated as follows (Johnson, Kotz and Balakrishnan, 1994):

[4] $mode = e^{\mu-\sigma^2}$

[5] $med = e^{\mu}$

For normal distributions the mode, median and mean value are equal, whereas the median value of a log-normal distribution is smaller than the mean value. The median is used as expectancy value, as it represents the 50 % threshold of all values. The median is preferred here to serve as expectancy value as it takes the inequalities into account, leading to a value that is not distorted by a few very high values.

## 3.3 Considering the Sample Size: Determination of t-Values

The sample size has a significance influence on the confidence interval, hence the parameter range, because the calculated values for mean and standard deviation are the values of discrete sample values (observations) and not of continuous distribution functions. Hence, not only the standard deviation represents the random distribution of true values, but also the mean shows a certain amount of inaccuracy, dispersed around the true mean. To account for this, the student's distribution is used to calculate the distribution of the difference between the mean of the sample to the true mean value. In practice, the z-value is substituted by the t-value for respective observations (number of values *n*) and used to calculate confidence intervals. Selected t-values for a two-sided confidence level of 0.9 are presented in following table and compared to the z-value of 1.645:

Table 8: t-values for a two-sided confidence level of 0.9 for various degrees of freedom

| n | t | (t-z)/z |
|---|---|---|
| **5** | 2.015 | 22.5% |
| **10** | 1.812 | 10.2% |
| **20** | 1.725 | 4.9% |
| **30** | 1.697 | 3.2% |
| **40** | 1.684 | 2.4% |
| **50** | 1.676 | 1.9% |
| **100** | 1.660 | 0.9% |
| **150** | 1.655 | 0.6% |
| **200** | 1.653 | 0.5% |

## 3.4 Calculation of Confidence Intervals to determine Min/Max Values

Estimating parameter ranges means calculating confidence intervals for the mean values of the respective distributions. Several methodologies have been presented by Olsson (2005) and Cimermanová (2007), which also take the sample size into account. However, most suitable methodologies require the log-transformation of each discrete value and back-transformation of confidence intervals, leading to excessive computation efforts. On the other hand, the Excel function *LOGNORM.INV*, which allows the calculation of parameter values for defined confidence levels of a log-normal distribution calculates values based on the continuous distribution function and is therefore inadequate for sample population and does not allow the consideration of the sample size. That is why the formula

[6] $Min/Max = e^{\mu \pm \sigma^2 \cdot z}$

With *z* being the confidence level of the standard normal distribution; defined here as z = 1.645, equivalent to the calculations presented in Chapter 2.4.3, representing the 90 % confidence interval of the logarithm of the normal distributed random variable. To account for the influence of the sample size the z-value is substituted with the t-value for respective sample sizes as explained above. Inserting formulas [2] and [3] in formula [6] gives the calculation specification for the min and max values using the arithmetic mean and the standard deviation of the sample:

$$[7]\ Min = e^{ln\left(\frac{\bar{x}^2}{\sqrt{s^2+\bar{x}^2}}\right)-ln\left(1+\frac{s^2}{\bar{x}^2}\right)\cdot t} = \frac{\bar{x}^2}{\sqrt{s^2+\bar{x}^2}\cdot\left(1+\frac{s^2}{\bar{x}^2}\right)^t}$$

$$[8]\ Max = e^{ln\left(\frac{\bar{x}^2}{\sqrt{s^2+\bar{x}^2}}\right)+ln\left(1+\frac{s^2}{\bar{x}^2}\right)\cdot t} = \left(\frac{\bar{x}^2}{\sqrt{s^2+\bar{x}^2}}\right)\cdot\left(1+\frac{s^2}{\bar{x}^2}\right)^t$$

Figure 8 shows the probability density functions (PDF) for water consumption for all values obtained, besides values from industrialised countries with the following parameters:

$$[9]\ \bar{x} = 105\frac{L}{cap\cdot d}$$

$$s = 64\frac{L}{cap\cdot d}$$

$$n = 185$$

$$t(n = 185) = 1.653$$

These parameters result in following values:

Normal distribution: 0 – 210 (105) L/cap*d

Log-normal distribution: 54 – 151 (90) L/cap*d

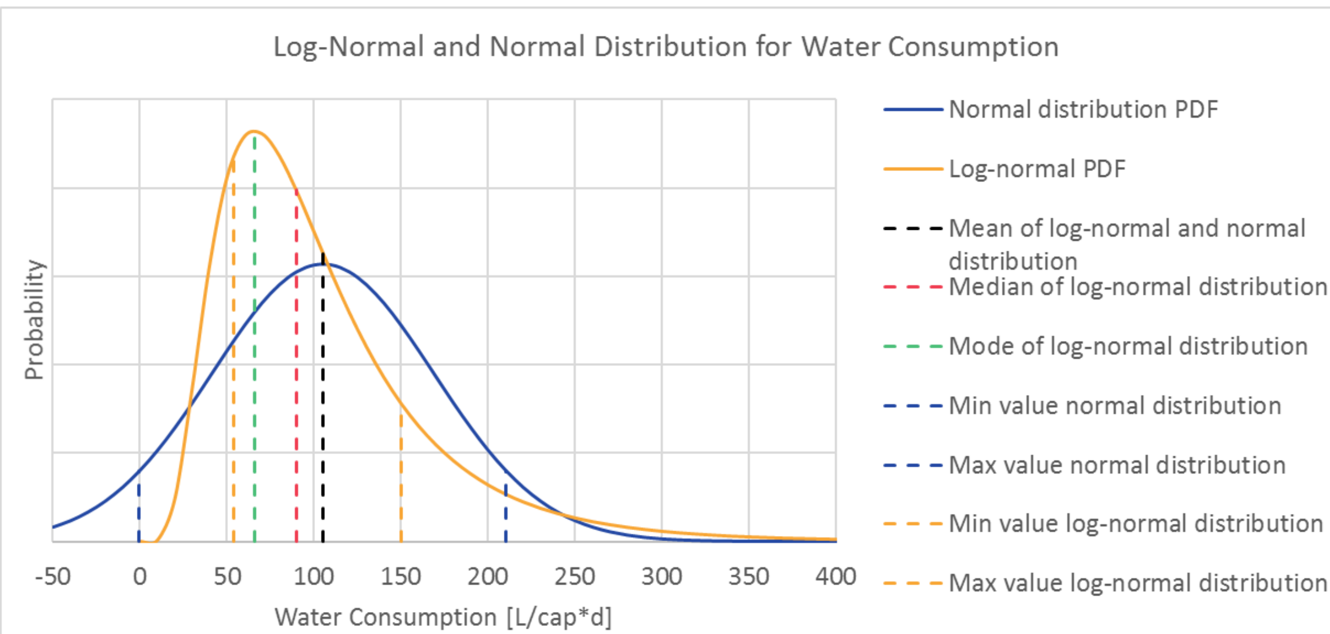



Figure 8: Log-normal and normal distribution for water consumption

These results clearly highlight the better representation of the distribution with the log-normal distribution as the normal distribution shows a minimum value of 0 and the PDF extents to negative values. Additionally, the median value for the log-normal distribution shows a slightly lower consumption, accounting for the fact that the average water consumption is distorted by a few very high values in the normal distribution. The parameter range for the log-normal distribution is significantly narrower, resulting from the back-transformation from the logarithmic values. The narrower range appears suitable, as it gives practitioners a more concentrated range of typical values.

Figure 9 visualises the two distribution functions and shows the actual data collected as columns with relative probability. This graph shows a way better matching of the log-normal distribution with the collected data as negative values are prevented and the mentioned inequalities in water consumption can be better represented by a skewed function, hence this function is used for the calculation of parameter ranges.

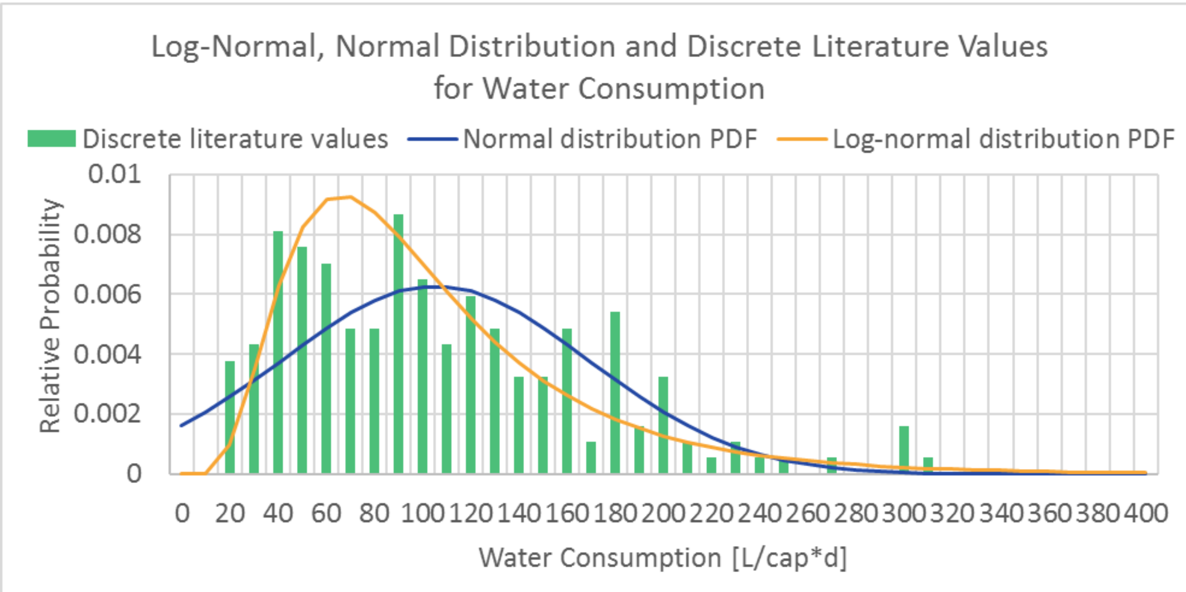



Figure 9: Log-normal and normal distribution and discrete literature values for water consumption

## 3.5 Classification of Data Quality

The sample size is an important indicator if sufficient data is available to draw meaningful conclusions. Statistically, the mean of a sample tends to converge towards the true mean value in good approximation for sample sizes greater than 30, shown by the fact that the difference between the Φ(z)-value of the standard normal distribution and the t-value of the student's distribution becomes marginal. Hence, samples consisting of at least 30 values are seen as appropriate to calculate meaningful factors to establish correlations between influencing parameters. Samples, which consist of at least 10 values are taken into account for comparison's and analysis reasons to assess, if trends are distinguishable. Following classification based on the number of data points is done:

< 10 data points: bad

10 – 29 data points: ok

≥ 30 data points: good

## 3.6 Classification of Regions and Countries according to Income and Climate Class

Based on the information and data gathered, wastewater characteristics on a country level are developed, taking the global income classification into account as well as the overall climate conditions, according to the definitions described in Chapter 2.4.1. The regions and countries under investigation are classified as follows:

Table 9: Regions and countries and their income and climate classes

| Region/Country | Income Class | Climate Class | Region/Country | Income Class | Climate Class |
|---|---|---|---|---|---|
| **EAP** | LMI | Tropical | **NAC** | HI | Moderate |
| **Bangladesh** | LMI | Tropical | **USA** | HI | Moderate |
| **Cambodia** | LMI | Tropical | **SAS** | LMI | Diverse |
| **China** | UMI | Diverse | **Afghanistan** | LI | Arid |
| **Fiji** | UMI | Tropical | **India** | LMI | Diverse |
| **Indonesia** | LMI | Tropical | **Pakistan** | LMI | Arid |
| **Lao** | LMI | Tropical | **SSA** | LMI | Diverse |
| **Philippines** | LMI | Tropical | **Botswana** | UMI | Arid |
| **South Korea** | HI | Moderate | **Kenya** | LMI | Arid |
| **Thailand** | UMI | Tropical | **Lesotho** | LMI | Moderate |
| **Vietnam** | LMI | Tropical | **Mali** | LI | Arid |
| **ECA** | UMI | Moderate | **Nigeria** | LMI | Tropical |
| **Turkey** | UMI | Moderate | **South Africa** | UMI | Moderate |
| **LAC** | UMI | Tropical | **Tanzania** | LI | Tropical |
| **Argentina** | UMI | Moderate | **Uganda** | LI | Tropical |
| **Brazil** | UMI | Diverse | **Zambia** | LMI | Moderate |
| **Mexico** | UMI | Diverse | **WCE** | HI | Moderate |
| **MNA** | UMI | Arid | **Denmark** | HI | Moderate |
| **Algeria** | UMI | Arid | **England** | HI | Moderate |
| **Egypt** | UMI | Arid | **Germany** | HI | Moderate |
| **Iran** | UMI | Arid | **Italy** | HI | Moderate |
| **Jordan** | UMI | Arid | **Sweden** | HI | Moderate |
| **Morocco** | LMI | Arid | | | |
| **Syria** | LMI | Arid | | | |
| **Tunisia** | LMI | Arid | | | |
| **Yemen** | LMI | Arid | | | |

## 3.7 Calculation of Factors

Factors are calculated by dividing the median value of a certain configuration (e.g. all values for LMI areas) by the benchmark value. A simple example is shown in Table 10. A total number of six values are given in the table of which three are associated to lower-middle income. Calculations of median values are executed according to Formulas [2] and [4] explained in Chapter 3.2. The benchmark value in this example (median of all six values) is 101 L/cap*d and the median water consumption for the three LMI parameter sets is 95 L/cap*d, hence the factor for LMI is 0.94. All factors are calculated using this procedure.

Table 10: Example to explain the procedure to generate factors

| Income classification | Water consumption [L/cap*d] |
|---|---|
| LI | 62 |
| LMI | 98 |
| LMI | 87 |
| HI | 157 |
| UMI | 134 |
| LMI | 101 |
| **Mean** | **107** |
| **SD** | **34** |
| **Median (Benchmark value)** | **101** |
| **Median for LMI** | **95** |
| **Factor for LMI** | **0.94** |

## 3.8 Propagation of Factors

In case of multiple factors influencing a parameter value and range, a methodology has to be found to propagate the respective factors. It has to be mentioned that all values found are influenced by a number of factors, hence include the independent influence of each parameter plus correlations between the different parameters. However, correlation terms between distinguished factors cannot be quantified in this study, because in most cases single factors cannot be isolated from other influences. An isolated interpretation would mean that one parameter (i.e income) is analysed for several standardised uniform contexts (e.g. various studies on the influence of income for each the same region/country/city, climate, etc.). A few studies taking this into account have been found, but the transferability to a general context is challenging and questionable. Therefore, it cannot be quantified, which factors influence each other and which factors are independent. If factors would be simply multiplied for propagation this might overrate the influence of each factor, because these factors are afflicted with the influence of other factors. The same applies to the Gaussian error propagation, which requires independent variables and the results are summing up and are in result always greater than the greatest single factor as it is a sum function. To propagate factors this has to be taken into account.

Different mathematical approaches have been analysed for its suitability, namely: Arithmetic mean, multiplication of factors and the geometric mean. Table 11 shows examples of factor propagations using the mentioned approaches for different factors $F_1$ and $F_2$. The first two pairs of factors ($F_1$ = 0.5; $F_2$ = 1.5) and ($F_1$ = 0.5; $F_2$ = 2) highlight some key considerations: the first pair shows one factor being 50% lower and one factor being 50% higher than the average value of 1. The second pair shows one factor being ½ of the average and the second factor being 2 times the average. The arithmetic mean shows a propagated factor of 1 for the first pair, whereas the multiplication and the geometric mean show a propagated factor of 1 for the second pair. Bearing in mind that a factor of 0.5 means half and a factor of 2 means twice the average consumption/production respectively a methodology leading to a factor of 1 for the second pair is more realistic. Same is shown for the next two pairs ($F_1$ = 0.2; $F_2$ = 1.8) and ($F_1$ = 0.2; $F_2$ = 5), but with more extreme results. A factor of 1.8 shows moderately high consumption/production, but a factor of 0.2 signalises extremely low values. This is also due to the log-normal distribution of values where the lower values are (even physically) limited through a lower boundary of 0 for all parameters but unlimited for the upper value (e.g. water consumption per capita has a minimum threshold for humans to survive but does not have a fixed upper threshold). It is therefore only realistic to have a propagated factor that is smaller than 1. The last configuration ($F_1$ = 1.2; $F_2$ = 1.5) shows values which are both greater than 1, hence the result has to be greater than 1. However, the multiplication of factors leads to a propagated value which is greater than the greatest single value. This might be realistic, if the parameters where independent and not influenced by correlations, but not in this particular case, where different factors influence each other.

Table 11: Example calculations for selected factor propagation methodologies

| $F_1$ | $F_2$ | Arithmetic Mean $\bar{F}_{arith} = \frac{\sum_{i=1}^{n} F_i}{n}$ | Multiplication of Factors $\bar{F}_{mult} = \prod_{i=1}^{n} F_i$ | Geometric Mean $\bar{F}_{geom} = \sqrt[n]{\prod_{i=1}^{n} F_i}$ |
|---|---|---|---|---|
| **0.5** | **1.5** | 1 | 0.75 | 0.87 |
| **0.5** | **2** | 1.25 | 1 | 1 |
| **0.2** | **1.8** | 1 | 0.36 | 0.6 |
| **0.2** | **5** | 2.6 | 1 | 1 |
| **1.2** | **1.5** | 1.35 | 1.8 | 1.34 |

Therefore, it is proposed to use the geometric mean for factor propagation, because it weighs extreme values higher than the arithmetic mean and takes a multiplicative rather than a sum approach, but limits the resulting factor to not exceed the boundaries of the single factors, as it happens if the factors are simply multiplicated. Hence, it combines the advantages and removes the disadvantages of the two other methodologies. The geometric mean is calculated as follows:

[10] $$\bar{F}_{geom} = \sqrt[n]{\prod_{i=1}^{n} F_i} = \sqrt[n]{F_1 \cdot F_2 \cdots F_n}$$

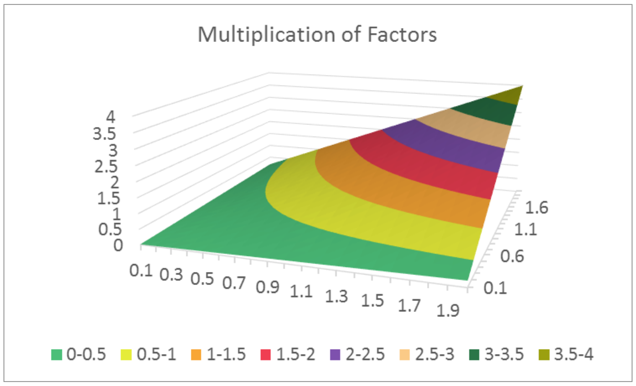



Figure 11: Propagated factors for factors between 0.1 and 2 for multiplication of factors

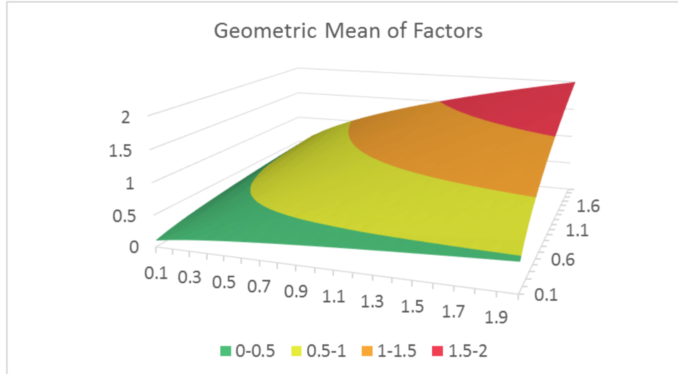



Figure 10: Propagated factors for factors between 0.1 and 2 using the geometric mean

A comparison between the multiplication of factors and the geometric mean is visualised in Figure 11 and Figure 10 for factors between 0.1 and 2. It shows that the multiplication of factors results in far more extreme results between 0.01 and 4 compared to 0.1 and 2 for the geometric mean. The surface displayed for the geometric mean shows flattened trends if the respective factors are similar and more accentuated factors if respected factors diverge.

## 3.9 Calculation of Benchmark Values and Parameter Ranges

Benchmark values of each wastewater characteristic are calculated to derive global average DEWATS design parameters. Because the objective of this study is to identify design parameters for DEWATS applicability the benchmark values calculated do not consider values from industrialised countries. Therefore, the term "*Global w/o industrialised countries*" is used as these values contain data from developing and emerging countries. Countries falling in this category were discussed in Chapter 2.4.1. The benchmark values are calculated using the median values of each sample as explained in Chapter 3.2, parameter ranges are calculated by determining confidence intervals as described in Chapter 3.4. The number of parameters (observations) *n* are listed to show the amount of data used for the calculations. Additionally, the mean values are given, as they are needed to calculate parameter ranges for median values calculated with the respective factors

## 3.10 Calculation of Parameter Ranges for Median Values based on Factors

Parameter ranges for design parameters with defined configurations of influencing factors (e.g. Income = LMI; Climate = Tropical) are calculated using the respective median value as shown in Table 10, the sample size for the configuration and the mean values and standard deviation of the benchmark value. The mean value and the standard deviation of the benchmark are used as a workaround. Hence, mean values and standard deviation of the design parameter configuration are not needed, as this would even make the calculation of factors obsolete and the propagation of values impossible.

Equations [5], [7] and [8] can be manipulated to calculate the minimum and maximum values based on the derived factors using the mean and standard deviation of the benchmark value:

[11] $$Min^* = e^{\ln(med^*) - \ln\left(1+\frac{s^2}{\bar{x}^2}\right)\cdot t^*} = \frac{med^*}{\left(1+\frac{s^2}{\bar{x}^2}\right)^{t^*}}$$

[12] $$Max^* = e^{\ln(med^*) + \ln\left(1+\frac{s^2}{\bar{x}^2}\right)\cdot t^*} = med^* \cdot \left(1+\frac{s^2}{\bar{x}^2}\right)^{t^*}$$

With $Min^*$, $Max^*$, $med^*$ and $t^*$ being the respective values of the factorised ranges, median and sample size values. Table 12 presents an example calculation of parameter ranges (results are underlined) for the example parameter set presented in Table 10:

**Table 12: Example calculation of design parameter ranges based on factors**

| Parameter | Sign | Water consumption | |
|---|---|---|---|
| | | Benchmark [L/cap*d] | Design Parameter (LMI) [L/cap*d] |
| **Mean** | $\bar{x}$ | 107 | - |
| **Median** | med; med* | 101 | 95 |
| **SD** | s | 34 | - |
| **Sample size** | n; n* | 6 | 3 |
| **t-Factor** | t; t* | 1.94 | 2.35 |
| **Factor** | - | 1 | 0.94 |
| **min** | min; min* | <u>84</u> | <u>76</u> |
| **max** | min; min* | <u>122</u> | <u>119</u> |

# 4 Wastewater Characteristics based on Literature Values

Following tables collate and present the obtained wastewater characteristics differentiating between communal (residential and domestic), institutional/commercial and agricultural/industrial setups and presenting data for per capita/unit water consumption, wastewater production, water return coefficient (WRC), peak flow factors, pollutant and nutrient loads. They contain summary tables of all data obtained and considered realistic and relevant. The analysis and interpretation of the collated data is presented in Chapter 5. For better readability the tables have been divided into subchapters for the different setups and characteristics. For communal systems, differentiation has been made for total wastewater, blackwater and greywater.

## 4.1 Communal per Capita Wastewater Characteristics

### 4.1.1 Communal per Capita Water Consumption and Wastewater Production

#### *4.1.1.1 Communal per Capita Water Consumption and Wastewater Production depending on Region, Country and Income Group*

Table 13: Communal per capita water consumption and wastewater production depending on region, country and income group for HH level water connections and toilets

| Location | Income – local context | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | Description | References |
|---|---|---|---|---|---|
| Global/General | | 90 – 140 | | Rural settlement (< 5,000 inhab.); HH connection; no severe water shortage | (von Sperling, 2008) |
| | | 100 – 160 | | Village (5,000 – 10,000 inhab.); HH connection; no severe water shortage | (von Sperling, 2008) |
| | | 110 – 180 | | Small town (10,000 – 50,000 inhab.); HH connection; no severe water shortage | (von Sperling, 2008) |
| | | 120 – 220 | | Average town (50,000 – 250,000 inhab.); HH connection; no severe water shortage | (von Sperling, 2008) |
| | | 150 – 300 | | Large city (> 250,000 inhab.); HH connection; no severe water shortage | (von Sperling, 2008) |
| | | 35 – 90 | | Global average | (Salvato, 1992) |

| | | | | | |
|---|---|---|---|---|---|
| **Industrialised countries** | | | 85 – 200 | General, average | (WHO and UNEP, 1997) |
| | | | 100 – 150 | Domestic wastewater production (HH only) | (WHO and UNEP, 1997) |
| | | | 150 – 250[3] | Residential wastewater production (HH + institutions) | (WHO and UNEP, 1997) |
| | | | 150 | HH wastewater production for non-ecological lifestyle | (Henze and Comeau, 2008) |
| **Developing countries** | | 40 – 100 | | Total consumption of average adult | (Mara, 2004) |
| | | | 65 – 125 | General value | (WHO and UNEP, 1997) |
| | | | 50 | Handpump or well | (WHO and UNEP, 1997) |
| | | | 50 – 80 | Public standpost | (WHO and UNEP, 1997) |
| | | | 50 – 125 | Private tab; domestic (HH only) | (WHO and UNEP, 1997) |
| | | | 100 – 250 | Private tab; residential (HH + institutions) | (WHO and UNEP, 1997) |
| **(Semi-) arid regions** | | | 35 – 75 | General value | (WHO and UNEP, 1997) |
| | | | 25 | Handpump or well | (WHO and UNEP, 1997) |
| | | | 20 – 40 | Public standpost | (WHO and UNEP, 1997) |
| | | | 40 – 80 | Private tab; domestic (HH only) | (WHO and UNEP, 1997) |
| | | | 80 – 120 | Private tab; residential (HH + institutions) | (WHO and UNEP, 1997) |
| **East Asia and Pacific** | | 30 – 70 | | Southeast Asia | (Salvato, 1992) |
| | | 30 – 90 | | Western Pacific | (Salvato, 1992) |
| **Bangladesh** | | 95 | | Dhaka | (UNEP, 2000) |
| **China** | | 80 | | | (Salvato, 1992) |
| | | 143 | | Shanghai; Residential (HH + institutions) | (UNEP, 2000) |
| **Indonesia** | | | 80 | Average of 9 LI – UMI communities in Java | (Reynaud, 2014) |
| | | 135 | | Jakarta; Residential (HH + institutions) | (UNEP, 2000) |
| | LI | | 88 | 1 LI community in Java | (Reynaud, 2014) |
| | LMI | | 62 – 88 | 5 LMI communities in Java | (Reynaud, 2014) |
| | UMI | | 81 – 91 | 3 UMI communities in Java | (Reynaud, 2014) |
| **Philippines** | | 202 | | Manila; Residential (HH + institutions) | (UNEP, 2000) |
| **South Korea** | | 209 | | Seoul; Residential (HH + institutions) | (UNEP, 2000) |

[3] Values defined as residential water consumption/wastewater production (HH + institutions) are colour coded

| | | | | | |
|---|---|---|---|---|---|
| **Thailand** | | | 204 – 212 (210) | Min: pour flush; Max: full flush | (Asian Institute of Technology (AIT), 2013) |
| | | | 74 | Estimated through water usage data for toilet, bathroom, laundry and kitchen | (Tsuzuki *et al.*, 2010) |
| | | 265 | | Bangkok; Residential (HH + institutions) | (UNEP, 2000) |
| **Vietnam** | | 104 – 136 | | Urban (Hanoi metropolitan area) | (Montangero, 2007a) |
| **Latin America and Caribbean** | | 70 – 190 | | | (Salvato, 1992) |
| | | 300 | | Latin American cities | (WHO and UNEP, 1997) |
| **Argentina** | | | 142 | Santa Fe Municipality; Communes, Municipalities, Cooperatives | (Bachur and Ferrer, 2013) |
| | | | 270 | Santa Fe Municipality; Aguas Santafesinas SA (CU supply) | (Bachur and Ferrer, 2013) |
| | | | 112 | Santa Fe Municipality; comm. Size < 5,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 193 | Santa Fe Municipality; comm. Size 5,000 – 10,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 209 | Santa Fe Municipality; comm. Size 10,000 – 50,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 176 | Santa Fe Municipality; comm. Size 50,000 – 100,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 331 | Santa Fe Municipality; comm. Size 100,000 – 1,000,000 inhab. | (Bachur and Ferrer, 2013) |
| **Brazil** | | | 247 | | (Henze *et al.*, 2002) |
| | | 50 – 100 | | | (Campos and von Sperling, 1996) |
| | | 93 – 298 | | Range for in house water supply | (von Sperling *et al.*, 2002) |
| | | 120 – 200 | | Main influencing parameters: HH income, mean annual precipitation (MAP), size of agglomeration (urban > rural) | (von Sperling, 2008); (von Sperling *et al.*, 2002) |
| | LI | 86 | 71 | Field study from Belo Horizonte/Minas Gerais[4] | (Campos and von Sperling, 1996) |
| | LMI | 100 – 139 | 81 – 105 | | |
| | UMI | 179 – 230 | 124 – 143 | | |
| | HI | 233 | 208 | | |
| | LMI | 120 – 165 | | MAP < 1350 mm/yr | (von Sperling, 2008); (von Sperling *et al.*, 2002) |

[4] Belo Horizonte used as benchmark of the country - to be representative in regards to climate, income distribution and urban setup

| | | | | | |
|---|---|---|---|---|---|
| | LMI | 130 – 190 | | MAP > 1350 mm/yr | (von Sperling, 2008); (von Sperling *et al.*, 2002) |
| | UMI | 140 – 180 | | MAP < 1350 mm/yr | (von Sperling, 2008); (von Sperling *et al.*, 2002) |
| | UMI | 150 – 200 | | MAP > 1350 mm/yr | (von Sperling, 2008); (von Sperling *et al.*, 2002) |
| **Middle East and North Africa** | | 40 – 85 | | Algeria, Morocco, Turkey | (Salvato, 1992) |
| | | 20 – 65 | | Eastern Mediterranean | (Salvato, 1992) |
| **Algeria** | | | 110 | | (Henze *et al.*, 2002) |
| **Egypt** | | 86 | | Rural; Average of 5 villages | (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a) |
| | | 120 | 98 – 116 | Rural; Average for SSS | (Reymond, Demars, Papangelou, Tawfik, Ulrich, *et al.*, 2014); (Demars and Reymond, 2014) |
| | | 90 – 110 | | Rural; Private full-flush toilets; min: intermittent water supply, max: good water supply | (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a) |
| | | 59 | | Rural; Private pour-flush toilets; Bayaras (open sewer drains) | (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a) |
| | | 21 – 43 (27) | | Rural; Bayaras (open sewer drains); intermittent water supply; Modelled based on sampling values | (Reymond and Hassan, 2014) |
| | | 43 – 174 (107) | | Rural; SSS; fair water supply; Modelled based on sampling values | (Demars and Reymond, 2014); (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014b) |
| | | | 150 | | (Henze *et al.*, 2002) |
| | | | 310 | Urban (Cairo); Residential (HH + institutions) | (UNEP, 2000) |
| **Jordan** | | 90 | | City of Amman | (Pescod, 1992) |
| **Morocco** | | | 50 | Average | (Salama *et al.*, 2014) |
| | | | 40 | Rural (< 20,000 inhab.) | (Salama *et al.*, 2014) |
| | | | 70 | Towns (20,000 – 100,000 inhab.) | (Salama *et al.*, 2014) |
| | | | 80 | Cities/Urban (> 100,000 inhab.) | (Salama *et al.*, 2014) |
| **Syria** | | | 96 | | (Henze *et al.*, 2002) |
| **Tunisia** | | | 82 | | (Henze *et al.*, 2002) |
| **Yemen** | | 80 | | City of Sana'a | (WHO and UNEP, 1997) |
| **South Asia** | | | | | |

## Wastewater Characteristics based on Literature Values

| | | | | | |
|---|---|---|---|---|---|
| **India** | | 80 – 310 (197) | | Class I cities (> 100,000 inhab.) | (CPCB, 2009) |
| | | 71 – 177 (111) | | Class II town (50,000 – 100,000 inhab.) | (CPCB, 2009) |
| | | 202 | | Calcutta; Residential (HH + institutions) | (UNEP, 2000) |
| | LI | | 17 – 42 | Low income communities; Arid; Bangalore | (Reynaud, 2014) |
| **Pakistan** | | 157 | | Karachi; Residential (HH + institutions) | (UNEP, 2000) |
| **Sub-Sahara Africa** | LI | 12 – 121 (52) | | Total water cons. (HH + commercial) | (Van Den Berg and Danilenko, 2017) |
| | LMI | 38 – 121 (76) | | Total water cons. (HH + commercial) | (Van Den Berg and Danilenko, 2017) |
| | | 15 – 35 | | WRC for sewered areas | (Salvato, 1992; UNEP, 2000) |
| **Nigeria** | | | 115 | Average for Lagos; Residential (HH + institutional) | (UNEP, 2000) |
| | LI | | 54 | High pop. density > 700 inhab. /ha | (UNEP, 2000) |
| | LMI | | 77 | Medium pop. density | (UNEP, 2000) |
| | HI | | 260 | Low pop. density | (UNEP, 2000) |
| **South Africa** | | | 114 | Full flush toilet with in house water supply | (Palmer Development Group, 1993) |
| | | | 30 | Dry toilet (VIP); Public water points | (Palmer Development Group, 1993) |
| | LI | 83 | | Survey in LI comm. in Durban with in house water supply | (Foxon *et al.*, 2006) |
| | LI | 35 - 40 | | CSC with flush toilets | (Roma, 2010) |
| | LI | 82 | 62 | CSC with water saving cisterns with public standpipes in informal settlements; including water carried to homes | (Crous, 2014) |
| | LI | 45 | 37 | CSC with water saving cisterns with public standpipes in informal settlements | (Crous, 2014); (Crous, Haarhoff and Buckley, 2012) |
| | LMI | | 62 – 110 | Flush-toilets with in house water supply | (Reynaud, 2014) |
| **Zambia** | LI | | 6 – 20 | Public tabs; CSC; Pour flush toilets | (Laramee, 2015a); (Laramee, 2016) |
| | LI | | 4 – 33 | Yard tabs; Pour flush toilets | (Laramee, 2015b); (Laramee, 2016) |
| | LMI | | 56 – 90 | In house water connections; flush-toilets; Mining town (~ 65,000 inhab.) | (Laramee, 2015a); (Laramee, 2016) |

#### 4.1.1.2 Communal per Capita Water Consumption and Wastewater Production depending on Region, Country and Income Group from (National) Design Guidelines and Recommendations

Table 14: Communal per capita water consumption and wastewater production depending on region, country and income group from (national) design guidelines

| Location | Income – local context | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | Description | References |
|---|---|---|---|---|---|
| **Industrialised countries** | | 250 - 300 | | Water supply demand | (UNEP, 2000) |
| **Developing countries** | | 160 – 200 | | Water supply demand | (UNEP, 2000) |
| **East Asia and Pacific** | | | | | |
| **Indonesia** | | | 160 | Feed to septic tank | (UNEP, 2000) |
| **Vietnam** | | | 125 | Mega-cities (> 3,000,000) | (UNEP, 2000) |
| | | | 69 | Large cities (1,000,000 – 3,000,000) | (UNEP, 2000) |
| | | | 39 | Cities (< 1,000,000) | (UNEP, 2000) |
| | | 180 | 150 | Water supply demand and calculation basis for utilities | (UNEP, 2000) |
| **South Asia** | | | | | |
| **Afghanistan** | | 85 | | Design recommendations | (BORDA and GIZ-WSIP, 2015) |
| **India** | | | 100 – 150 | | (CPHEEO, 1993) |
| **Sub-Sahara Africa** | | | | | |
| **South Africa** | LI | 12 – 15 | | Water demand for public standpipe < 200 m distance | (SABS, 2010) |
| | LI | 45 – 55 | | Water demand for private yard tab | (SABS, 2010) |
| | LI | 50 – 70 | | Water demand for LI inhouse water connection | (SABS, 2010) |
| **Tanzania** | LI | 25 | | Water kiosk or public tabs | (The United Republic of Tanzania, 2007) |
| | LI | 40 – 50 | | Yard tab, multiple HH | (The United Republic of Tanzania, 2007) |
| | LI | 50 – 70 | | Yard tab, single HH | (The United Republic of Tanzania, 2007) |
| | LMI | 90 – 130 | | HH water connection; Urban | (The United Republic of Tanzania, 2007) |
| | UMI | 150 – 250 | | HH water connection; Urban | (The United Republic of Tanzania, 2007) |

#### 4.1.1.3 Communal per Capita Water Consumption depending on Country from Utility Benchmark Database (IBNET)[5]

Table 15: Communal per Capita Water Consumption depending on Country from Utility Benchmark Database (IBNET, 2017)

| Location | $W_{cons}$ [L/cap*d] | Description |
|---|---|---|
| East Asia and Pacific | | |
| Bangladesh | 92 | Utility benchmark of 60 CUs; Mains supply/ Overall[6] |
| Cambodia | 112 | Utility benchmark of 1 CU; Mains supply |
| Indonesia | 117 | Utility benchmark of 14 CUs; Overall |
| Lao | 154 | Utility benchmark of 10 CUs; Overall |
| Philippines | 110 | Utility benchmark of 52 CUs; Overall |
| | 118 | Utility benchmark of 52 CUs; Mains supply |
| | 53 | Utility benchmark of 52 CUs; Public water point |
| Vietnam | 103 | Utility benchmark of 102 CUs; Overall |
| Latin America and Caribbean | | |
| Brazil | 109 | Utility benchmark of 1832 CU; Overall |
| Mexico | 188 | Utility benchmark of 53 CUs; Overall |
| Middle East and North Africa | | |
| Jordan | 73 | Utility benchmark of 16 CU; Overall |
| South Asia | | |
| Afghanistan | 31 | Utility benchmark of 1 CU; Overall |
| India | 84 | Utility benchmark of 32 CUs; Overall |
| | 95 | Utility benchmark of 32 CUs; Mains supply |
| | 20 | Utility benchmark of 32 CUs; Public water point |
| Sub-Sahara Africa | | |
| Kenya | 43 | Utility benchmark of 99 CUs; Overall |
| Lesotho | 53 | Utility benchmark of 1 CU; Overall |
| Mali | 66 | Utility benchmark of 2 CUs; Overall |
| | 93 | Utility benchmark of 2 CUs; Mains supply |
| | 24 | Utility benchmark of 2 CUs; Public water points |
| South Africa | 155 | Utility benchmark of 26 CUs; Overall |
| | 178 | Utility benchmark of 26 CUs; Mains supply |
| | 51 | Utility benchmark of 26 CUs; Public water points |
| Zambia | 58 | Utility benchmark of 15 CUs; Overall |
| | 127 | Utility benchmark of 15 CUs; Mains supply |

[5] IBNET is the International Benchmarking Network for Water and Sanitation Utilities with the world's largest database for water and sanitation utilities performance data. IBNET supports and promotes good benchmarking practice among water and sanitation services (IBNET, 2017)

[6] Mains supply = Private water connection (i.e. household connection, yard tap); Public water point = Water supply through public water points (i.e. public stand pipe, water kiosk); Overall = Weighted average of mains supply and public water points; CU = commercial utility, such as municipal water supplier; Utility benchmark = value from IBNET database

#### 4.1.1.4 *Communal per Capita Blackwater Production depending on Region, Country and Toilet Type*

**Table 16: Communal per capita blackwater production depending on region, country and toilet type**

| Location | Toilet type | BW [L/cap*d] | Description | References |
|---|---|---|---|---|
| **General** | Private – full flush | 52 | | (Henze and Comeau, 2008) |
| **East Asia and Pacific** | | | | |
| **Indonesia** | Private – pour flush | 14 | LMI community | (Reynaud *et al.*, 2009) |
| | Private – pour flush | 15 – 20 | | (BORDA SEA and BSD, 2007) |
| **Thailand** | Private – average | 14 | Weighted average of pour flush and full flush | (Asian Institute of Technology (AIT), 2013) |
| | Private – full flush | 34 | | (Asian Institute of Technology (AIT), 2013) |
| | Private – pour flush | 8 | | (Asian Institute of Technology (AIT), 2013) |
| **Middle East and North Africa** | | | | |
| **Egypt** | Private – full flush | 42 | Rural | (Demars and Reymond, 2014) |
| | Private – pour flush | 13 | Rural | (Demars and Reymond, 2014) |
| | Private – average | 18 | Rural; Weighted average of pour flush and full flush | (Demars and Reymond, 2014) |
| **Sub-Sahara Africa** | | | | |
| **South Africa** | Shared – full flush | 7 | CSC in informal settlements; Water saving cisterns | (Crous, Haarhoff and Buckley, 2012) |
| | Private | 22 | Questionnaire in Kwa-Mashu Newlands; No definition if full or pour flush | (Foxon *et al.*, 2006) |

#### 4.1.1.5 Water Return Coefficients for Communal Setups depending on Region, Country, Income, Climate and Urban/Rural Setting

**Table 17: Water return coefficients for communal setups depending on region, country, income, climate and urban/rural Setting**

| Location | Income – local context | WRC [%] | Description | References |
|---|---|---|---|---|
| **Global/General** | | 80 – 90 | WRC is lower than quoted range in rich areas, where water is used for car-washing and irrigation | (Mara, 2004) |
| | HI | 60 – 70 | Due to irrigation and leakages | (Fair, Geyer and Okun, 1966) |
| **Industrialised countries** | | 75 | General, average | (WHO and UNEP, 1997) |
| **(Semi-) arid regions** | | 50 | General value | (WHO and UNEP, 1997) |
| **East Asia and Pacific** | | | | |
| **Vietnam** | | 119 | Mega-cities (> 3,000,000) | (UNEP, 2000) |
| | | 87 | Large cities (1,000,000 – 3,000,000) | (UNEP, 2000) |
| | | 62 | Cities (< 1,000,000) | (UNEP, 2000) |
| **Latin America and Caribbean** | | | | |
| **Brazil** | | 60 – 100 | Main influencing parameters: HH income, mean annual precipitation (MAP), size of agglomeration (urban > rural) | (von Sperling, 2008); (von Sperling *et al.*, 2002) |
| | LI | 83 | Field study from Belo Horizonte/Minas Gerais[7] | (Campos and von Sperling, 1996) |
| | LMI | 58 – 87 | | |
| | UMI | 62 – 74 | | |
| | HI | 89 | | |
| **Middle East and North Africa** | | | | |
| **Egypt** | | 86 – 100 | Rural; Private full-flush toilets; min: intermittent water supply, max: good water supply | (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a) |
| | | 56 – 68 | Rural; Private pour-flush toilets; Bayaras (open sewer drains) | (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a) |
| **Morocco** | | 65 | Average | (Salama *et al.*, 2014) |
| | | 50 | Rural (< 20,000 inhab.) | (Salama *et al.*, 2014) |
| | | 75 | Towns (20,000 – 100,000 inhab.) | (Salama *et al.*, 2014) |

[7] Belo Horizonte used as benchmark of the country - to be representative in regards to climate, income distribution and urban setup

| | | | | |
|---|---|---|---|---|
| | | 80 | Cities/Urban (> 100,000 inhab.) | (Salama *et al.*, 2014) |
| **South Asia** | | | | |
| **India** | | 40 - 90 | Low WRC for arid regions | (CPHEEO, 1993) |
| **Sub-Sahara Africa** | | 80 | WRC for sewered areas | (Salvato, 1992; UNEP, 2000) |
| **Botswana** | | 50 – 65 | WRC for Gaborone | (UNEP, 2000) |
| **South Africa** | LI | 75 | CSC with water saving cisterns with public standpipes in informal settlements; including water carried to homes | (Crous, 2014) |
| | LI | 78 | CSC with water saving cisterns with public standpipes in informal settlements | (Crous, 2014); (Crous, Haarhoff and Buckley, 2012) |

### 4.1.2 Peak Flow Factors for Communal Setups

**Table 18: Peak flow factors for communal setup depending on income and number of connected users for different regions and countries**

| Location | Connected users [inhab.] | PFF diurnal [-] | PFF daily [-] | PFF total [-] | Description | References |
|---|---|---|---|---|---|---|
| **Global** | | | | 2 - 3 | General range | (Henze *et al.*, 2002) |
| | | | | 1.7 – 2.4 | Small town | (Henze *et al.*, 2002) |
| | | | | 1.3 – 1.7 | Large city | (Henze *et al.*, 2002) |
| **Developing countries** | | | | | | |
| **Industrialised countries** | | | | 4 – 6 | min: collector sewers; max: branch sewers | (Butler and Graham, 1995) |
| **East Asia and Pacific** | | | | | | |
| **Indonesia** | 195 | 2.2 | | | LMI; Central Java | (Reynaud, 2014) |
| | 103 | 2.1 | | | LI; Central Java | (Reynaud, 2014) |
| | 480 | 1.5 | | | UMI; Central Java | (Reynaud, 2014) |
| | 125 | 1.4 | | | LMI; Central Java | (Reynaud, 2014) |
| | 251 | 2.3 | | | UMI; Central Java; HH taps | (Reynaud, 2014) |
| | 213 | 1.2 | | | LMI; Central Java | (Reynaud, 2014) |
| | 168 | 2.6 | | | LMI; Central Java | (Reynaud, 2014) |
| | 450 | 1.8 | | | UMI; Central Java; HH taps | (Reynaud, 2014) |
| | 271 | 1.8 | | | LMI; Central Java | (Reynaud, 2014) |
| **Middle East and North Africa** | | | | | | |
| **Egypt** | 3,093 | 1.6 | | | Village in the Nile delta with intermittent water supply (interruption frequency >2/week) | (Demars and Reymond, 2014; Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014b) |
| **Latin America and Caribbean** | | | | | | |
| **Brazil** | 286 | 2.5 | 1.4 | 3.5 | HI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 747 | 2.2 | 1.3 | 2.9 | LMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 881 | 2.1 | 1.5 | 3.0 | UMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 906 | 1.6 | 1.2 | 1.9 | LMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 991 | 2.3 | 1.5 | 3.5 | UMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 1,412 | 2.2 | 1.4 | 3.0 | LMI; Belo Horizonte | (Campos and von Sperling, 1996) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 2,133 | 2.1 | 1.3 | 2.7 | LMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 2,919 | 2.0 | 1.2 | 2.3 | LI; Belo Horizonte | (Campos and von Sperling, 1996) |
| | 3,012 | 1.9 | 1.4 | 2.6 | UMI; Belo Horizonte | (Campos and von Sperling, 1996) |
| **South Asia** | | | | | | |
| **India** | 575/605 | 2.2/1.8 | | | LI; Workers colony housing in Bangalore; two measuring campaigns | (Reynaud, 2014) |
| | 608 | 1.2 | | | LI; Bangalore | (Reynaud, 2014) |
| | 1,000 – 10,000 | | | 3 | Design guidelines for different number of connections | (CPHEEO, 1993) |
| | 10,000 – 100,000 | | | 2.3 – 2.5 | | (CPHEEO, 1993) |
| | > 100,000 | | | 2 | | (CPHEEO, 1993) |
| **Sub-Sahara Africa** | | | | | | |
| **Kenya** | 100,000 | 1.83 | | | Nakuru town; based on flow table | (Mara, 2004) |
| **South Africa** | 420 | | | 1.7 | LMI; Durban | (Reynaud, 2014) |
| | 218[8] | 3.3 – 4.6 | 1.3 – 1.7 | 4.9 – 6.9 | CSC; LI informal settlement | (Crous, Haarhoff and Buckley, 2012; Crous, 2014); |
| **Tanzania** | - | 2.5 | 1.5 | 3.8 | LI | (The United Republic of Tanzania, 2007) |
| | - | 2.5 | 1.3 | 3.3 | LMI | (The United Republic of Tanzania, 2007) |
| | - | 2.5 | 1.1 | 2.8 | UMI | (The United Republic of Tanzania, 2007) |
| | - | 3.4 | 1 | 3.4 | LI; CSC | (The United Republic of Tanzania, 2007) |
| | 1,000 – 10,000 | 2 – 2.4 | 1.5 – 1.8 | 3.6 | Design guidelines for different number of connections | (The United Republic of Tanzania, 2007) |
| | 10,000 – 100,000 | 1.6 – 2 | 1.3 – 1.5 | 2.5 | | (The United Republic of Tanzania, 2007) |
| | > 100,000 | 1.5 – 1.6 | 1.3 | 2.0 | | (The United Republic of Tanzania, 2007) |
| **Zambia** | 202 | | 1.2 – 1.6 | | LI; pour flush; yard taps; average for 9 BGD | (Laramee, 2015b; Simwambi, 2015a) |
| | 1,909 | | 1.2 | | LI; pour flush; yard taps; total for 9 BGD | (Laramee, 2015b; Simwambi, 2015a) |
| | 305 | | 1.4 | | LI; CSC; pour flush | (Laramee, 2015b; Simwambi, 2015a) |
| | 219 | | 1.3 | | LI; CSC; pour flush; average for 2 BGD | (Laramee, 2015b; Simwambi, 2015a) |
| | 438 | | 1.3 | | LI; CSC; pour flush; total for 2 BGD | (Laramee, 2015b; Simwambi, 2015a) |
| | 133 | | 1.3 | | LI; CSC; pour flush | (Laramee, 2015b; Simwambi, 2015a) |
| | 394 | 1.6 – 2.2 | 1.1 – 1.2 | 1.7 – 2.7 | LMI; private full-flush | (Laramee, 2016) |
| | 44 | | 1.3 | | LMI; private full-flush | (Laramee, 2015b; Simwambi, 2015a) |

[8] Flow measurements from four CSC with average population of 99 HH/CSC and average HH size of 2.2 cap/HH

| | | | | | | |
|---|---|---|---|---|---|---|
| | 99 | | 1.2 | | LMI; private full-flush | (Laramee, 2015b; Simwambi, 2015a) |
| | 95 | | 1.2 | | LMI; private full-flush | (Laramee, 2015b; Simwambi, 2015a) |
| | 55 | | 1.2 | | LMI; private full-flush | (Laramee, 2015b; Simwambi, 2015a) |
| | 200 | | 1.2 | | LMI; private full-flush; total of 5 BGD | (Laramee, 2015b; Simwambi, 2015a) |

### 4.1.3 Communal per Capita Pollutant, Solids and Nutrient Loadings depending on Region, Country and Income

Table 19: Per capita pollutant and nutrient loads depending on region, country and income group

| Location | Income – local context | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TSS [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] | Description | References |
|---|---|---|---|---|---|---|---|---|
| General | | 220 | 90 | | 14.8 | 2.8 | Maximum values incl. disposal of organic waste | (Henze and Comeau, 2008) |
| | | 130 | 60 | | 14 | 2.4 | Values for "non-ecological" lifestyle | (Henze and Comeau, 2008) |
| | | 25 – 200 | 15 – 80 | | 2 – 15 | 1 – 3 | Average range | (Henze and Comeau, 2008) |
| | | | | | | 1 – 2 | | (Metcalf and Eddy, 2003) |
| | | 70 – 150 | 30 – 60 | 40 – 80 | 8 - 12 | 1 – 3 | | (WHO and UNEP, 1997) |
| | | | 59 – 109 | 59 – 113 | 9 – 14 | 3.2 – 5 | | (Muttamara, 1996) |
| Developing countries | | 80 – 120 | 40 – 60 | 35 – 70 | 6 – 10 | 0.7 – 2.5 | Collation of different sources | (von Sperling, 2008) |
| | | | 20 – 40 | | 5.6 | 0.8 | India, Indonesia, South Africa; different income groups | (Reynaud, 2014) |
| | | | 28 – 30 | | | | Tropical countries | (Mara, 2004) |
| | | | 40 | | | | Sum of blackwater and greywater pollutants in developing countries | (Mara, 1976, 2004) |
| | | | 30 – 65 | | | | DEWATS design guidelines | (Sasse, 1998) |
| East Asia and Pacific | | | 43 | | | | | (Mara, 1986) |
| Indonesia | | | 20 – 40 | | | | Conclusion over long-term sampling campaigns of 9 communities | (Reynaud, 2014) |
| | LI | | | | 6.8 | 1 | 1 community in Java | (Reynaud, 2014) |
| | LMI | 71 | | | 6.5 | 0.5 | 1 community in Java | (Reynaud, 2014) |
| | UMI | 56 – 95 | | | 5.5 – 6 | 0.5 – 0.6 | 2 communities in Java | (Reynaud, 2014) |
| Thailand | | 81 | 46.4 | | 11.5 | 1.9 | Peri-urban Bangkok | (Tsuzuki, 2013) |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 49[9] | | 15.6 | 6.3 | Residential wastewaters in proximity of rivers and lakes | (Tsuzuki *et al.*, 2007) |
| **Eastern Europe and Central Asia** | | | 28 – 75 (53) | 30 – 70 (45) | 8 – 12 | 1 – 2 | West Asia | (UNEP, 2000) |
| **Turkey** | | 62 – 92 | 27 – 50 | 41 – 68 | 8 – 14 | 0.4 – 2 | | (Henze *et al.*, 2002; Metcalf and Eddy, 2003) |
| **Latin America and Caribbean** | | | | | | | | |
| **Argentina** | | 71 | 3 – 44 (26) | 17 | 8.5 | 0.8 | Santa Fe Municipality, Communes, Municipalities, Cooperatives; Peri-urban/rural (avg. pop. 16,471) | (Bachur and Ferrer, 2013) |
| | | 98 | 21 – 60 (41) | 54 | 12.1 | 1.5 | Santa Fe Municipality, Aguas Santafesinas SA (CU supply); Urban (avg. pop. 152,400) | (Bachur and Ferrer, 2013) |
| | | | 9 – 28 (19) | | | | Santa Fe Municipality; comm. Size < 5,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 23 – 81 (40) | | | | Santa Fe Municipality; comm. Size 5,000 – 10,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 16 – 60 (39) | | | | Santa Fe Municipality; comm. Size 10,000 – 50,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 25 – 37 (31) | | | | Santa Fe Municipality; comm. Size 50,000 – 100,000 inhab. | (Bachur and Ferrer, 2013) |
| | | | 46 | | | | Santa Fe Municipality; comm. Size 100,000 – 1,000,000 inhab. | (Bachur and Ferrer, 2013) |
| **Brazil** | | | 45 | | | | Small towns, domestic residual liquids | (Afini, 1989) |
| | | | 60 | | | | Medium to large towns, residual liquids in general | (Afini, 1989) |

[9] Values defined as residential water consumption/wastewater production (HH + institutions) are colour coded

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 75 | | | | Big cities; with great developments | (Afini, 1989) |
| | | 123 – 154 | 55 – 68 | | 8 – 14 | 0.6 - 1 | | (Henze *et al.*, 2002; Metcalf and Eddy, 2003) |
| | | | 38 | | | | Weighted average of 9 areas of Belo Horizonte | (Campos and von Sperling, 1996) |
| | LI | | 33.5 | | | | 1 area of Belo Horizonte | (Campos and von Sperling, 1996) |
| | LMI | | 27 – 47 | | | | 4 areas of Belo Horizonte | (Campos and von Sperling, 1996) |
| | UMI | | 39 – 51 | | | | 3 areas of Belo Horizonte | (Campos and von Sperling, 1996) |
| | HI | | 56 | | | | 1 areas of Belo Horizonte | (Campos and von Sperling, 1996) |
| | | | 40 – 57 | | | | Municipalities of the State of Sao Paulo and Paraná | (Uehara and Vidal, 1989) |
| | | | 45 | | | | Vista Verde residential complex; Urban | (Uehara and Vidal, 1989) |
| | | | 33 | | | | Santa Fe do Sul; Rural | (Uehara and Vidal, 1989) |
| **Middle East and North Africa** | | | | | | | | |
| **Egypt** | | 62 – 92 | 27 – 41 | 41 – 68 | 8 – 14 | 0.4 – 0.6 | | (Henze *et al.*, 2002; Metcalf and Eddy, 2003) |
| | | 95 | | 41 | 14 | 1.7 | Rural areas in the Nile delta | (Reymond and Demars, 2014) |
| **Iran** | LI | 41 – 79 (60) | 24 – 46 (39) | 26 – 43 (34) | 5.9 – 17.4 (11) | 0.6 – 1.2 (0.9) | Peri-urban area of Tehran; annual range and average | (Miranzadeh, 2005) |
| | LI | 41 – 63 | 24 - 41 | | | | Peri-urban area of Tehran; dry season | (Miranzadeh, 2005) |
| | LI | 63 – 79 | 42 - 48 | | | | Peri-urban area of Tehran; wet season | (Miranzadeh, 2005) |
| **Jordan** | | 132 | 55 | 65 | 10.8 | 1.8 | City of Amman | (Pescod, 1992) |
| **Morocco** | | | 50 | | | | Rural areas | (Abarghaz *et al.*, 2011) |
| **Palestine** | | | 32 – 68 | 52 – 72 | 4 – 7 | 0.4 – 0.7 | Gaza and West Bank | (Metcalf and Eddy, 2003) |
| **South Asia** | | | | | | | | |
| **Afghanistan** | | | 40 – 60 | | | | DEWATS design guidelines | (BORDA and GIZ-WSIP, 2015) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **India** | | 62 – 92 | 27 – 41 | | | | | (Henze *et al.*, 2002; Metcalf and Eddy, 2003) |
| | LI | 27 – 52 (45) | | | 5 | 0.7 | Low income community in Bangalore | (Reynaud, 2014) |
| **Sub-Sahara Africa** | | | | | | | | |
| **Kenya** | | | 23 | | | | Medium size town (Kisumu); domestic sewerage | (UNEP, 2000) |
| | | | 19 – 22 | | | | Medium size town (Kisumu); pit latrine | (UNEP, 2000) |
| | | | 30 | | | | Medium size town (Kisumu); septic tank | (UNEP, 2000) |
| **South Africa** | | 100 | | | 10 | 2.5 | Estimated values | (UNEP, 2000) |
| | LMI | | | | 5.2 | 0.8 | | (Reynaud, 2014) |
| **Uganda** | | 123 – 154 | 55 – 68 | 41 – 55 | 8 – 14 | 0.4 – 0.6 | | (Henze *et al.*, 2002; Metcalf and Eddy, 2003) |
| **Zambia** | | | 36 | | | | | (UNEP, 2000) |
| | LI | 15 – 51 | | | 1.2 – 4.6 (2.9) | | Peri-urban community (Ndola); CSC, pour-flush | (Laramee, 2015a) |
| | LI | 42 | | | | | Peri-urban community in small town (Livingstone); private toilet, pour flush | (Laramee, 2016) |
| | LMI | 42 – 82 (62) | | | 3.2 – 10.1 (6.6) | | Peri-urban community in small mining town (Solwezi); private toilet, full flush | (Laramee, 2015a) |

#### 4.1.3.1 Communal Blackwater per Capita Pollutant and Nutrient Loads

Table 20: Blackwater per capita pollutant and nutrient loads depending on region and country[10]

| Location | $COD_{BW}$ [g/cap*d] | $BOD_{5,BW}$ [g/cap*d] | $TKN_{BW}$ [g/cap*d] | $TP_{BW}$ [g/cap*d] | Description | References |
|---|---|---|---|---|---|---|
| **General** | 75 | 25 | 12 | 1.9 | | (Henze and Comeau, 2008) |
| | | | 5.2 – 15.8 | 2.2 – 3.8 | Based on percentages of dry excreta | (Mara, 1976) |
| | | | 12.5 | 1.6 | | (UNEP, 2000) |
| | | | 9.9 – 13.2 | | | (Strauss, 1985) |
| | 46 – 96 (71) | 14 – 34 (24) | 13 | 1.9 | Values for BOD and COD only measured for faeces (urine + anal cleansing material neglected) | (Rose *et al.*, 2015) |
| **Industrialised countries** | 96 | 38 | | | Faecal sludge treatment in South Korea | (Choi *et al.*, 2004) |
| | | 25 | | | Speculative values | (Feachem *et al.*, 1983) |
| | 50 | 32 | | | Assessment based on European data | (Meinzinger and Oldenburg, 2009) |
| **Developing countries** | | 30 | | | Urban + Rural; Speculative values | (Feachem *et al.*, 1983) |
| | | 22 | | | Faeces, urine + anal cleansing material | (Mara, 1976, 2004) |
| | | 45 | | | | (Heinss, Larmie and Strauss, 1998) |
| | 46 - 55 | 14 - 34 | | | Assessment from tropical countries | (Kujawa-Roeleveld and Zeeman, 2006) |
| **Middle East and North Africa** | | | | | | |
| **Egypt** | 44 | | 12 | 1.2 | Rural | (Demars and Reymond, 2014) |
| **Sub-Sahara Africa** | | | | | | |
| **South Africa** | | | | 1.6 | | (Palmer Development Group, 1993) |
| | | 19 | | | From on-site sanitation systems | (Fourie and van Ryneveld, 1995) |

[10] No data to differentiate between income groups

### 4.1.3.2 Communal Greywater per Capita Pollutant and Nutrient Loads

**Table 21: Greywater per capita pollutant and nutrient loads depending on region and country[11]**

| Location | $COD_{GW}$ [g/cap*d] | $BOD_{5,GW}$ [g/cap*d] | $TKN_{GW}$ [g/cap*d] | $TP_{GW}$ [g/cap*d] | Description | References |
|---|---|---|---|---|---|---|
| **General** | 54 | 35 | 1.9 | 0.5 | "Non-ecological" lifestyle, e.g. disposal of cooking waste in sink | (Henze and Comeau, 2008) |
| | 32 | 20 | 1.5 | 0.4 | Cleantech cooking: part of cooking waste diverted from kitchen sink to waste bin | (Henze and Comeau, 2008) |
| | 21 | 13 | 0.5 | 0.16 | Average from several collated sources | (Eriksson *et al.*, 2002) |
| **Developing countries** | | 18 | | | Shower/bath, kitchen + laundry | (Mara, 1976, 2004) |
| **East Asia and Pacific** | | | | | | |
| **Vietnam** | | | | 0.1 – 1.1 | Urban and peri-urban areas | (Montangero, 2007a) |
| **Middle East and North Africa** | | | | | | |
| **Egypt** | 51 | | 2 | 0.5 | | (Demars and Reymond, 2014) |
| **Sub-Sahara Africa** | | | | | | |
| **South Africa** | 28 | | 2.8 | 4.3 | Unrealistic high value for TP! | (Fourie and van Reyneveld, 1993) |
| | | | | 0.88 | | (Palmer Development Group, 1993) |

[11] No data to differentiate between income groups

## 4.2 Per Unit Wastewater Characteristics for Institutional Setups

### 4.2.1 Per Unit Water Consumption and Wastewater Production for Institutional Setups

**Table 22: Per unit water consumption and wastewater production for institutional setups**

| Institution | Unit | $W_{cons}$ [L/unit*d] | $WW_{prod}$ [L/unit*d] | Region/ Country | Description | References |
|---|---|---|---|---|---|---|
| **Accommodation** | | | | | | |
| **Camping site** | guest | | 68 – 82 | General | | (Henze *et al.*, 2002) |
| **Cottage** | cottage | | 110 – 164 | General | | (Henze *et al.*, 2002) |
| **Hostel/Boarding house** | bed | | 164 – 274 | General | | (Henze *et al.*, 2002) |
| **Hotel** | guest | 100 – 200 | | Industrialised countries | | (von Sperling, 2008) |
| | employee | 30 – 50 | | | | (von Sperling, 2008) |
| **Lodge** | resident | 80 – 150 | | Industrialised countries | | (von Sperling, 2008) |
| **School/Learning institution** | | | | | | |
| **Day school** | pupils + teachers | | 15 – 30 | Indonesia | | (BORDA SEA and BSD, 2007) |
| | | | 20 | India | College; Pour flush; Design value | (Zimmermann, Wafler and Thakur, 2010) |
| | | | 22 – 27 | General | | (Henze *et al.*, 2002) |
| | | 20 – 60 | | Industrialised countries | without cafeteria and gym | (von Sperling, 2008) |
| | | 40 – 80 | | Industrialised countries | with cafeteria only | (von Sperling, 2008) |
| | | 50 – 100 | | Industrialised countries | with cafeteria and gym | (von Sperling, 2008) |
| **Boarding school** | pupils + staff | | 143 – 154 | Zambia | Secondary school; UMI setting | (Simwambi, 2015b) |
| | | | 77 | Indonesia | | (Reynaud, 2014) |

## Wastewater Characteristics based on Literature Values

| | | | | | | |
|---|---|---|---|---|---|---|
| **<u>Hospitals/Clinics</u>** | | | | | | |
| **Feeding centre** | patient | | 25 | Developing countries | | (Peter, Baghri and Reed, 2002) |
| **Field hospital** | patient | | 55 | Developing countries | | (Peter, Baghri and Reed, 2002) |
| **Cholera treatment centre** | patient | | 100 | Developing countries | | (Peter, Baghri and Reed, 2002) |
| **Hospital (out-patient)** | patient | | 100 | Developing countries | | (Peter, Baghri and Reed, 2002) |
| **Hospital (in-patient)** | bed | | 410 – 680 | General | | (Henze *et al.*, 2002) |
| | bed | | 500 – 700 | Indonesia | | (BORDA SEA and BSD, 2007) |
| | bed | | 300 – 1000 | Industrialised countries | | (von Sperling, 2008) |
| | employee | | 20 – 60 | Industrialised countries | | (von Sperling, 2008) |
| **Nursing home/ sanatorium** | resident | | 270 – 410 | Industrialised countries | | (Henze *et al.*, 2002) |
| | resident | | 200 – 450 | | | (von Sperling, 2008) |
| | employee | | 20 – 60 | | | (von Sperling, 2008) |
| **Prison** | inmate | 200 – 500 | | Industrialised countries | | (von Sperling, 2008) |
| | employee | 20 – 60 | | | | (von Sperling, 2008) |
| **Office** | staff | 30 – 70 | | Industrialised countries | | (von Sperling, 2008) |
| | staff | 50 – 80 | | | Human wastewater in industrial plants | (von Sperling, 2008) |
| | staff | 50 | | India | | (CPCB, 2009) |
| | staff | | 15 – 30 | Indonesia | | (BORDA SEA and BSD, 2007) |
| | staff | | 40 – 55 | General | | (Henze *et al.*, 2002) |
| **Public toilet** | user | 10 – 25 | | Industrialised countries | | (von Sperling, 2008) |

### 4.2.2 Peak Flow Factors for Institutional and Industrial Setups

| Institution/Industry | Connected users [inhab.] | PFF diurnal [-] | PFF daily [-] | PFF total [-] | Description | References |
|---|---|---|---|---|---|---|
| **School/Learning institution** | | | | | | |
| **Day school** | | 2 | 1.1 | 2.2 | College | (The United Republic of Tanzania, 2007) |
| | | 4 | 1.1 | 4.4 | Primary school | (The United Republic of Tanzania, 2007) |
| | | 4 | 1.1 | 4.4 | Secondary school | (The United Republic of Tanzania, 2007) |
| **Boarding school** | 478 | 2 | | | Indonesia; Secondary school | (Reynaud, 2014) |
| | 258 boarding; 175 day scholars | 2.2 – 2.8 | 1.2 | 2.6 – 3.4 | Boarding school with day school section; UMI setup; Zambia | (Simwambi, 2015b) |
| **Hospitals/Clinics** | | | | | | |
| **Dispensary** | | 2.5 | 1.1 | 2.8 | Design guidelines | (The United Republic of Tanzania, 2007) |
| **Hospital** | | 2.5 | 1.1 | 2.8 | Design guidelines | (The United Republic of Tanzania, 2007) |
| **Prison** | | 4 | 1.1 | 4.4 | Design guidelines | (The United Republic of Tanzania, 2007) |
| **Office** | | 1.8 | 1.2 – 2.3 | 2.2 – 4.1 | Design guidelines | (The United Republic of Tanzania, 2007) |
| **Production industry** | | | | 1 – 6 | min: continuous production 24/7; max: seasonal and/or batch production | (Henze *et al.*, 2002) |
| | | | | 3 – 4 | Average range | (Henze *et al.*, 2002) |

### 4.2.3 Per Unit Pollutant and Nutrient Loads of Institutional Setups

Table 23: Per unit pollutant and nutrient loads for institutional setups[12]

| Institution | Unit | COD [g/unit*d] | $BOD_5$ [g/unit*d] | TKN [g/unit*d] | TP [g/unit*d] | References |
|---|---|---|---|---|---|---|
| **School** | | | | | | |
| **Day school** | pupils + teachers | 24 | 12 | 2.2 | 0.4 | (BORDA Africa, 2015) |
| **Boarding school** | pupils + staff | 90 | 45 | 8.3 | 1.4 | (BORDA Africa, 2015) |

[12] Values from BORDA DEWATS design spreadsheet included, because of lack of literature data

## 4.3 Per Unit Wastewater Characteristics for selected Industries

Table 24: Per unit wastewater characteristics for selected industries

| Industry | Unit | $WW_{prod}$ [L/unit*d] | $BOD_5$ [g/unit*d] | Description | References |
|---|---|---|---|---|---|
| **Animal breeding** | | | | | |
| **Cattle** | cow | 16 | | Small-scale subsistence farming; Egypt | (Demars and Reymond, 2014) |
| | cow | 60 | | Indonesia | (BORDA SEA and BSD, 2007) |
| | live weight (tons) | 150 | 1,600 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Dairy cattle** | live weight (tons) | 20 – 80 | 50 – 100 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Horses** | live weight (tons) | 150 | 4,000 – 8,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Pigs** | pig | 20 – 50 | | Indonesia | (BORDA SEA and BSD, 2007) |
| | live weight (tons) | 200 | 2,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Poultry** | live weight (tons) | 380 | 900 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Drinks** | | | | | |
| **Alcohol distillation** | 1 ton cane processed | 60,000 | 220,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Brewery** | 1,000 L product | 5,000 – 20,000 | 8,000 – 20,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Soft drinks** | 1,000 L product | 2,000 – 5,000 | 3,000 – 6,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Wine** | 1,000 L product | 5,000 | 250 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Food** | | | | | |
| **Bakery** | 1 ton product | 2,000 – 4,000 | | Water cons. = WW prod. | (von Sperling, 2008) |
| **Beef processing** | 1 ton product | 10,000 – 16,000 | 1,000 – 24,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Canned fruit & vegetables** | 1 ton product | 4,000 – 50,000 | 30,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Carrot processing** | 1 ton product | 11,000 | 18,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Chicken meat processing** | 1 ton product | 15,000 – 60,000 | 4,000 – 30,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Citrus fruit processing** | 1 ton product | 9,000 | 3,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Dairy (cheese or butter)** | 1 ton product | 2,000 – 10,000 | 5,000 – 40,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Dairy (milk)** | 1 ton product | 1,000 – 10,000 | 1,000 – 5,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Fish processing** | 1 ton product | 5,000 – 35,000 | 3,000 – 55,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Margarine** | 1 ton product | 20,000 | 30,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Pea processing** | 1 ton product | 13,000 – 18,000 | 16,000 – 20,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Potato processing** | 1 ton product | 7,500 – 16,000 | 10,000 – 25,000 | Water cons. = WW prod. | (von Sperling, 2008) |

| | | | | | |
|---|---|---|---|---|---|
| **Sugar cane** | 1 ton product | 500 – 10,000 | 2,500 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Sweets** | 1 ton product | 5,000 – 25,000 | 2,000 – 8,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Tempe industry** | 1 ton product | 5,000 – 10,000 | | Indonesia | (BORDA SEA and BSD, 2007) |
| **Tofu industry** | 1 ton product | 15,000 – 20,000 | | Indonesia | (BORDA SEA and BSD, 2007) |
| **Tomato processing** | 1 ton product | 4,000 – 8,000 | 1,000 – 4,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Yeast production** | 1 ton product | 150,000 | 1,100,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Slaughterhouse** | | | | | |
| **Cows** | cow | 500 – 3,000 | 500 – 5,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| | cow | 150 – 300 | | Indonesia | (BORDA SEA and BSD, 2007) |
| **Pigs** | pig | 200 – 1,200 | 200 – 2,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| | pig | 80 – 100 | | Indonesia | (BORDA SEA and BSD, 2007) |
| **Chicken** | chicken | 5 – 10 | | Indonesia | (BORDA SEA and BSD, 2007) |
| **Pulp & Paper** | | | | | |
| **Paper fabrication** | 1 ton product | 30,000 – 250,000 | 10,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Pulp fabrication** | 1 ton product | 15,000 – 200,000 | 30,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Pulp bleaching** | 1 ton product | 80,000 – 200,000 | | Water cons. = WW prod. | (von Sperling, 2008) |
| **Pulp & paper integrated** | 1 ton product | 200,000 – 250,000 | 60,000 – 500,000 | Water cons. = WW prod. | (von Sperling, 2008) |
| **Textiles - Cotton** | 1 ton product | 120,000 – 750,000 | 150,000 | Water cons. = WW prod. | (von Sperling, 2008) |

# 5 Qualitative Analysis of influencing Parameters

Prior to the quantitative data analysis, a qualitative assessment of influencing factors is conducted – partially derived from literature sources, partially derived from specialised knowledge gathered through the data obtained. Following chapters list and explain influencing factors and quantitative correlations for water consumption and wastewater production (combined), WRC, PFF and pollutant/nutrient loads.

## 5.1 Factors that influence Water Consumption and Wastewater Production

Wastewater production correlates with the water consumption. Therefore, same factors that influence the water consumption influence the wastewater production. In this table the term "water consumption" is used, but also refers to wastewater production. Only the factor "system losses" does only affect the wastewater production as the water is "lost" and does not get consumed. Factors influencing the ratio of wastewater produced per unit of water consumed are listed in the factors influencing the water return coefficient (see Chapter 5.2).

Table 25: Factors that influence water consumption (adapted from von Sperling, 2008)

| Influencing Factor | Comment |
|---|---|
| **Water availability** | In locations of water shortage consumption tends to be less.<br><br>Conversely in areas with high mean annual precipitation water consumption tends to be higher and less dependent on the economic status of the population (von Sperling *et al.*, 2002; Reynaud, 2014). |
| **Climate** | Higher mean annual temperatures (MAT) induce a greater water consumption.<br><br>Water consumption tends to be higher and less dependent on the economic status of the population in areas with high mean annual precipitation (MAP) and can also be influenced by seasons (higher in rainy season) (von Sperling *et al.*, 2002; Reynaud, 2014). |
| **Community size; urban vs. rural** | Larger cities generally present a larger per capita water consumption (to account for strong commercial and institutional activities and different lifestyles in urban areas) (UNEP, 2000; Bachur and Ferrer, 2013). |
| **Economic level of the community** | A higher economic level is associated with a higher water consumption. However, this influence tends to be less in places with easily accessible and readily available groundwater resources and sufficient recharge (von Sperling *et al.*, 2002; Reynaud, 2014). |
| **Level of industrialisation** | Industrialised locations present a higher consumption. Higher levels of industrialisation typically go along changed lifestyles with higher water consumption.<br><br>However, many households in developing countries include small-scale household industries, institutions or commercial establishments (e.g. tofu |

| | |
|---|---|
| | production, religious congregation, restaurant/bar), which cannot be fully excluded and contribute to the water consumption. |
| **Lifestyle** | "Ecological" lifestyle (i.e. water saving habits, use of water saving appliances) reduces water consumption (Henze and Comeau, 2008). |
| **Use of technical appliances** | The use of technical appliances (i.e dishwasher, washing machine) is more efficient and therefore reduces the water consumption. |
| **Metering of household consumption** | Metering inhibits greater consumption. |
| **Water cost** | A higher cost reduces consumption, particularly in LI areas (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a; Reymond *et al.*, 2015). |
| **Water pressure** | High pressure in the distribution system induces greater use and wastage. |
| **System losses ("Non-revenue water")** | Losses in the water distribution network and illegal water connections imply the necessity of a greater water production, which is reflected in a greater water supply and pretends a higher water consumption (Bachur and Ferrer, 2013; IBNET, 2017). |
| **Sanitation system** | Water consumption is lower for shared facilities and drastically decreases as the distance to the sanitation facility increases, due to lower usage ratios (Crous, 2014; Laramee, 2016). |
| **Flush system** | Full-flush toilets use about 2 – 4 times as much water than pour flush toilets (Asian Institute of Technology (AIT), 2013; Crous, 2014; Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a). |
| **Water supply** | A household water connection leads to higher water consumption. In case of public water supply the distance to the water collection point greatly influences the water consumption (Crous, 2014). |

A number of factors influencing the water consumption and wastewater production represent the socio-economic status of a community, such as *economic level, sanitation system* and *water supply,* which is the main influencing factor on water consumption according to a study by Campos and Von Sperling (1996). Furthermore, factors such as *level of industrialisation, lifestyle* and *system losses* represent the overall country's development and infrastructure. The average water consumption is higher for industrialised countries; the range of water consumption is higher for developing countries, because of huge inequalities between low- and high-income communities, typical for developing countries.

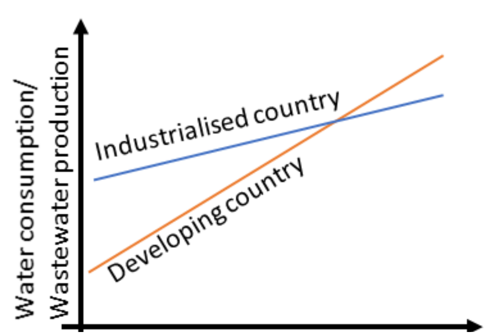

Figure 12: Qualitative per capita water consumption/ wastewater production in industrialised and developing countries based on socio-economic status

Moreover, water saving appliances and habits are less common in developing countries, also due to lower coverage of water meters and lower prices for freshwater, leading to a trend of higher water consumption and wastewater production in high-income communities of developing countries as shown in Figure 12.

## 5.2 Factors that influence the Water Return Coefficient

Table 26: Factors that influence the WRC

| Influencing Factor | Comment |
|---|---|
| **Sewer system** | The WRC is lower for open sewer connections (e.g. discharge of wastewater into stormwater drainages) as less water gets disposed of in the sewage system, because especially greywater gets discharged into the ground (Reymond, Demars, Papangelou, Tawfik, Hassan, *et al.*, 2014a).<br>However, open sewer connections present high evaporation rates in arid and hot climate and high rainwater infiltration in tropical climates. |
| **Water supply** | In house water connections increase the WRC as taps are directly connected to the sewer system. In reverse, water supply which is not in-house lead to low WRCs, as major parts of greywater use are directly discharged into the soil. |
| **Water usage habits** | The WRC is lower in high income areas where high amounts of water are used for irrigation/gardening and car washing (Mara, 2004). |
| **Climate** | A higher MAT reduces the WRC due to evaporation losses. High MAP rates increase the WRC due to infiltration into the sewage system (WHO and UNEP, 1997; UNEP, 2000; Henze *et al.*, 2002). Hence, locations with hot and dry and rainy seasons show high seasonal fluctuations in WRCs. |
| **Groundwater table** | Locations with high groundwater tables tend to have high WRCs due to infiltration into the sewage system (UNEP, 2000; Henze *et al.*, 2002; Demars and Reymond, 2014). |
| **Condition of sewer network** | Old and bad condition of sewer pipes lead to low WRC in arid locations due to exfiltration and to high WRC in tropical locations due to infiltration into the sewer system (Henze *et al.*, 2002; von Sperling *et al.*, 2002). |

The factors *sewer system, water supply* and *water usage habits* are parameters representing the socio-economic status of a community, but with opposing influence on the WRC. A maximum WRC occurs in socio-economic setups where the population can afford inhouse water connections but do not occupy large plots with extensive irrigation water usage as well as water use for car washing. This trend is different to most paramters characterising wastewater, which are in most cases either monotonically increasing or decreasing. A qualitative curve of the WRC based on socio-economic status is visualised in Figure 13.

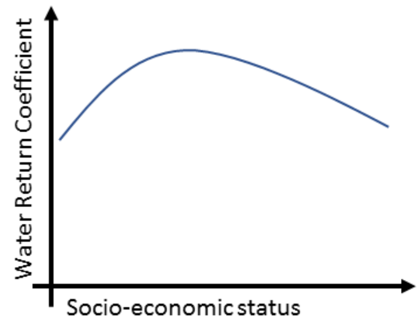


Figure 13: Qualitative curve of WRC based on socio-economic status

## 5.3 Factors that influence Peak Flows

Table 27: Factors that influence peak flows

| Influencing Factor | Comment |
|---|---|
| **Sanitation system** | Shared sanitation facilities tend to have very high PFFs, as the number of persons per toilet is higher than with private facilities. Additionally, sanitation centres usually have limited operating hours, leading to higher peak flows during hours of operations. |
| **Homogeneity of community** | Peak flows tend to be high in homogenous communities, such as workers' housing estates, particularly where shift-work is prevalent, leading to the occurrence of peak flows at the same time of the day. In contrast, communities with predominantly white-collar workers tend to have low PFF, as flexible working hours extend the duration of peak flow, leading to less extreme peaks. |
| **Wastewater production** | Communities that have low daily per capita wastewater production rates tend to have higher PFF, because a slight change in wastewater production has a higher impact on peak flows, since the peak flow is the maximum flow based on the average flow. |
| **Number of connected people** | The number of connected people greatly influences the PFF. Peak flows are equalised with higher numbers of connected people, because average flows increase and user patterns become less homogeneous, hence peak flows of individual users more evenly distributed. |
| **Number of users per toilet (here: CSC)** | PFF are lower for lower number of users per toilet. This is contrary to higher number of connected users leading to smaller peak flow factors. |

The factors *sanitation system, homogeneity of community* and *wastewater production* are indicators of the socio-economic status. Communities with improved socio-economic status are less homogeneous in terms of daily routines, have improved and private sanitation facilities and higher average water consumption, leading to lower peak flows. However, more flexible day-to-day routines in high income communities lead to higher daily peak flow factors, but these are outnumbered by the diurnal peak flows by several multiples.

## 5.4 Factors that influence Pollutant and Nutrient Loads

Table 28: Factors that influence pollutants and nutrient loads

| Influencing Factor | Comment |
|---|---|
| **Fibre intake** | The higher the fibre intake the higher the daily organic pollutant load in the excreta. Because the food intake of people of lower economic level tends to be more fibrous, the organic load in blackwater is higher in low-income communities (Rose *et al.*, 2015). |
| **Average body mass of community** | The organic pollutant and nitrogen load excreted correlate directly with the calorie uptake, which is related to the average body mass. Communities with a tall population and/or a high ratio of heavy or overweight people have higher per capita pollutant loads (Rose *et al.*, 2015).<br>Furthermore, males excrete higher pollutant loads than females and adults higher loads than children and elderly people (ibid.). |
| **Ecologic lifestyle** | Households that dispose kitchen waste into the kitchen sink or toilet, instead of diverting it into solid waste bins, generate higher per capita pollutant loads (Henze and Comeau, 2008).<br>Households using excessive loads of detergents for dishwashing and laundry generate higher nutrient loads in the greywater (Henze and Comeau, 2008). |
| **Use of technical appliances** | The use of technical appliances (i.e dishwasher, washing machine) is more efficient and therefore reduces the detergent use, hence the pollutant loads. Particularly high-income communities in low-income countries tend to generate high pollutant loads in greywater, because of cheap manual labour and the low degree of dissemination of technical household appliances. |
| **Anal cleansing practices (wiper vs. washer)** | Practices of anal cleansing influence the per capita pollutant loads in the blackwater. Wiping practice significantly increase the pollutant loads, whereas washing practice does not introduce additional pollutant loads to the blackwater (Rose *et al.*, 2015). |
| **Community demographics** | Adult population generate higher per capita pollutant loads than young persons and old persons (Rose *et al.*, 2015). |
| **Health status** | Diarrhoea increases the pollutant and nutrient loads excreted. Hence, localities with high diarrhoea prevalence rates possess higher pollutant and nutrient loads in blackwater (Rose *et al.*, 2015). |

Based on the qualitative assessment of factors influencing the pollutant and nutrient loads a similar conclusion can be drawn as for the water consumption/ wastewater production. The key influencing factor on the pollutant and nutrient load is the socio-economic status of a community according to Bachur and Ferrer (2013). However, because of huge inequalities within a countries society in developing countries, the lower dissemination rate of technical household appliances and less prevalence of ecological lifestyles, the per capita pollutant and nutrient loads tend to be higher for high incomes in developing countries, compared to equal incomes in developing countries. These correlations are qualitatively shown in Figure 14.

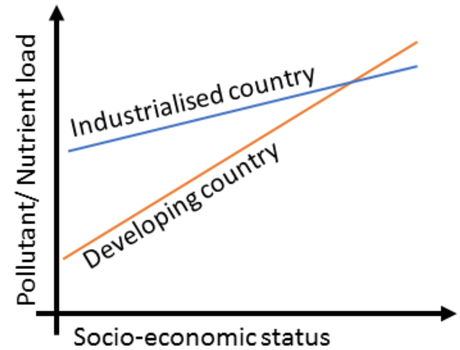


**Figure 14: Qualitative per capita pollutant and nutrient loads in industrialised and developing countries based on socio-economic status**

# 6 Results of the Quantitative Data Analysis

Following chapters describe how expectancy values and parameter ranges for wastewater characteristics are derived from the collated literature data. It is analysed which quantifiable correlations between the influencing factors and the respective wastewater characteristics exist. This approach aims to provide a systematic methodology to improve DEWATS design input parameters based on context specific information. It provides data to interpolate between existing data and furthermore to extrapolate and estimate parameters, for previously unknown conditions and thereby serves as baseline data to identify knowledge gaps for future investigations.

The data analysis is structured in following parts:

1. Calculation of benchmark values as parameter baseline
2. Calculation of macro factors to derive country specific values
3. Calculation of country level wastewater characteristics based on income and climate
4. Calculation of factors for the local context to specify values for a community specific context

## 6.1 Results of Benchmark Values Calculations

Following tables summarise the benchmark values for the main wastewater characteristics stating the number of observations (data points) *n*, parameter ranges *min – max* and median values *med.*

**Table 29: Benchmark values for water consumption and wastewater production**

| | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | BW [L/cap*d] | GW [L/cap*d] | BW ratio [%] |
|---|---|---|---|---|---|---|
| **n** | 159 | 125 | 43 | 18 | 14 | 14 |
| **mean** | 104 | 90 | 73 | 21 | 91 | 25 |
| **min – max (median)** | 54 – 147 (89) | 44 – 132 (76) | 66 – 78 (72) | 10 – 31 (17) | 39 – 145 (75) | 21 – 28 (24) |

**Table 30: Benchmark values for COD, BOD and TSS loads**

| | COD [g/cap*d] | $BOD_5$ [g/cap*d] | $COD_{BW}$ [g/cap*d] | $BOD_{5,BW}$ [g/cap*d] | $COD_{GW}$ [g/cap*d] | $BOD_{5,GW}$ [g/cap*d] | TSS [g/cap*d] |
|---|---|---|---|---|---|---|---|
| **n** | 55 | 107 | 10 | 13 | 5 | 4 | 32 |
| **mean** | 86 | 43 | 62 | 28 | 37 | 21 | 54 |
| **min – max (median)** | 55 – 110 (78) | 31 – 52 (40) | 48 – 72 (59) | 21 – 32 (26) | 26 – 46 (35) | 13 – 29 (20) | 39 – 64 (50) |

**Table 31: Benchmark values for Nitrogen and Phosphorus**

| | TKN [g/cap*d] | TP [g/cap*d] | $TKN_{BW}$ [g/cap*d] | $TP_{BW}$ [g/cap*d] | $TKN_{GW}$ [g/cap*d] | $TP_{GW}$ [g/cap*d] |
|---|---|---|---|---|---|---|
| **n** | 57 | 54 | 10 | 12 | 5 | 12 |
| **mean** | 9.1 | 1.6 | 11.8 | 2.1 | 1.8 | 0.9 |
| **min – max (median)** | 6.5 – 10.8 (8.4) | 0.6 – 2.7 (1.2) | 10.5 – 12.7 (11.5) | 1.2 – 2.7 (1.8) | 1.1 – 2.4 (1.6) | 0.1 – 3.1 (0.5) |

**Table 32: Benchmark values for peak flow factors**

| | $PFF_{tot}$ [-] | $PFF_{diurnal}$ [-] | $PFF_{daily}$ [-] |
|---|---|---|---|
| **n** | 38 | 54 | 42 |
| **mean** | 2.7 | 2.3 | 1.3 |
| **min – max (median)** | 2.2 – 3.0 (2.6) | 1.8 – 2.6 (2.1) | 1.3 – 1.4 (1.3) |

A very high number of values for water consumption, wastewater production and $BOD_5$ (all above 100 data points) were recorded and also sample sizes for COD, TKN and TP are above 50 observations and therefore expected to enable reasonable conclusions and data analysis. Values for blackwater and greywater and the respective loads in these wastewater types are insufficient to derive factors and not considered for further analysis. Number of data points for PFF are acceptably high, but as the influencing parameters differ fundamentally from the ones of the other wastewater characteristics, a different methodology is used for analysis and discussed separately in Chapter 6.4.

The tables present realistic and reasonable parameter ranges and expectancy values. Also, the relation between water consumption and wastewater production is in a realistic range, although most values were derived from different studies and sources. WRC calculated for the median, minimum and maximum values result in 85 %, 81 % and 90 % respectively, which are rather high values and exceed the calculated range for WRC. These values also do not conform with the qualitative analysis drawn in Chapter 5.2, where the highest WRC was expected for medium incomes. Furthermore, this could lead to wastewater production values higher than water consumption values in further calculations, hence special attention has to be paid in the following analysis.

Summing up the values for the parameters differentiating between wastewater types it becomes apparent that all parameters (wastewater production, COD, $BOD_5$, TKN and TP loads) are significantly higher than the values for mixed wastewater. In the case of wastewater production, the sums of blackwater and greywater result in 49, 92 and 176 L/cap*d for minimum, median and maximum values respectively as compared to 44, 76 and 132 L/cap*d for mixed wastewater, hence being up to 33 % higher. This can be explained with the assumption that studies differentiating between wastewater types are biased towards higher socio-economic status with improved water supply and sanitation infrastructure, whereas the values for mixed wastewater have a higher influence of lower socio-economic setups. This assumption is furthermore supported by the fact that a certain level of water and sanitation infrastructure is needed to conduct measurements of grey- and blackwater flows. Nonetheless, these values can be used to make general estimations of blackwater to greywater ratio for future design considerations. Same applies to pollutant and nutrient ratios for greywater and blackwater.

## 6.2 Development of Country Level Wastewater Characteristics

Based on the benchmark values and conclusions drawn above, further investigations are conducted to calculate factors and derive country values based on these factors. The development of country level wastewater characteristics is done successively and follows the methodology highlighted in Chapters 3.6 ff.

### 6.2.1 Calculation of Macro Factors

Following tables present the results of the calculations of the macro factors. Parameters included are those with a sufficient number of data points as defined in Chapter 3.5 and highlighted elaborated above. The number of values used for the calculations are stated in brackets.

Table 33: Factors for global income classification

| Income Class | $W_{cons}$ | $WW_{prod}$ | WRC | COD | $BOD_5$ | TKN | TP |
|---|---|---|---|---|---|---|---|
| **LI** | 0.73 (20) | | | | | | |
| **LMI** | 0.92 (40) | 0.90 (79) | 1.00 (12) | 0.79 (20) | 0.84 (27) | 0.64 (15) | |
| **UMI** | 1.02 (81) | 1.49 (35) | 1.02 (23) | 1.01 (27) | 0.97 (63) | 1.20 (28) | 0.99 (28) |
| **HI** | | 2.06 (12) | | 1.99 (15) | 1.75 (21) | 1.62 (19) | 1.62 (19) |

The number of data points recorded show a bias towards lower-middle income countries for wastewater production and a trend towards upper-middle income countries for the other parameters under investigation. This explains, why most factors are around a value of 1 for these income classes with one exception: The factor for wastewater production for UMI is significantly higher (1.49) than the other factors in this income class. Most likely this is due to a bias towards lower-middle income for this parameter, leading to a lower benchmark value with high deviation for UMI. Particularly as the factor for water consumption is only 1.02 this could lead to distorted ratios between water consumption and wastewater production, when deriving parameter ranges based on factors and benchmark values. The number of values for low-income countries are low for all parameters (between 0 and 20 data points), so that only a factor for water consumption could be calculated. This presents challenges to calculate country factors for low-income countries.

Table 34: Factors for global climate classification

| Climate Classification | $W_{cons}$ | $WW_{prod}$ | WRC | COD | $BOD_5$ | TKN | TP |
|---|---|---|---|---|---|---|---|
| **Arid** | 0.73 (31) | 0.67 (27) | 0.91 (15) | 0.80 (17) | 0.93 (28) | 0.99 (15) | 0.70 (15) |
| **Moderate** | 1.13 (38) | 1.27 (41) | | 1.29 (31) | 1.18 (52) | 1.23 (37) | 1.27 (31) |
| **Tropical** | 1.17 (61) | 1.20 (54) | 1.07 (16) | 1.36 (11) | 1.11 (21) | 1.10 (12) | 0.59 (12) |

The number of values for respective climate classifications are similar to the ones for the income classes. Water consumption and wastewater production expectedly show a clear trend of higher values for wetter climate, hence increased water availability as explained in Chapter 5.1. However, the wastewater production is highest for moderate climate. Same applies to the WRC where exfiltration/evaporation of sewage and infiltration of rainwater influence the values, although not as significantly as for the first two parameters. Pollutant loads show minimum values for arid climate which may be due to minimum amounts of external pollutants infiltrating the system (e.g. with rain and stormwater). This is further underlined by maximum COD loads for Tropical climate as stormwater contains high levels of inorganic components, whereas BOD loads are less for Tropical climate compared to Moderate climate. The factors for TKN show a bias towards arid climate (factor closest to 1). The factors for moderate climate are considerably high, showing an influence of the socio-economic status in these factors as most countries with moderate climate fall into the UMI categories. Noticeable is the significantly low value for TP for tropical climate (0.59), which is the only factor below 1 in this climate classification. This may be due to the low number of recorded values, which are influenced by factors other than the climate conditions. Another observation to be mentioned is that the influence of climate on wastewater characteristics is more pronounced on the water related parameters than on the pollutant and nutrient loads.

### 6.2.2 Calculation of Parameter Ranges based on Macro Factors

Parameter ranges are calculated using the calculation specifications defined in Chapter 3.10 and in particular formulas [11] and [12]. The distinguished values are summarised in Table 35 and Table 36. Parameters that require special attention or that seem unrealistic are highlighted in the tables. In general, the different characteristics present wide ranges, which is due to the fact that the standard deviation of the benchmark sample was used and multiplied with the t-value of the smaller sample sizes leading to comparably high variations.

**Table 35: Median values and parameter ranges of wastewater characteristics depending on income classes**

| Income Class | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] |
|---|---|---|---|---|---|---|---|
| LI | 39 – 110 (65) | | | | | | |
| LMI | 49 – 137 (82) | 39 – 119 (68) | 66 – 78 (72) | 43 – 88 (62) | 25 – 44 (33) | 4.2 – 7.1 (5.4) | |
| UMI | 55 – 151 (91) | 64 – 198 (113) | 67 – 79 (73) | 56 – 112 (79) | 30 – 50 (39) | 7.8 – 13.1 (10.1) | 0.6 – 2.7 (1.2) |
| HI | | 86 – 283 (156) | | 109 – 224 (157) | 53 – 91 (69) | 10.5 – 17.8 (13.6) | 0.8 – 3.8 (1.7) |

As mentioned before, the discrepancy in the factors for water consumption and wastewater production for upper-middle income lead to wastewater production rates that exceed the water consumption. This is possible in cases where excessive infiltration in the sewer system and subsequent WWTP occurs or where additional non-accounted water (e.g. where water from private wells or boreholes is consumed, but is not recorded in the water consumption), but it is not realistic to reflect that pronounced on the average values. However, WRC are expected to reach a maximum at this income level. Several values are extremely high for high income classes, which is due to the characteristic of the used distribution function with a positive skewness (see Chapter 3.2) leading to high maximum values within a confidence interval.

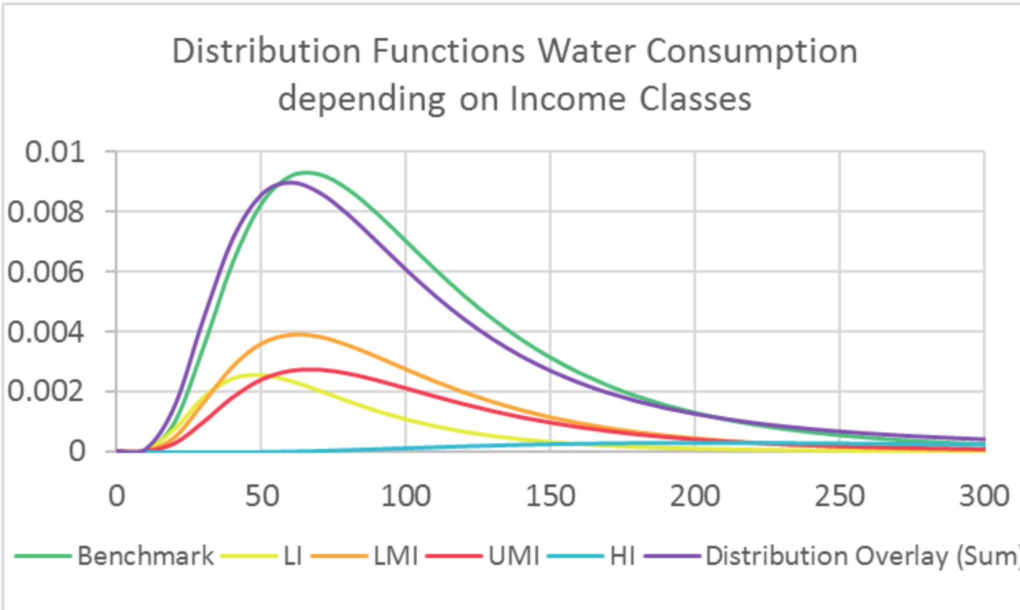


Figure 15: Overlaid distribution functions for water consumption depending on income class

An overlay of the distributions functions for the water consumption is shown in Figure 15 including the functions for the benchmark value, the four income classes and an overlay, summarising the probabilities of the income class distributions. The overlaid function follows the benchmark function in good approximation, allowing the conclusion that the total parameter range can be subdivided as presented with the factors.

Table 36: Median values and parameter ranges of wastewater characteristics depending on climate classification

| Climate Classification | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] |
|---|---|---|---|---|---|---|---|
| **Arid** | 39 – 108 (65) | 29 – 89 (51) | 60 – 71 (65) | 44 – 90 (63) | 28 – 49 (37) | 6.4 – 10.9 (8.4) | 0.4 – 2.0 (0.9) |
| **Moderate** | 60 – 167 (100) | 55 – 169 (96) | | 72 – 144 (102) | 36 – 61 (47) | 8.0 – 13.4 (10.4) | 0.7 – 3.5 (1.6) |
| **Tropical** | 63 – 172 (104) | 52 – 159 (91) | 71 – 83 (77) | 74 – 155 (107) | 34 – 58 (44) | 7.1 – 12.1 (9.3) | 0.3 – 1.7 (0.7) |

The calculated values for water consumption, wastewater production and WRC show good consistency and realistic values for all climate classifications as the quotients of wastewater production and water consumption result in values covered in the range of stated WRC. Furthermore, WRC are significantly lower for arid climate. As mentioned in the previous chapter, the values for TP in tropical climate are very low, whereas the range between median value and maximum value presents a realistic range with the minimum value being extremely small.

### 6.2.3 Propagated Factors for Income and Climate

Based on the derived factors and the methodology used for factor propagation (see Chapter 3.8) country level factors are developed and presented in the following table. Conclusions to be drawn follow the peculiarities associated with the single factors: wastewater production factors for upper-middle income are comparably high compared to the water consumption factors and TP loads are remarkably low for tropical climate. This methodology enables the calculation of twelve different main parameter sets for four different income classes and three climate classifications.

Table 37: Country level wastewater characteristics - factors

| Income Class | Climate Classification | $W_{cons}$ | $WW_{prod}$ | WRC | COD | $BOD_5$ | TKN | TP |
|---|---|---|---|---|---|---|---|---|
| LI | Arid | 0.73 | | | | | | |
| | Moderate | 0.91 | | | | | | |
| | Tropical | 0.92 | | | | | | |
| LMI | Arid | 0.82 | 0.78 | 0.95 | 0.79 | 0.89 | 0.80 | |
| | Moderate | 1.02 | 1.07 | | 1.01 | 0.99 | 0.89 | |
| | Tropical | 1.04 | 1.04 | 1.03 | 1.03 | 0.97 | 0.84 | |
| UMI | Arid | 0.86 | 1.00 | 0.96 | 0.90 | 0.95 | 1.09 | 0.83 |
| | Moderate | 1.07 | 1.37 | | 1.14 | 1.07 | 1.22 | 1.12 |
| | Tropical | 1.09 | 1.33 | 1.05 | 1.17 | 1.04 | 1.15 | 0.76 |
| HI | Arid | | 1.17 | | 1.26 | 1.28 | 1.27 | 0.98 |
| | Moderate | | 1.62 | | 1.61 | 1.43 | 1.41 | 1.32 |
| | Tropical | | 1.57 | | 1.65 | 1.39 | 1.34 | 0.89 |

Figure 16 visualises the resulting values for water consumption based on income class and climate classification. It can be observed that the graph for high-income countries is far above the other income classes, which can be explained with the fact that only household water connections and private full-flush toilets are included in the parameters, whereas the other income classes include parameters from shared facilities and public connections, which considerably lowers the consumption. In the income classes LI, LMI and UMI the climate zone has an even higher influence than the income so that the average water consumption for UMI with arid climate is lower than the consumption for LI in tropical climate.

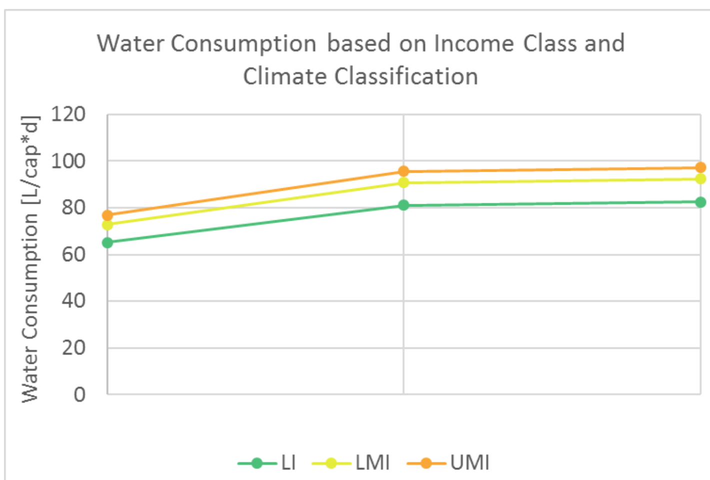


Figure 16: Water consumption based on income class and climate classification

### 6.2.4 Region and Country Level Wastewater Characteristics based on Income and Climate

Based on the propagated factors region and country level wastewater characteristics are calculated using the country classification described in Chapter 3.6. For regions/countries with diverse climatic zones, values for each climate classification are listed. Countries within the same region falling in the same income class and climate classification are grouped and listed together. Noticeable values and ranges are the same as previously stated. Besides the values for water consumption and wastewater production revealing inconsistencies in their quotient, expressed as WRC, the expectancy values and ranges show realistic ranges (e.g. 37 – 147 L/cap*day with an expectancy value of 74 L/cap*day for arid climate in upper-middle income countries).

Table 38: Country level wastewater characteristics – values derived from factors[13]

| Region/Country | Climate Classification (if diverse) | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] |
|---|---|---|---|---|---|---|---|---|
| **Benchmark value** | | 54 – 151 (90) | 35 – 138 (69) | 66 – 78 (72) | 51 – 108 (74) | 31 – 52 (40) | 6.5 – 10.8 (8.4) | 0.6 – 2.7 (1.2) |
| **EAP** | | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **Bangladesh, Cambodia, Indonesia, Lao, Vietnam** | | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **Thailand** | | 60 – 168 (100) | 51 – 206 (103) | 69 – 81 (75) | 63 – 134 (92) | 32 – 54 (41) | 7.5 – 12.5 (9.7) | 0.4 – 2.1 (0.9) |
| **LAC** | **Arid** | 46 – 131 (78) | 37 – 147 (74) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| | **Moderate** | 56 – 159 (95) | 49 – 194 (97) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |
| | **Tropical** | 60 – 168 (100) | 51 – 206 (103) | 69 – 81 (75) | 63 – 134 (92) | 32 – 54 (41) | 7.5 – 12.5 (9.7) | 0.4 – 2.1 (0.9) |
| **Argentina** | | 56 – 159 (95) | 49 – 194 (97) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |

[13] January 2018: Some values in the sheet "1. Database - raw" have been corrected and formulas in sheet "2. Database – clean" have been changed to only consider domestic values for the calculations. Table 29 up to Table 37 have been updated accordingly. This table has not been updated, hence small deviations for $W_{cons}$, $WW_{prod}$ and COD occur.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Brazil** | **Moderate** | 56 – 159 (95) | 49 – 194 (97) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |
| | **Tropical** | 60 – 168 (100) | 51 – 206 (103) | 69 – 81 (75) | 63 – 134 (92) | 32 – 54 (41) | 7.5 – 12.5 (9.7) | 0.4 – 2.1 (0.9) |
| **Mexico** | **Arid** | 46 – 131 (78) | 37 – 147 (74) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| | **Moderate** | 56 – 159 (95) | 49 – 194 (97) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |
| | **Tropical** | 60 – 168 (100) | 51 – 206 (103) | 69 – 81 (75) | 63 – 134 (92) | 32 – 54 (41) | 7.5 – 12.5 (9.7) | 0.4 – 2.1 (0.9) |
| **MNA** | | 46 – 131 (78) | 37 – 147 (74) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| **Algeria, Egypt, Iran, Jordan** | | 46 – 131 (78) | 37 – 147 (74) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| **Morocco, Syria, Tunisia, Yemen** | | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| **Palestine** | | 39 – 112 (66) | | | | | | |
| **SAS** | **Arid** | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| | **Moderate** | 55 – 154 (92) | 35 – 137 (69) | | 52 – 109 (75) | 30 – 51 (40) | 5.8 – 9.7 (7.5) | |
| | **Tropical** | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **Afghanistan** | | 39 – 112 (66) | | | | | | |
| **India** | **Arid** | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| | **Moderate** | 55 – 154 (92) | 35 – 137 (69) | | 52 – 109 (75) | 30 – 51 (40) | 5.8 – 9.7 (7.5) | |
| | **Tropical** | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **Pakistan** | | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **SSA** | **Arid** | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| | **Moderate** | 55 – 154 (92) | 35 – 137 (69) | | 52 – 109 (75) | 30 – 51 (40) | 5.8 – 9.7 (7.5) | |
| | **Tropical** | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **Botswana** | | 46 – 131 (78) | 37 – 147 (74) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| **Kenya** | | 45 – 127 (76) | 26 – 104 (52) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| **Lesotho, Zambia** | | 55 – 154 (92) | 35 – 137 (69) | | 52 – 109 (75) | 30 – 51 (40) | 5.8 – 9.7 (7.5) | |
| **Mali** | | 39 – 112 (66) | | | | | | |
| **Nigeria** | | 58 – 163 (97) | 37 – 146 (73) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| **South Africa** | | 56 – 159 (95) | 49 – 194 (97) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |
| **Tanzania, Uganda** | | 50 – 142 (85) | | | | | | |

## 6.3 Development of Wastewater Characteristics considering the Local Context

Knowing that local conditions vary significantly within countries, provinces and also cities, local factors are developed for local income groups, water supply, sanitation systems and the categorisation if it is an urban, rural or semi-urban/peri-urban setting. Most sample sizes do not meet the requirements of sufficient data points according to the definitions in Chapter 3.5, so that this assessment is limited to the parameters water consumption and wastewater production. Wastewater characteristics regarding pollutant and nutrient loads are adopted from the country specific values and need to be selected using engineer's knowledge and practical experience.

### 6.3.1 Calculation of Local Factors

The local income class factors reveal a huge difference between LI and LMI/UMI, leading to the conclusion that low-income communities are in many cases not served by household water connections, which reduces water consumption and wastewater production significantly. The significant difference in the factors for UMI can lead to equalisation of the values for UMI communities in UMI countries, where the wastewater production was found to be very high in relation to the water consumption. No factors are available for local high-income communities. Following table summarises the factors with the number of samples *n* in brackets

Table 39: Factors for local income classes

| Income Class – local | $W_{cons}$ | $WW_{prod}$ |
|---|---|---|
| **LI – local** | 0.63 (10) | 0.49 (17) |
| **LMI – local** | 1.52 (16) | 1.06 (36) |
| **UMI – local** | 1.93 (13) | 1.07 (15) |

As expressed by the factors concerning the water access, the type of connection has a major impact on water usage, whereas the usage is three times as high for inhouse water connections compared to public taps (see Table 40). The number of data points found for water usage with yard tap water supply were not numerous enough to derive factors, but it is estimated that the factor will converge between household connections and public water points. The values for public water supply are of particular interest for CSC.

Table 40: Factors for water access

| Water Access | $W_{cons}$ | $WW_{prod}$ |
|---|---|---|
| **In house** | 1.14 (134) | 1.15 (104) |
| **Public - unltd** | 0.38 (17) | 0.44 (15) |

The factors regarding the sanitation interface show similar results as the factors for water access, due to the fact that private full-flush toilets require household water connections and shared toilets are usually associated with public water access points. However, the magnitude in the difference of water usage is lower and about a factor 2 for shared facilities compared to private toilets. Factors for pour flush toilets could not been distinguished due to lack of data. Private sanitation interfaces are of major interest for the design of SSS, whereas shared facilities are of interest for systems treating water of CSCs.

Table 41: Factors for sanitation interfaces

| Sanitation Interface | $W_{cons}$ | $WW_{prod}$ |
|---|---|---|
| **Private - full flush** | 1.04 (151) | 1.05 (116) |
| **Shared - full flush** | 0.47 (7) | 0.53 (5) |

### 6.3.2 Propagation of Factors for Local Contexts

As correlations between the different classification criteria were determined (a considerable number of data points refer to the same parameter set), the same calculation procedure as for the propagation of country factors is used. As stated above the factors derived for water access and sanitation interface are combined into a single category "system type" with the categories SSS and CSC. The scenario of private flush toilets and public water access is highly unlikely, but cases of household water supply and shared toilet facilities can occur, because water access is usually prioritised higher than private toilet facilities. Nonetheless, this scenario is not considered in these investigations. Factors for SSS (HH water access and private toilet) and CSC (public water access and shared toilets) are summarised in the following table:

Table 42: Propagated factors for system types

| System Type | $W_{cons}$ | $WW_{prod}$ |
|---|---|---|
| **SSS** | 1.09 | 1.10 |
| **CSC** | 0.42 | 0.48 |

To calculate the geometric mean of the above mentioned three classification criteria, the cubic root of the products of the respective factors has to be determined:

$$F_{local\ context} = \sqrt[3]{F_{Income-local} \cdot F_{Water\ access} \cdot F_{Sanitation\ interface}} \quad [13]$$

The resulting factors are presented in Table 43. The quotient of water usage of SSS and CSC is in the range of 1.6 – 1.9 for all cases, which appears to be a reasonable ratio. Although CSCs are unlikely to exist in UMI communities, they are listed for completeness.

Table 43: Propagated factors for different local contexts

| Income Class – local | System Type | $W_{cons}$ | $WW_{prod}$ |
|---|---|---|---|
| **LI – local** | SSS | 0.96 | 0.77 |
| | CSC | 0.52 | 0.49 |
| **LMI – local** | SSS | 1.50 | 1.13 |
| | CSC | 0.80 | 0.71 |
| **UMI – local** | SSS | 1.69 | 1.13 |
| | CSC | 0.91 | 0.72 |

### 6.3.3 Calculation of Wastewater Characteristics considering the Local Context

All factors and values derived and calculated enable the consideration of 72 different scenarios (4 global income classes x 3 climate classifications x 3 local income classes x 2 system types = 72 combinations). A comprehensive list of all possible combinations is presented below, but HI countries are not considered here, because the study focusses on wastewater characteristics in developing countries. This brings the total number of scenarios to 54.

Table 44: Wastewater characteristics considering global and local context based on factors[14]

| Income Class - Global | Climate Classification | Income Class - Local | System Type | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] |
|---|---|---|---|---|---|---|---|---|---|---|
| LI | Arid | LI | SSS | 35 - 98 (58) | | | | | | |
| | | | CSC | 19 - 52 (31) | | | | | | |
| | | LMI | SSS | 45 - 127 (76) | | | | | | |
| | | | CSC | 24 - 68 (41) | | | | | | |
| | | UMI | SSS | 52 - 145 (87) | | | | | | |
| | | | CSC | 28 - 78 (46) | | | | | | |
| | Moderate | LI | SSS | 42 - 119 (71) | | | | | | |
| | | | CSC | 23 - 64 (38) | | | | | | |
| | | LMI | SSS | 55 - 154 (92) | | | | | | |
| | | | CSC | 29 - 82 (49) | | | | | | |
| | | UMI | SSS | 63 - 176 (105) | | | | | | |
| | | | CSC | 34 - 94 (56) | | | | | | |
| | Tropical | LI | SSS | 45 - 125 (75) | | | | | | |
| | | | CSC | 24 - 67 (40) | | | | | | |
| | | LMI | SSS | 58 - 163 (97) | | | | | | |
| | | | CSC | 31 - 87 (52) | | | | | | |
| | | UMI | SSS | 66 - 186 (111) | | | | | | |
| | | | CSC | 36 - 100 (59) | | | | | | |

[14] January 2018: Some values in the sheet "1. Database - raw" have been corrected and formulas in sheet "2. Database – clean" have been changed to only consider domestic values for the calculations. Table 29 up to Table 37 have been updated accordingly. This table has not been updated, hence small deviations for $W_{cons}$, $WW_{prod}$ and COD occur.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LMI | Arid | LI | SSS | 40 - 112 (67) | 21 - 84 (42) | 63 – 74 (68) | 40 – 84 (58) | 27 – 46 (35) | 5.2 – 8.7 (6.7) | |
| | | | CSC | 21 - 60 (36) | 12 - 49 (25) | | | | | |
| | | LMI | SSS | 52 - 145 (87) | 31 - 122 (61) | | | | | |
| | | | CSC | 28 - 78 (46) | 18 - 71 (36) | | | | | |
| | | UMI | SSS | 59 - 166 (99) | 31 - 122 (62) | | | | | |
| | | | CSC | 32 - 89 (53) | 18 - 72 (36) | | | | | |
| | Moderate | LI | SSS | 48 - 136 (81) | 28 - 111 (56) | | 52 – 109 (75) | 30 – 51 (40) | 5.8 – 9.7 (7.5) | |
| | | | CSC | 26 - 73 (43) | 16 - 65 (33) | | | | | |
| | | LMI | SSS | 63 - 176 (105) | 41 - 161 (81) | | | | | |
| | | | CSC | 34 - 94 (56) | 24 - 94 (47) | | | | | |
| | | UMI | SSS | 72 - 201 (120) | 41 - 161 (81) | | | | | |
| | | | CSC | 38 - 108 (64) | 24 - 94 (48) | | | | | |
| | Tropical | LI | SSS | 51 - 143 (86) | 30 - 118 (59) | 68 – 80 (74) | 54 – 114 (78) | 29 – 50 (38) | 5.5 – 9.2 (7.1) | |
| | | | CSC | 27 - 77 (46) | 17 - 69 (35) | | | | | |
| | | LMI | SSS | 66 - 186 (111) | 43 - 170 (86) | | | | | |
| | | | CSC | 36 - 100 (60) | 25 - 100 (50) | | | | | |
| | | UMI | SSS | 76 - 213 (127) | 43 - 171 (86) | | | | | |
| | | | CSC | 41 - 114 (68) | 25 - 100 (50) | | | | | |
| UMI | Arid | LI | SSS | 41 - 115 (69) | 30 - 118 (60) | 64 – 75 (69) | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| | | | CSC | 22 - 62 (37) | 18 - 69 (35) | | | | | |
| | | LMI | SSS | 54 - 150 (90) | 44 - 171 (86) | | | | | |
| | | | CSC | 29 - 80 (48) | 25 - 100 (51) | | | | | |
| | | UMI | SSS | 61 - 171 (102) | 44 - 172 (87) | | | | | |
| | | | CSC | 33 - 92 (55) | 26 - 101 (51) | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Moderate** | **LI** | **SSS** | 50 - 140 (84) | 40 - 156 (79) | | 61 – 128 (88) | 33 – 55 (43) | 7.9 – 13.2 (10.2) | 0.6 – 3.1 (1.4) |
| | | | **CSC** | 27 - 75 (45) | 23 - 91 (46) | | | | | |
| | | **LMI** | **SSS** | 65 - 182 (109) | 57 - 226 (114) | | | | | |
| | | | **CSC** | 35 - 97 (58) | 34 - 132 (67) | | | | | |
| | | **UMI** | **SSS** | 74 - 208 (124) | 58 - 227 (114) | | | | | |
| | | | **CSC** | 40 - 111 (67) | 34 - 133 (67) | | | | | |
| | **Tropical** | **LI** | **SSS** | 53 - 148 (88) | 42 - 166 (83) | 69 – 81 (75) | 63 – 134 (92) | 32 – 54 (41) | 7.5 – 12.5 (9.7) | 0.4 – 2.1 (0.9) |
| | | | **CSC** | 28 - 79 (47) | 25 - 97 (49) | | | | | |
| | | **LMI** | **SSS** | 69 - 192 (115) | 61 - 240 (121) | | | | | |
| | | | **CSC** | 37 - 103 (61) | 36 - 140 (71) | | | | | |
| | | **UMI** | **SSS** | 78 - 219 (131) | 61 - 241 (121) | | | | | |
| | | | **CSC** | 42 - 118 (70) | 36 - 141 (71) | | | | | |

## 6.4 Calculation of Peak Flow Factors (PFF)

The factors influencing the peak flow are known to be fundamentally different to the ones influencing the wastewater characteristics discussed above. Despites the socio-economic status having an impact on the PFF as discussed in Chapter 5.3, no clear trend can be distinguished from the raw data. This may be due to different sampling and recording methodologies, where most literature sources differentiate between daily and diurnal PFFs ($K_1$ and $K_2$) and calculate the resulting total PFF out of the product $K_1 \times K_2$ (Campos and von Sperling, 1996; Metcalf and Eddy, 2003; Mara, 2004; Crous, 2014). However, a number of research studies presented by Reynaud (2014), Simwambi (2015b) and Laramee (2016) only present a single factor as PFF, which leads to incompatibility of results. Additionally, the number of samples differs from study to study from as few as four daily samples up to several hundred days of observations (ibid.). Shorter sampling periods are expected to lead to lower PFFs, as the occurrence of extreme flows increases with the number of samples, whereas the average flow converges towards a long-term average. The need for standardised methodologies becomes apparent as the method of sampling should not influence the results.

Although only a few values are listed, the PFF for shared sanitation facilities is found to be significantly higher than the peak flow for private toilets. The reasons therefore are presented in Chapter 5.3. The PFFs of shared facilities are found to be 1.75 times as high as PFFs of private toilets with median values being 4.2 and 2.4 respectively. This factor is used to differentiate between different communal systems in the following assessments and value calculations.

### 6.4.1 Mathematical Functions to calculate Peak Flow Factors based on connected Population

**A number of different mathematical models were found in the literature, which take the connected population into account as main influencing factor. The formulas are listed in Table 45, PFFs are calculated for selected populations using the stated formulas (see**

Table 46). The graphs of the various functions are visualised in Figure 17. The calculated PFFs for populations below 10,000 connected people are extremely high, showing that these models are only applicable for centralised systems with high numbers of connected people, which is also confirmed by the sources from which the formulas are cited from.

Table 45: Mathematical models to calculate peak flow factors based on connected population

| Formula | Description | References |
|---|---|---|
| $PFF_{tot}(pop) = \begin{cases} 4, & pop \leq 5{,}000 \\ -0.43 \cdot \ln(pop) + 7.7, & pop > 5{,}000 \end{cases}$ | | (Metcalf and Eddy, 2003) |
| $PFF_{tot}(\mathrm{pop}) = 5 \cdot \left(\frac{pop}{1{,}000}\right)^{-0.16}$ | Gifft's formula | (von Sperling, 2008) |
| $PFF_{tot}(\mathrm{pop}) = 1 + \left(\frac{14}{4 + \sqrt{\frac{pop}{1{,}000}}}\right)$ | Harmon's formula | (von Sperling, 2008) |
| $PFF_{tot}(\mathrm{pop}) = \frac{14}{\sqrt[6]{pop}}$ | | (Mara, 2004) |
| $PFF_{tot}(\mathrm{pop}) = 5 \cdot \left(\frac{1{,}000}{pop}\right)^{a}\ ;\ 0.15 < a < 0.2$ | | (Butler and Graham, 1995) |

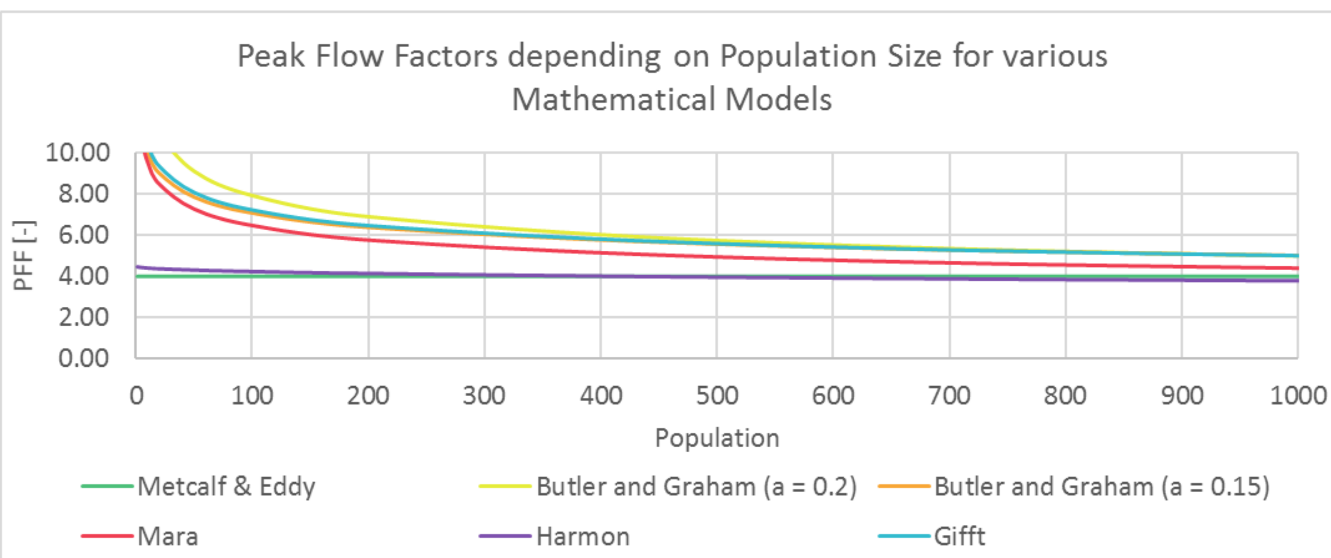


Figure 17: Peak flow factors depending on population size for various mathematical models for populations ≤ 1,000

Table 46: Peak flow factors for different mathematical models and populations

| Population | Metcalf & Eddy | Butler and Graham (a = 0.2) | Butler and Graham (a = 0.15) | Mara | Harmon | Gifft |
|---|---|---|---|---|---|---|
| **1** | 4.0 | 19.9 | 14.1 | 14.0 | 4.5 | 15.1 |
| **10** | 4.0 | 12.6 | 10.0 | 9.5 | 4.4 | 10.5 |
| **100** | 4.0 | 7.9 | 7.1 | 6.5 | 4.2 | 7.2 |
| **1,000** | 4.0 | 5.0 | 5.0 | 4.4 | 3.8 | 5.0 |
| **10,000** | 3.7 | 3.2 | 3.5 | 3.0 | 3.0 | 3.5 |
| **100,000** | 2.8 | 2.0 | 2.5 | 2.1 | 2.0 | 2.4 |
| **1,000,000** | 1.8 | 1.3 | 1.8 | 1.4 | 1.4 | 1.7 |

### 6.4.2 Development of a Mathematical Model to describe Peak Flow Factors of Small-Scale Sanitation Systems

Literature confirms the possibility to describe mathematical models to calculate PFFs based on the connected population size. To develop a model applicable for small-scale sanitation systems with connected populations between 10 and 10,000 people the data presented by Campos and von Sperling (1996) is used for a regression analysis, as it is the most comprehensive field study on peak flow factors obtained. The pairs of values are listed in Table 18 in Chapter 4.1.2. Harmon's formula is the model that shows least extreme values for small populations, hence a non-linear regression model is developed based on Harmon's formula. The model is described as:

[14] $$PFF(pop, a, b) = 1 + \left( \frac{\boldsymbol{a}}{\mathrm{b} + \sqrt{\frac{pop}{1,000}}} \right)$$

With a and b being the regression coefficients. The numerical problem is solved using the Excel-Solver and applying the method of least square errors, resulting in a = 4.7 and b = 1.5 as regression coefficients:

[15] $$PFF(pop) = 1 + \left( \frac{\mathbf{4.7}}{1.5 + \sqrt{\frac{\boldsymbol{pop}}{\mathbf{1,000}}}} \right)$$

The resulting graph and the data points used for the regression model are shown in Figure 18 and compared with Harmon's formula, showing significantly lower values throughout the population range under investigation.

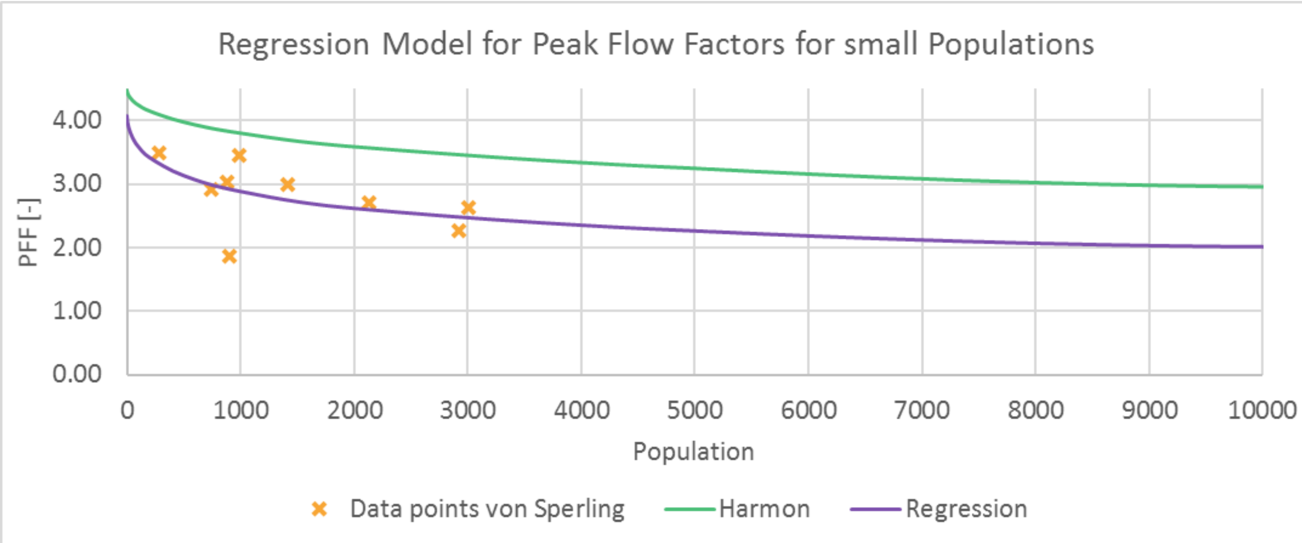


Figure 18: Regression model for peak flow factors for small populations

Peak flow factors for selected populations and SSS and CSC systems calculated using the developed regression function are presented below. The PFFs for CSCs show remarkably high values, but correspond with the observations made by Crous (2014) who found total PFF in a range of 4.5 – 7 for CSC with an average of around 200 – 250 users.

Table 47: Peak flow factors for SSS and CSC systems for various populations

| Population | System Type | Regression |
|---|---|---|
| 1 | SSS | 4.1 |
| 10 | SSS | 3.9 |
| | CSC | 6.9 |
| 100 | SSS | 3.6 |
| | CSC | 6.3 |
| 1,000 | SSS | 2.9 |
| | CSC | 5.1 |
| 10,000 | SSS | 2.0 |
| | CSC | 3.5 |

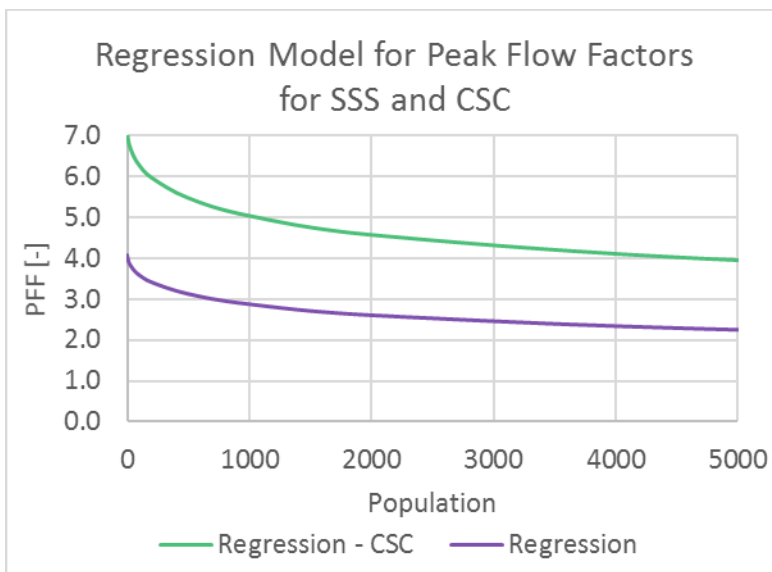


Figure 19: Regression model for peak flow factors for SSS and CSC

# 7 Plausibility Check

## 7.1 Random Sampling and Biases in the Datasets

As the data for this study was purely derived from literature that was available to the author, certain biases within the datasets exist, hence a purely random sample selection cannot be assured. The biases are due to the authors network and data sources and also due to the fact that besides a few exceptions only English literature was obtained and analysed, with a lack of data from i.e. Francophone, Spanish and Mandarin speaking countries. Due to the focus on wastewater characteristics in developing countries a bias towards LMI occurred. This poses a risk of overrepresenting certain values, but it also shows that LMI setups are the typical configuration for wastewater systems in developing countries and therefore most suitable for DEWATS, justifying a higher weighting of such configurations.

The frequency distribution of the number of respective datapoints over income classes follows a skewed normal distribution with a maximum at lower-middle incomes, showing that LMI setups are the typical scenario for the systems under investigation. However, data from LI countries is scarce and most data stems from LMI and UMI countries. This has to be taken into account as LI setups may be misinterpreted.

Additionally, the correlations between the classification criteria could not be determined, because the exact local context was not given in many cases and the amount of data was insufficient to develop complex correlation terms. However, this is taken into account and addressed through the use of the geometric mean for the factor propagation.

## 7.2 Plausibility Check of Wastewater Characteristics Computed by Factors

A plausibility check is conducted to conclude whether the derived factors are able reproduce meaningful values. Therefore, calculated values are compared with obtained literature values and variances are computed.[15] Two plausibility checks are carried out: one test on country level values (average values based on sampling studies) and one test on site specific values from single sampling results. Following colour coding is used to rate the accuracy of the calculated values, compared to the literature values:

- Good matching — Variance ≤ 10 % of lit. value — Green shading
- Matching OK — Variance ≤ 20 % of lit. value — Yellow shading
- Insufficient matching — Variance > 20 % of lit. value — Red shading

Table 48 summarises country level values for 13 parameters with 5 values showing very good matching with an average deviation of 3 % and 5 and 3 values showing OK and insufficient matching respectively. The insufficient matches show a 30 % underestimation of the water consumption in Brazil. The inconsistencies regarding the water usage factors were discussed at length in Chapter 6.2. The other insufficient matches underestimate the COD load

[15] Factors and design parameter values are calculated based on the available literature to date and compared with the average values obtained from the literature collected to date. Therefore, this test shall be repeated with updated values when major updates of the database is conducted.

in Egypt and overestimate the BOD load in Indonesia. However, all means of literature values are within the calculated ranges and 77 % of the values are matched with a deviation of 16% or less. On average the expectancy values of the calculated ranges are below the average literature values. This leads to the assumption that means of the calculated values might lead to better matching as means are higher than median values. However, this is not further assessed in this study.

Table 48: Plausibility check of calculated country values

| Country | Description | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] | WRC [%] | COD [g/cap*d] | $BOD_5$ [g/cap*d] | TKN [g/cap*d] | TP [g/cap*d] |
|---|---|---|---|---|---|---|---|---|
| Brazil; UMI; Moderate | Lit. value | 86 – 233 (143) | 71 – 208 (120) | 58 – 89 (76) | | 27 – 56 (46) | | |
| | Calculation | 60 – 168 (100) | 51 – 206 (103) | 69 – 81 (75) | | 32 – 54 (41) | | |
| | Variance | 30 % | 14 % | 1 % | | 11 % | | |
| Egypt; UMI; Arid | Lit. value | 43 – 174 (75) | | | 95 | | | |
| | Calculation | 46 – 131 (78) | | | 47 – 98 (68) | | | |
| | Variance | - 4 % | | | 28 % | | | |
| Indonesia; LMI; Tropical | Lit. value | | 62 – 91 (76) | | 56 – 95 (80) | 20 – 40 (30) | | |
| | Calculation | | 37 – 146 (73) | | 54 – 114 (78) | 29 – 50 (38) | | |
| | Variance | | 4 % | | 3 % | -27 % | | |
| Iran; LMI; Arid | Lit. value | | | | 41 – 79 (60) | 24 – 46 (39) | 5.9 – 17.4 (11) | 0.6 – 1.2 (0.9) |
| | Calculation | | | | 47 – 98 (68) | 29 – 49 (38) | 7.1 – 11.9 (9.2) | 0.5 – 2.3 (1.0) |
| | Variance | | | | - 13 % | - 3 % | 16 % | - 11 % |

Table 49: Plausibility check of calculated values for local contexts

| Macro Context | Local Context | Description | $W_{cons}$ [L/cap*d] | $WW_{prod}$ [L/cap*d] |
|---|---|---|---|---|
| Brazil; UMI; Moderate | LI; SSS | Value range | 86 | 71 |
| | | Factor calculation | 50 - 140 (84) | 40 - 156 (79) |
| | | Variance | 2 % | - 11 % |
| | LMI; SSS | Value range | 100 – 139 (125) | 81 – 105 (94) |
| | | Factor calculation | 65 - 182 (109) | 57 - 226 (114) |
| | | Variance | 13 % | 21 % |
| | UMI; SSS | Value range | 179 – 230 (201) | 124 – 143 (137) |
| | | Factor calculation | 74 - 208 (124) | 58 - 227 (114) |
| | | Variance | 38 % | 17 % |
| Egypt; UMI; Arid | LMI; SSS | Value range | 86 | |
| | | Factor calculation | 54 - 150 (90) | |
| | | Variance | -5 % | |
| India; LMI; Arid | LI; SSS | Value range | | 28 – 42 (34) |
| | | Factor calculation | | 21 - 84 (42) |
| | | Variance | | -24 % |
| Indonesia; LMI; Tropical | LI; SSS | Value range | | 88 |
| | | Factor calculation | | 30 - 118 (59) |
| | | Variance | | 33 % |
| | LMI; SSS | Value range | | 62 – 88 (77) |
| | | Factor calculation | | 43 - 170 (86) |
| | | Variance | | -12 % |
| | UMI; SSS | Value range | | 81 – 91 (85) |
| | | Factor calculation | | 43 - 171 (86) |
| | | Variance | | -1 % |
| South Africa; UMI; Moderate | LI; CSC | Value range | 45 | 37 |
| | | Factor calculation | 27 - 75 (45) | 23 - 91 (46) |
| | | Variance | 0 % | 24 % |
| | LMI; SSS | Value range | | 62 – 110 (86) |
| | | Factor calculation | | 57 - 226 (114) |
| | | Variance | | -33 % |
| Zambia; LMI; Moderate | LMI; SSS | Value range | | 56 – 90 (76) |
| | | Factor calculation | | 41 - 161 (81) |
| | | Variance | | -7 % |

### Plausibility Check

Table 49 summarises 15 sample results regarding water usage for specified local contexts, out of which 5 values meet good matching criteria with an average deviation of 3 %. All values with deviations greater than 20 % are from UMI countries or from LI local settings, showing better matching for LMI countries and local LMI and UMI communities. Here, the water consumption shows an average deviation of 12 % compared to 18 % for wastewater production. The average deviation over all 15 values results to 16 %, showing acceptable overall matching. 60 % of all values are matched with a deviation of ≤ 17 % and 80 % with a maximum deviation of 24 %. Again, all means of literature values fall within the calculated ranges and the trend shows an underestimation of values as discussed above.

In conclusion, the plausibility check showed a good average matching with about 70 % of all tested values resulting in deviations of maximum 17 %. However, 4 out of 28 values (14 %) show a deviation of 30 % or more, revealing discrepancies in the computation of values. This can be improved either through increased data collection and revision of factors taking correlations of influencing parameters into account.

# 8 Development of Design Parameter User Interface

Based on the methodologies presented and the factors derived a design parameter user interface is developed to support designers of decentralised wastewater treatment facilities by providing input parameters for system dimensioning. The interface is defined for residential systems, designed as SSS, CSC or Hybrid systems. The tool uses colour codes to guide designers, which cells require data input and which cells present the results. The colour coding differentiates between five categories, namely

- Headlines and Comments/Descriptions
- Input cells
- Intermediate results
- Final results
- Warnings, in the case that factors are not available for a given scenario

Table 50: Colour coding of design parameter user interface

| **Colour Coding** | | |
|---|---|---|
| **Headline Level 1** | **Headline Level 2** | **Comment/Description** |
| **Input Headline** | | **Input Value** |
| **Intermediate Result Headline** | | **Intermediate Result Value** |
| **Final Result Headline** | | **Final Result Value** |
| **Caution, certain factors are not available! May lead to distorted values!** | | |

The interface is structured in a successive manner - users determine relevant design parameters by filling in the rows from the top to the bottom. This procedure is subdivided in five sections:

1. System Location and Size: Input section
2. General Country Values: Intermediate results
3. System Specific Factors: Input section
4. Input Parameters: Input section
5. System Design Parameters: Final results section

The procedure is explained in a design example in the following paragraphs. Most rows contain comments and descriptions to guide users, which are not depicted here, but provided in the spreadsheet.

## 8.1 System Location and Size

In this section the macro setup of the system and the community size are defined, by defining the country, the income of the community under investigation and the local climate and provides intermediate results on the region, the income classification of the country and the predominant climate zone in the selected country. The climatic zone for the system has to be defined by the user as most countries show areas with different climate zones. Following climate classifications are defined as

- Arid: Köppen-Geiger classification ‘B’
- Moderate: Köppen-Geiger classification ‘C’ or ‘D’
- Tropical: Köppen-Geiger classification ‘A

An example of a system in an upper middle-income community with moderate climate, located in Zambia is depicted in following table:

Table 51: Definition of system location and community size in design interface

| 1. System Location and Community Size | | | |
|---|---|---|---|
| **Country Input** | **Location** | | |
| **Country** | Zambia | | |
| **Region** | Sub-Saharan Africa (SSA) | | |
| **Income** | Lower Middle Income (LMI) | | |
| **Classification of income of community** | LMI - local | | |
| **Climate** | Moderate | | |
| **Local Climate** | Moderate | | |
| | | | |
| **Community Size** | **# of users discharging** | | |
| | **Mixed (BW + GW)** | **BW only** | **GW only** |
| **SSS** | 200 | | |
| **CSC** | 250 | 100 | |
| **Hybrid (SSS + CSC)** | 450 | | |
| **Extension reserve** | 25% | | |
| | | | |
| **System Type** | **Water Access** | **Sanitation Interface** | |
| **SSS** | In house | Private - full flush | |
| **CSC** | Public - unltd | Shared - pour flush | |

The system in this example comprises of a hybrid system with 200 users connected via SSS and 250 users of CSCs, bringing the total number of users to 450. A second system with 100 users of CSCs discharging blackwater only is included. It shall be noted that each column (‘Mixed (BW + GW)’, ‘BW only’ and ‘GW only’) represents a single system.

The extension reserve is set to 25 %, which is a rather high value, typical for fast growing communities. On the contrary, systems for residential complexes such as gated communities can be designed with 0 % extension reserve, as the expansion of such complexes is unlikely. Typical recommended values are 10 – 20% extension reserve.

**Calculations and results in following sections will only be visible, when user numbers are defined!**

The water access and sanitation interface for SSS and CSC are fixed as displayed in Table 51, due to lack of sufficient data on yard tap or public limited water supply and pour flush toilets as captured in Chapter 6.3. This has to be considered when defining the input parameters (section 4 of the user interface), in case a water supply or sanitation interface that is not captured here is used.

Note: Calculations and results in following sections will only be visible, when user numbers are defined! This is to tailor the results to the setup under investigation so to not overload the data output screen.

## 8.2 General Country Values

This section is informative and provides information on general country values regarding water consumption, water return coefficient and wastewater production (mixed, blackwater and greywater). The comment section provides information on whether all factors for all parameters are available or not. If a certain factor is not available in the database (see Chapter 6.2) a factor 1 is used, which has to be considered in the input parameter selection in section 4, because values can be distorted through this assumption. Here, no factor is available for moderate climate for the water return coefficient.

This table uses a global benchmark value for the blackwater ratio as insufficient data is available to differentiate between different contexts. Experience and engineer's knowledge is required to define a realistic blackwater ratio. As a rule of thumb the blackwater ratio reduces with higher water consumption, but also pour flush toilets show lower blackwater ratios than full flush systems. Values for blackwater and greywater are calculated using the wastewater production and the blackwater ration to ensure that the sum of the two wastewaters equal the total wastewater production.

Table 52: Intermediate results for general country values

| 2. General Country Values | | | | |
|---|---|---|---|---|
| **Water** | **Min** | **Max** | **Average** | **Unit** |
| **Water consumption** | 55 | 154 | 92 | L/(cap.*day) |
| **Water return coefficient** | 66% | 78% | 72% | - |
| **Wastewater production** | 35 | 137 | 69 | L/(cap.*day) |
| **Blackwater ratio** | 21% | 28% | 24% | - |
| **Blackwater** | 7 | 39 | 17 | L/(cap.*day) |
| **Greywater** | 27 | 99 | 52 | L/(cap.*day) |

## 8.3 System Specific Factors

This section provides information on the system specific factors used, representing the local context. The calculation follows the methodology described in Chapter 6.3.2 and 6.4. The PFF factor for SSS is set to 1 here, as it SSS represent the benchmark for the PFF calculation. Values from the previous section and factors presented here are used to determine system specific values depending on country and local context.

As mentioned above, factors for SSS and CSC are only displayed when respective user numbers are defined.

Table 53: Intermediate results for system specific factors

| 3. System Specific Factors | | |
|---|---|---|
| **Water** | **SSS** | **CSC** |
| **Water consumption** | 1.15 | 0.79 |
| **Wastewater production** | 1.17 | 0.82 |
| **Peak Flow Factor** | 1 | 1.94 |

## 8.4 Input Parameter

Recommendations for input parameters are presented in this section as average, minimum and maximum values. The user can choose appropriate values and enter them in the provided input cells. It is important to note that design parameters are already calculated using the average values, if no manual values are defined by the user. This is to allow a quick design option for concept designs, without the provision of user defined values.

**Design parameters are calculated using the average values, if no manual values are defined by the user. This is to allow a quick design option for concept designs.**

In this example values in the range of the recommended averages are selected as input parameters for the SSS setup. Values below the average values are selected for the CSC setup. It is hinted to the user in the comments that pollutant and nutrient loads are recommended to be defined lower than the average value for CSC setups. This is due to the fact that activities like cooking (and in some cases laundry and shower) are not carried out at the CSC, but at the household, wherefore the wastewater and its loads do not get discharged into the system. Hence, the total load and the GW loads are reduced and the BW ratio of nutrients and pollutants is expected to be higher. This assumption is reflected in the defined values in the example in Table 54.

Wastewater production, blackwater and greywater amounts as well as greywater pollutant and nutrient loads are calculated based on defined ratios and coefficients.

Table 54: Definition of input parameters as per capita loads

| 4. Input Parameter | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Water | | SSS | | | | CSC | | | | Unit |
| | | Min | Max | Average | Chosen | Min | Max | Average | Chosen | |
| Water consumption | | 63 | 177 | 105 | 105 | 43 | 122 | 73 | 70 | L/(cap.*day) |
| Water return coefficient | | 66% | 78% | 72% | 75% | 66% | 78% | 72% | 60% | - |
| Wastewater production | | 41 | 161 | 81 | 79 | 28 | 113 | 57 | 42 | L/(cap.*day) |
| Peak Flow Factor | Mixed (BW + GW) | | | 3.4 | 3 | | | 6.5 | 6 | - |
| | Blackwater | | | | | | | 6.9 | 6.5 | - |
| | Greywater | | | | | | | | | - |
| Blackwater ratio | | 21% | 28% | 24% | 25% | 21% | 28% | 24% | 35% | - |
| Blackwater | | 9 | 45 | 20 | 20 | 6 | 32 | 14 | 15 | L/(cap.*day) |
| Greywater | | 32 | 116 | 61 | 59 | 22 | 81 | 43 | 27 | L/(cap.*day) |
| Pollutants | | SSS | | | | CSC | | | | Unit |
| | | Min | Max | Average | Chosen | Min | Max | Average | Chosen | |
| BOD | total | 30 | 51 | 40 | 40 | 30 | 51 | 40 | 35 | g/(cap.*day) |
| | BW | 17 | 29 | 23 | 25 | 17 | 29 | 23 | 25 | g/(cap.*day) |
| | GW | 13 | 22 | 17 | 15 | 13 | 22 | 17 | 10 | g/(cap.*day) |
| COD | total | 52 | 109 | 75 | 80 | 52 | 109 | 75 | 75 | g/(cap.*day) |
| | BW | 33 | 70 | 48 | 50 | 33 | 70 | 48 | 50 | g/(cap.*day) |
| | GW | 19 | 39 | 27 | 30 | 19 | 39 | 27 | 25 | g/(cap.*day) |
| Nutrients | | SSS | | | | CSC | | | | Unit |
| | | Min | Max | Average | Chosen | Min | Max | Average | Chosen | |
| Nitrogen | total | 5.8 | 9.7 | 7.5 | 7.5 | 5.8 | 9.7 | 7.5 | 6.5 | g/(cap.*day) |
| | BW | 5.1 | 8.5 | 6.6 | 6.5 | 5.1 | 8.5 | 6.6 | 6.0 | g/(cap.*day) |
| | GW | 0.7 | 1.2 | 0.9 | 1.0 | 0.7 | 1.2 | 0.9 | 0.5 | g/(cap.*day) |
| Phosphorus | total | 0.6 | 3.1 | 1.4 | 1.5 | 0.6 | 3.1 | 1.4 | 1.3 | g/(cap.*day) |
| | BW | 0.5 | 2.4 | 1.1 | 1.0 | 0.5 | 2.4 | 1.1 | 1.0 | g/(cap.*day) |
| | GW | 0.1 | 0.7 | 0.3 | 0.5 | 0.1 | 0.7 | 0.3 | 0.3 | g/(cap.*day) |

## 8.5 System Design Parameter

The last section presents the final results, to be used as system design input parameters. Water amounts, loads and concentrations are issued for Hybrid, SSS and CSC setup and differentiate between the different wastewater types, given the number of connected users are defined for respective setups. The nine cells for each main wastewater characteristic represent a different setup. With the values provided in the sections above a Hybrid system with SSS and CSC discharging mixed wastewater and a blackwater treatment system receiving water from CSC can be designed. Only these respective values are shown in the output table. If the system types shall be changed, the number of users has to be adjusted. The extension reserve (here: 25%, see Chapter 8.1) is considered in these calculations, which reflects in the water amounts and loads, but does not affect the concentrations.

The results in Table 56 show $BOD_5$ and COD concentrations between 508 mg/L $BOD_5$ and 1,016 mg/L COD (SSS – mixed wastewater) and 1,361 mg/L $BOD_5$ and 3,401 mg/L COD (CSC – blackwater). Mara, 2004 defines wastewater strength in regards to $BOD_5$ and COD as shown in following table:

**Table 55: Domestic wastewater strength in terms of $BOD_5$ and COD (Mara, 2004)**

| Strength | $BOD_5$ [mg/L] | COD [mg/L] |
|---|---|---|
| **Weak** | < 200 | < 400 |
| **Medium** | 350 | 700 |
| **Strong** | 500 | 1000 |
| **Very Strong** | > 750 | > 1500 |

The values for the SSS setup precisely match the definition of strong wastewater and the results for mixed wastewater from CSC are about 25 % higher than the definition given for very strong wastewaters. It is not surprising that the blackwater concentration for the CSC exceeds the threshold for very strong wastewater by more than factor 2 as blackwater represents only a small fraction of the wastewater, but contains the majority of pollutants. Pescod, 1992 provides definitions for several major wastewater constituents, whereas the calculated Nitrogen and Phosphorus concentrations for mixed wastewaters from SSS match the definition for strong wastewater accurately. The respective concentrations from CSC blackwater exceed these definitions by a magnitude between 3 and 5, again due to the comprehensible high strength of blackwater.

It can be concluded here that the user interface is able to produce realistic input parameters for system design.

Table 56: Final results: system design parameters

| 5. System Design Parameter | | | | | |
|---|---|---|---|---|---|
| **Water** | | **Hybrid (SSS + CSC)** | **SSS** | **CSC** | **Unit** |
| **Wastewater inflow** | **Mixed (BW + GW)** | 32.8 | 19.7 | 13.1 | $m^3/day$ |
| | **Blackwater** | | | 1.8 | $m^3/day$ |
| | **Greywater** | | | | $m^3/day$ |
| **Peak Flow Factor** | **Mixed (BW + GW)** | 4.2 | 3.0 | 6.0 | - |
| | **Blackwater** | | | 6.5 | - |
| | **Greywater** | | | | - |
| **Peak Flow (1-hr)** | **Mixed (BW + GW)** | 5.7 | 2.5 | 3.3 | $m^3/hr$ |
| | **Blackwater** | | | 0.5 | $m^3/hr$ |
| | **Greywater** | | | | $m^3/hr$ |

| **Pollutants and Nutrients** | | **Load** | | | | **Concentration** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Hybrid (SSS + CSC)** | **SSS** | **CSC** | **Unit** | **Hybrid (SSS + CSC)** | **SSS** | **CSC** | **Unit** |
| **BOD** | **Mixed (BW + GW)** | 22.5 | 10.0 | 12.5 | kg/day | 686 | 508 | 952 | mg/L |
| | **Blackwater only** | | | 3.1 | kg/day | | | 1,701 | mg/L |
| | **Greywater only** | | | | kg/day | | | | mg/L |
| **COD** | **Mixed (BW + GW)** | 45.0 | 20.0 | 25.0 | kg/day | 1,371 | 1,016 | 1,905 | mg/L |
| | **Blackwater only** | | | 6.3 | kg/day | | | 3,401 | mg/L |
| | **Greywater only** | | | | kg/day | | | | mg/L |
| **Nitrogen** | **Mixed (BW + GW)** | 4.2 | 1.9 | 2.3 | kg/day | 129 | 95 | 179 | mg/L |
| | **Blackwater only** | | | 0.8 | kg/day | | | 442 | mg/L |
| | **Greywater only** | | | | kg/day | | | | mg/L |
| **Phosphorus** | **Mixed (BW + GW)** | 0.8 | 0.4 | 0.5 | kg/day | 26 | 19 | 36 | mg/L |
| | **Blackwater only** | | | 0.1 | kg/day | | | 68 | mg/L |
| | **Greywater only** | | | | kg/day | | | | mg/L |

# 9 Conclusion

## 9.1 Discussion of Results

The comprehensive data collection and analysis conducted in this study discussed all seven research questions defined in the project objectives. The total numbers of datapoints and datasets found for different regions and countries are summarised in Table 57. Most data was found for Sub-Saharan Africa followed by Latin America and Caribbean, East Asia and Pacific and Middle East and North Africa. Data on South Asia was found to be scarce; however, it has to be considered that this region contains least countries (8) and Sub-Saharan Africa the most (47). Countries with the most data available was Brazil (68 domestic datapoints) followed by Indonesia (50), South Africa (41), Egypt (34), Zambia (29) and India (26). All other countries show less than 20, most less than 10 recorded values.

It was foregone to define population equivalents in this study. Low and lower-middle income countries present higher disparities in terms of wastewater characteristics between poor and rich communities. Wealthy communities are expected to consume/produce similar or higher amounts of water, wastewater and pollutants as wealthy communities of high-income countries; whereas low-income communities in low-income countries are expected to consume/produce by far less than low-income communities in high-income countries. This was presented and discussed in Chapters 5.1 and 5.4.. Nonetheless, quasi-population equivalents were determined by assessing domestic water consumption and wastewater production.

Methodologies were developed to collate and standardise the collected data in terms of classification criteria. The collected data is summarised in a structured manner to inform design engineers on wastewater characteristics in developing and emerging countries. Due to lack of information on institutional/commercial and industrial wastewater characteristics, the qualitative and quantitative data analysis was limited to domestic/residential setups. A qualitative analysis of influencing factors is listed in this study to inform on the entirety of factors influencing wastewater characteristics.

The analysis of main influencing factors affecting the wastewater characteristics enabled the projection of discrete literature values on a more general context, deriving quantitative factors for global and local settings. Income, climate, water supply, sanitation interface and community size (for PFF) were determined as main influencing factors.

However, the influence of other factors such as the level of urbanisation could not be assessed in detail, due to lack and inconsistency of data. The inconsistency relates to the challenge that many sources, such as UNEP (2000) do not clearly define if values for water consumption or wastewater production are related to domestic usage or if proportions of commercial usage are included. For data from centralised treatment plants it is self-evident that all connected establishments in an area, community or town are accounted for and inevitably increase the per capita water usage values, as the users of commercial facilities are not included in the population headcount.

Table 57: Number of datapoints (datasets "mean values" in brackets) by region and country

| | | Domestic (excl. Residential) | | | | | | Residential | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Water consumption | Wastewater production | COD | BOD | Nitrogen | Phosphorus | Water consumption | Wastewater production | COD | BOD | Nitrogen | Phosphorus |
| Global w/o Industrialised Countries | | 159 (91) | 125 (73) | 46 (27) | 95 (46) | 53 (28) | 50 (27) | 24 (12) | 8 (4) | 9 (3) | 12 (6) | 4 (2) | 4 (2) |
| Regions | East Asia & Pacific | 22 (16) | 41 (21) | 5 (5) | 5 (3) | 5 (5) | 5 (5) | 5 (5) | | | 1 (1) | 1 (1) | 1 (1) |
| Regions | Eastern Europe & Central Asia | | | 3 (1) | 6 (2) | 6 (2) | 6 (2) | | | | | | |
| Regions | Latin America & Caribbean | 36 (20) | 17 (17) | 5 (3) | 37 (21) | 5 (3) | 5 (3) | | | | 2 (2) | | |
| Regions | Middle East & North Africa | 25 (15) | 10 (10) | 6 (4) | 11 (5) | 11 (5) | 11 (5) | | 1 (1) | 9 (3) | 9 (3) | 3 (1) | 3 (1) |
| Regions | South Asia | 7 (7) | 11 (5) | 5 (3) | 6 (2) | 1 (1) | 1 (1) | 8 (4) | | | | | |
| Regions | Sub-Saharan Africa | 45 (25) | 25 (13) | 14 (8) | 9 (5) | 13 (7) | 7 (5) | 12 (4) | 1 (1) | | | | |
| Countries | Afghanistan | 2 (2) | | | 3 (1) | | | | | | | | |
| Countries | Algeria | | 1 (1) | | | | | | | | | | |
| Countries | Bangladesh | 3 (3) | | | | | | | | | | | |
| Countries | Botswana | | | | | | | | | | | | |
| Countries | Brazil | 31 (17) | 10 (10) | 3 (1) | 18 (14) | 3 (1) | 3 (1) | | | | 2 (2) | | |
| Countries | Cambodia | 1 (1) | | | | | | | | | | | |
| Countries | China | 1 (1) | | | | | | 1 (1) | | | | | |
| Countries | Egypt | 16 (10) | 3 (3) | 4 (2) | 3 (1) | 4 (2) | 4 (2) | | 1 (1) | | | | |
| Countries | India | 5 (5) | 11 (5) | 5 (3) | 3 (1) | 1 (1) | 1 (1) | 7 (3) | | | | | |
| Countries | Indonesia | 1 (1) | 30 (12) | 4 (4) | 3 (1) | 4 (4) | 4 (4) | 1 (1) | | | | | |
| Countries | Iran | | | 1 (1) | 3 (1) | 3 (1) | 3 (1) | | | 9 (3) | 9 (3) | 3 (1) | 3 (1) |
| Countries | Jordan | 2 (2) | | 1 (1) | 1 (1) | 1 (1) | 1 (1) | | | | | | |
| Countries | Kenya | 1 (1) | | | 5 (3) | | | | | | | | |
| Countries | Lao | 1 (1) | | | | | | | | | | | |
| Countries | Lesotho | 1 (1) | | | | | | | | | | | |
| Countries | Mali | 3 (3) | | | | | | | | | | | |
| Countries | Mexico | 1 (1) | | | | | | | | | | | |
| Countries | Morocco | | 4 (4) | | 1 (1) | | | | | | | | |
| Countries | Nigeria | | 3 (3) | | | | | | 1 (1) | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pakistan** | | | | | | | 1 (1) | | | | | |
| | **Philippines** | 3 (3) | | | | | | 1 (1) | | | | | |
| | **South Africa** | 20 (10) | 10 (6) | 3 (3) | | 4 (4) | 4 (4) | | | | | | |
| | **Syria** | | 1 (1) | | | | | | | | | | |
| | **Tanzania** | 15 (7) | | | | | | | | | | | |
| | **Thailand** | | 4 (4) | 1 (1) | 1 (1) | 1 (1) | 1 (1) | 1 (1) | | | 1 (1) | 1 (1) | 1 (1) |
| | **Tunisia** | | 1 (1) | | | | | | | | | | |
| | **Uganda** | | | 3 (1) | 3 (1) | 3 (1) | 3 (1) | | | | | | |
| | **Vietnam** | 6 (4) | 4 (4) | | | | | | | | | | |
| | **Yemen** | 1 (1) | | | | | | | | | | | |
| | **Zambia** | 2 (2) | 12 (4) | 8 (4) | 1 (1) | 6 (2) | | | | | | | |

Furthermore, some sources seem to not clearly differentiate between water consumption and wastewater production and also the terms water consumption and water supply demand are used interchangeably by sources such as Fourie and van Reyneveld (1993) and UNEP (2000), although these terms describe different parameters. The reasons stated above lead to distorted relationships between water consumption and wastewater production. Although clear trends could be found from the data (e.g. lower WRC for arid climate and non-household water supply) the distortion is reflected in the derived factors, where in some cases the wastewater production is higher than the water consumption. Although this is technically not impossible to occur (particularly in case of high storm water intrusion in tropical climate or ground water intrusion in high groundwater tables), but it is not assumed to be the general case and therefore should not be reflected in the average values. The quantitative influence of storm water and groundwater intrusion was not further analysed and discussed here.

It was found and discussed that different methodologies are used to determine peak flow factors of systems. Crous (2014) and Pietruschka (2017) conducted continuous measurements over a longer time period, whereas Laramee (2015b) and Simwambi (2015b) conducted a significantly lower number of manual measurements with the use of buckets and a stopwatch to determine the peak flow. Here, the time for a 10 L bucket for measured and 3 measurements were taken per hour. It is acknowledged that detailed long-term flow measurements require either costly technical equipment (water meter capable of wastewater flows and data loggers) or extensive labour for manual measurements. Nonetheless it is necessary to normalise peak flow factors by taking the number of measurements into account, where values derived from a small number of samples would be penalised by a defined factor. Recommendations are presented in the outlook of this report (see Chapter 9.3).

Several formulas to calculate peak flow factors for centralised sanitation systems were found in the literature. Using a consistent data set from Campos and von Sperling (1996) enabled the development of a formula to calculate peak flow factors for small scale sanitation systems of up to 5,000 users (see Chapter 6.4.2). The results from Crous (2014) were used to extend the applicability to CSC. However, it shall be noted that the applicability is limited to similar numbers of users and user per toilet ratio (75 – 100 HH or 200 – 250 users per CSC with 9 toilets/urinals per CSC).

In conclusion, comprehensive data was found to guide designers of DEWATS systems on per capita/unit wastewater characteristics. However, the data found was not sufficient to develop recommendations for all setups and options. Particularly data on institutional setups was found to be scarce as well as data differentiating between blackwater and greywater.

Using the data with sufficient data points it was possible to determine factors considering main influencing parameters, although the correlation between different factors could not be determined. This factorisation presents a reasonable method to derive characteristics for unknown contexts, although also inconsistencies were found within the factorised values (discussed in Chapter 7) so caution shall be exercised and field experience and engineering knowledge need to be applied when using factorised wastewater characteristics. Besides the factor propagation providing realistic results, the statistical significance was not determined here. Additionally, values for scenarios with missing factors might output distorted data. The developed design tool takes these challenges into consideration and issues warning notes where special attention from the user is required.

## 9.2 Knowledge Gaps

It is mentioned in several investigations on wastewater characteristics in developing countries, such as Campos and von Sperling (1996) and Reynaud (2014) that reliable data is not available. This is not entirely true, as more than 2,000 data points were found in this study. However, what is lacking in many sources, which do not discuss specific sampling studies, is a detailed description and classification of the context. In contrary, results from sampling studies are at times only applicable to the specific context the data was obtained from. Hence, it can be stated that data is available, but scattered with no over-regional approach. This study aimed to standardise and harmonise the existing data, but still requires further development and investigations to be applicable on a broader scale. Data on pollutant concentrations can be found in abundance, but data on per capita/per unit load is scarce.

By far the most data was found on communal setups, whereas a differentiation between domestic and residential wastewater production is not always clear. Although the data collection focussed on wastewater production values, the highest number of data points was obtained for water consumption. This is however not surprising as metering and measuring water consumption is less demanding from a technical point of view. Nonetheless, it is recommended to carry out more frequent wastewater production measurements, e.g. together with sampling of pollutant concentrations. This would significantly increase the data availability of per capita pollutant loads, as these are always calculated backwards, using the level of concentration, the wastewater production and the number of connected people. Hence, it is also self-evident that data on pollutant concentrations is more easily obtainable than data regarding the per capita loads. As recommendation, if only a few wastewater production measurements of selected sites were carried out and recorded in a standardised database when sampling wastewater concentrations, this would significantly increase the available data within a relatively short time period.

In regards to communal characteristics the least data is available on low income countries. This becomes apparent when analysing the calculated benchmark values and factors (see Chapter 6.1 and 6.2). The reasons for this are the fact that a number of countries have been upgraded to lower-middle income countries in the past decades from a maximum of 66 low income countries in 2001 to 31 low income countries in 2015 (The World Bank, 2017b). Additionally, low income countries generally present the least developed infrastructure with extremely low rates of off-site sanitation systems enabling utility tracking and database records. Additional data needs to be collected in these countries to improve the general data availability, in particular with a focus on poverty alleviation and basic needs service provision to the urban poor. From the countries under investigation in this study these countries include:

- Afghanistan
- Mali
- Tanzania
- Uganda

Most data incorporated originates from anglophone countries or English reports. This is also due to the authors language capabilities, but an improved global data assessment would require similar studies on available data in languages such as French, Spanish, Arabic, Mandarin, Hindi or Portuguese.

Very few data was obtained from institutional setups such as hotels, hospitals, prisons, religious centres and schools with the latter presenting the most data, but no data was found on pollutant and nutrient loads. It is therefore recommended to carry out investigations on such setups or to include such assessments in related research activities of institutional setups. This data acquisition requires a systematic approach by grouping these setups in categories like price range for hotels, day or boarding schools and a differentiation between primary, secondary and tertiary education institutions to ensure applicability of discrete data collection on a broader scale.

As mentioned before, the methodology to determine peak flow factors differs between literature sources. It is recommended to differentiate between daily and diurnal peak flows as this is the most commonly used procedure in the literature. This can significantly reduce the number of diurnal samples to be taken for statistical significance as a smaller number of total samples is required if a peak flow factor derived from a limited number of diurnal samples can be multiplied with a limited number of daily peak flow factors. Nonetheless a minimum number of samples required shall be defined to ensure confidence in the statistical significance. It is furthermore recommended to take the number of data samples into account when calculating peak flow factors, with the suggestion to use the t-distribution to 'penalise' factors obtained from a smaller sample size. As an example, assuming a two-tailed confidence interval of 90%, a sample size of 5 would be penalised by about 23% and a sample size of 50 would attract an adjustment of 1.9%, reducing to 0.5% for 200 samples.

From all the literature obtained and evaluated only eight presented data of actual sample campaigns with statistically relevant sample sizes (Campos and von Sperling, 1996; Miranzadeh, 2005; Bachur and Ferrer, 2013; Crous, 2014; Reymond and Demars, 2014; Laramee, 2016; Pietruschka, 2017). It is assumed that a higher number sampling studies is conducted globally, leading to the conclusion that accessibility of data needs to be improved to reduce future needs for intensive sampling.

## 9.3 Outlook

The developed and presented user interface to determine design input parameters shall be implemented and embedded into a DEWATS design software, considering treatment performance, construction costs and BOQs to significantly increase the effectiveness of DEWATS design and to reduce the engineering costs. This tool may also include the option to simulate and compare different design scenarios to determine the most cost-effective solution for a given context. A methodology and algorithms need to be developed to determine wastewater characteristics for institutional and industrial setups and may be integrated in an advanced design software to allow for systems treating wastewater from domestic and institutional sources.

To improve the accuracy of the wastewater characteristics calculations, it can be considered to include a higher number of macro parameters to increase the level of detail to differentiate between countries and regions. The tool *Gapminder* presents a large number of statistical data with more than 500 data sets (Stiftelsen Gapminder, 2017). Particularly the data on demographics, income, inequality and water availability may be of interest for further investigation.

The climatic conditions proved to have a major influence on the wastewater characteristics as arid regions show significantly lower water usage values compared to moderate climate and tropical regions showing water consumptions values above average and less dependent on income. However, only the main climatic groups were considered in this study (arid, moderate, tropical). M. C. Peel, Finlayson and McMahon (2007a) provide collated long climate data consisting of 12,396 and 4,844 stations recording rainfall and temperature data respectively. The provision of GPS coordinates can be used to define the exact climatic conditions of a treatment plant location to increase the accuracy of climate data taken into account. An Excel based tool that outputs climatic data of key interest for any given GPS coordinate (mean annual temperature, hottest month, coldest month, mean annual precipitation, wettest month, driest month, climatic zone) has been developed during this study and can be obtained as appendix of this report.

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# 11 Annex

Following documents have been developed during this study and can be obtained as annexes of this study:

- Excel Research Database
- Excel Design Database
- Excel based tool: Location Climate Assessment

## 11.1 World Köppen-Geiger Map

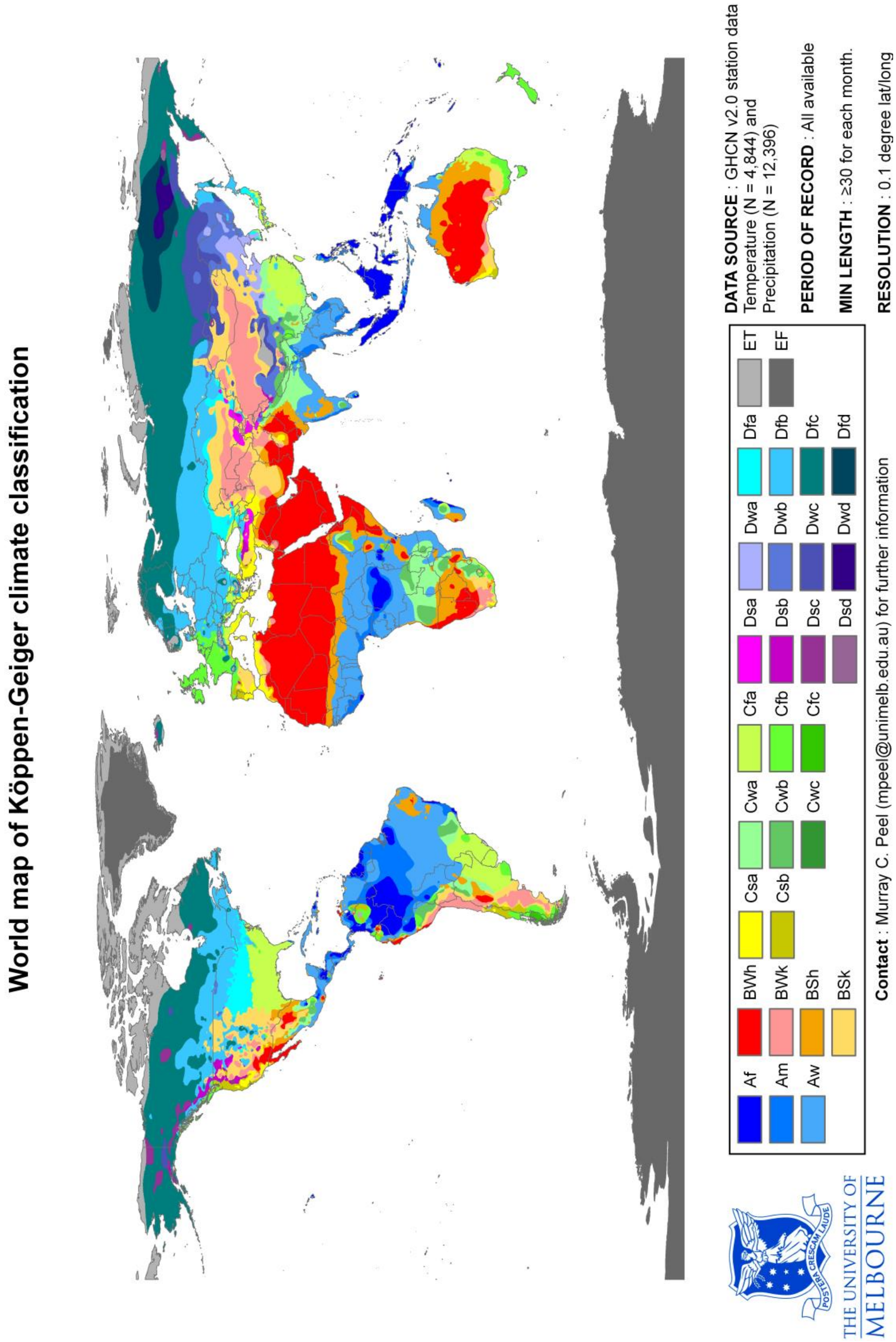


**Figure 20: World map of Köppen-Geiger climate classification (M. Peel, Finlayson and McMahon, 2007)**