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# Towards an Egyptian Benchmark for Water Efficiency During the Core Manufacturing Processes of Building Materials

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**Abstract:** Egypt is ranked as a country with extreme water stress in several indexes, being predicted to face a more severe shortage due mainly to the accelerating Climate Change and population in the future, with a per capita share predicted to reach "absolute water scarcity" in 2025. Egypt has basically reached a situation where the available water amount is limiting its national urban and economic growth. Construction industry utilizes massive quantities of water-consuming materials. Previous studies proved that the construction demands surpass the operational demands in housing case studies, highlighting the importance of water efficiency measures during construction. Choosing building materials of high embodied water results in a high initial level of water consumption in building construction. This paper summarizes a comparative analysis for water demands of building materials, aiming to deepen the knowledge of water footprint for building materials and providing recommendations for selection decisions. The study proves that the water footprints of common building materials can be considerably reduced by promoting the best water-efficient alternatives, and concluding guidelines for both manufacturers and architects. This would stimulate competition between manufacturers to adopt additional standards to enhance the water footprints of their building products, introducing water-efficient alternatives declared using environmental certifications.

**Keywords:** Water Efficiency, Water Footprint, Building Material, Manufacture, Egypt

## 1. Introduction

Egypt is ranked number four among the world's highly water stressed countries [1]. With an accelerating population, the per capita share decreased to 750 $m^3$/capita/year in 2010, below the 'water scarcity' limit (1,000 $m^3$/capita according to the Falkenmark indicator [2]). Population predictions will lower Egypt's per capita share to 'absolute water scarcity' of 500 $m^3$/capita/year in 2025 [3], being expected to drop to less than 300 $m^3$/capita/year in 2050 [4].

The natural flow of the Nile is greatly sensitive to changing rainfall and temperature rates, where some studies suggest a spacing in the rainfall periods with a rise in heavy rainfall rates that causes more annual floods and droughts. The economic development and adaptation programs to such climate changes in upstream riparian countries would probably put more stress on the water resources of Egypt. In addition, the forecasted rise of sea levels will increase the salinity of Delta aquifers, decreasing their validity for use.

Construction industry is a major consumer of global water resources. It is estimated that the built environment globally consumes 20% of water [5] and that green buildings can reduce usage by almost 40% [6]. Some materials consume water during processing, manufacturing or construction. The research primarily aims to demonstrate the footprints of manufacturing water consumption for common building materials in Egypt, highlighting the best water-efficient alternatives with minimum manufacturing impacts, beside recommendations for material selection.

## 2. Life Cycle Assessment

LCAs are tools for systematically analysing the life-long environmental performance intended for products, covering raw material processing, product manufacture, recurrent use and either disposal, reuse or recycling at last [7]. The specification of LCAs depends on the International ISO 14040 standard series, comprising four analytical steps:

scope and goal definition, inventory creation, impacts assessment and results interpretation [8]. LCAs should support the architects to mainly reach the best building material alternatives through construction-related databases.

### 2.1. Environmental Product Declaration

EPDs have been evolved to demonstrate the environmental specifications from LCA studies using a common format, according to standardized rules, known globally as Product Category Rules (PCRs). Construction EPDs are so modular that EPDs of concrete, for instance, can be basically reached by combining EPDs of cement and aggregates. EPDs with same PCRs can be comparable, ensuring the similarity of data quality, methodology, scope and indicators. Due mainly to the differences in PCRs, they should all come from one EPD program. Moreover, products assessed are not comparable until having the same functional unit.

### 2.2. Core Processes

The manufacturing of building materials is always included in the 'core processes' stage in EPDs, representing the entire processes required to deliver the products desired. They may comprise secondary stages with intermediate products over the processing chain.

## 3. Embodied Water in Building Construction

Embodied water is referred to as the overall water needed to deliver a product during production stages, comprising direct and indirect demands for all the processes and resources used. Direct water is that water needed to mainly manufacture a specific product, while Indirect water is that water specifically needed to process all the resources that go through the main product. Indirect water is basically harder to assign due basically to the numerous forms of consumption possibly involved. Many parameters including locality, climate, technology, specification and analysis can cause considerable variability in embodied water data. Studies that evaluate water demands of buildings only consider the operational demands, excluding the embodied water of materials [9].

A case study conducted by Islam, Jollands and Setunge resulted in water usage outcomes of 62.6%, 35.20%, 2.11% and 0.01% for construction, maintenance, operation and EOL respectively [10]. This shows that the studies which focus only on water use during operation possibly fail to accurately identify the most optimum solutions for effectively improving the water efficiency of buildings, highlighting the significant impact of water efficiency during building construction.

### 3.1. Water Footprint

Water footprints are used to mathematically measure water demands. The actual water footprint measured for a product represents the total water demand needed for its delivery, being possibly quantified using the input-output or bottom-up analytical approaches [9].

### 3.2. Previous Water Inventory Databases

A research by Bribián, Capilla and Usón compared some building materials according to energy use, $CO_2$ emission and water demand [11]. The summarized loads covered from the material manufacture to disposal. The study included general products with less specifications concerning dimensions and other properties. Another research by Meng et al. used a database of embodied intensities previously introduced by Chen and Chen in 2010 [12]. The water intensities represented general families of products and processes as many items from the same production sector were believed to have the same intensity.

In a study by Crawford and Pullen, the concluded embodied water of the case studied was estimated based on the manufacturing demands of building materials [13]. The I-O data were afterwards used to mainly fill in the missing gaps of upstream data for the materials. This resulted in hybrid coefficients of the embodied water of all the studied materials. The study introduced a comparably more detailed database with various functional units for selected building materials.

## 4. Research Methodology

Quantitative methods were mainly applied, summarizing and comparing information across categories. Resources included technical specifications, interviews with manufacturers, site visits to factories detailed in (Table 1), and international EPDs for imported components. The conducted comparative analysis defines the manufacturing water demands of selected building materials.

***Table 1.*** *Locations of Local Factories Surveyed in Egypt.*

| Category | Factory 1 | Factory 2 | Factory 3 | Factory 4 |
|---|---|---|---|---|
| Concrete | Sadat | 6th of October | | |
| Steel | 10th of Ramadan | 10th of Ramadan | | |
| Brick | 10th of Ramadan | Sadat | Delta | Delta |
| Insulation | Badr | Sadat | El-Obour | Alexandria |
| Natural stone | Cairo | Cairo | | |
| Manufactured tile | Ain Sokhna | 10th of Ramadan | Sadat | |
| Coating | 6th of October | Fayoum | | |
| Glass | 10th of Ramadan | Ain Sokhna | | |
| Doors/Windows | El-Obour | 6th of October | Ain Sokhna | 10th of Ramadan |
| Sanitary | 10th of Ramadan | 10th of Ramadan | | |

# 5. Results and Discussion

(Tables 2-11) show water footprints of manufacturing processes for different assessed building materials using varied functional units by category, including local and imported components.

## 5.1. Concrete

As figured in (Table 2), precast concrete has the least demand of 0.198 $m^3$ per 1 $m^3$, compared to readily mixed concrete of the same compressibility with 0.214 $m^3$ per 1 $m^3$ of product.

***Table 2.*** *Manufacturing Water Demands of Assessed Concrete Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^3$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Ready-Mixed | 250 kg/cm$^2$ | 2,360 | 0.214 | | 0.214 | 1,2 |
| | 300 kg/cm$^2$ | 2,360 | 0.216 | | 0.216 | 1,2 |
| Precast | 250 kg/cm$^2$ | 1,850 | 0.198 | | 0.198 | 1 |
| | 300 kg/cm$^2$ | 1,850 | 0.201 | | 0.201 | 1 |

## 5.2. Reinforcing Steel

The demand in quenched rebars reaches 2.43 $m^3$ per 1 ton, due to water-intensive cooling. The un-quenched rebars only consume 2.06 $m^3$ per 1 ton of product as figured in (Table 3).

***Table 3.*** *Manufacturing Water Demands of Assessed Reinforcing Steel Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ ton] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Reinforcing rebars | Un-quenched | | 0.06 | 2.00 | 2.06 | 1 [14] |
| | Quenched | 7,850 | 0.43 | 2.00 | 2.43 | 2 [14] |

## 5.3. Bricks

(Table 4) shows that cement bricks in average require less than half the amount of water consumed by clay bricks, consuming only 0.000185 $m^3$ per unit brick. The water demands of both solid and perforated clay bricks reach 0.00056 and 0.00039 $m^3$ per unit brick respectively.

***Table 4.*** *Manufacturing Water Demands of Assessed Bricks.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ unit] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Clay brick | Solid | 1,993 | 0.00056 | | 0.00056 | 3,4 |
| | Perforated | 1,395 | 0.00039 | | 0.00039 | 3,4 |
| Cement brick | 60 kg/cm$^2$ | | 0.00017 | | 0.00017 | 1,2 |
| | 130 kg/cm$^2$ | | 0.00020 | | 0.00020 | 1,2 |

## 5.4. Bituminous Insulation

According to (Table 5), the bituminous coating has less than half the average water demand of polyester reinforced membranes, with only 0.000032 $m^3$ per 1 $m^2$ of coating. Among membranes, the multi-layered membrane has the lowest water demand of 0.000077 $m^3$ per 1 $m^2$ of membrane.

***Table 5.*** *Manufacturing Water Demands of Assessed Bituminous Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/m$^2$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Coating | | 950 | 0.000032 | | 0.000032 | 1,4 |
| PES reinforced membrane | Single, torched | | Negl. | 0.000098 | 0.000098 | 1,2,3 [15] |
| | Multi, torched | | Negl. | 0.000077 | 0.000077 | 1,2,3 [15] |

Negl. = Neglected fractional amount consumed during local calendaring and cutting

## 5.5. Natural Stones

(Table 6) shows that granite has higher water demand than marble, reaching 9 $m^3$ per 1 $m^3$. While marble consumes only 3.6 $m^3$ per 1 $m^3$ of product.

***Table 6.*** *Manufacturing Water Demands of Assessed Natural Stones.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^3$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Marble | Polished | 2,563 | 3.6 | | 3.6 | 1,2 |
| Granite | Polished | 2,691 | 9.0 | | 9.0 | 1,2 |

## 5.6. Manufactured Tiles

The water demand of cement tiles is approximately 16.7 times larger than the water demand of ceramic tiles, which consume only 0.03 m$^3$ per 1 m$^2$ of product as figured in (Table 7).

***Table 7.*** *Manufacturing Water Demands of Assessed Manufactured Tiles.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^2$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Ceramic tiles | | 2,000 | 0.03 | | 0.03 | 1 |
| Cement tiles | 1.5 cm thick. | 2,380 | 0.50 | | 0.50 | 2,3 |

## 5.7. Coating Products

(Table 8) shows that oil-based paints consume only 0.000017 m$^3$ per 1m$^2$, while external water-based Graviato paint has the highest water demand reaching 0.00096 m$^3$ per 1 m$^2$ of single layer.

***Table 8.*** *Manufacturing Water Demands of Assessed Coating Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^2$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Acrylic Paint | Interior/Exterior | 1,500 | 0.000043 | | 4.3 x10$^{-5}$ | 1 |
| Oil Paint | Interior/Exterior | 1,230 | 0.000017 | | 1.7 x10$^{-5}$ | 1,2 |
| Graviato | Exterior | 1,950 | 0.000959 | | 96 x10$^{-5}$ | 1 |

## 5.8. Glass

(Table 9) shows that flat glass consumes almost double the water demand of tinted glass, due to the tin bath used, reaching 1.23 m$^3$ per 1 m$^2$ of 4mm-thick sheets.

***Table 9.*** *Manufacturing Water Demands of Assessed Glass Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^2$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Flat glass | 4 mm thick. | | 1.23 | | 1.23 | 2 |
| Tinted glass | 4 mm thick. | | 0.66 | | 0.66 | 1 |

## 5.9. Profiles of Doors and Windows

According to (Table 10), softwood profile has the highest water demand of 168.76 m$^3$ per 1 m$^3$ of profile, representing almost 5 times larger than coated aluminium profiles. Coated PVC profiles have the lowest water demand reaching only 1.14 m$^3$ per 1 m$^3$ of profile.

***Table 10.*** *Manufacturing Water Demands of Assessed Profiles.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ m$^3$] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| Aluminium profile | Coated | 2,600 | 6.87 | 22.31 | 29.18 | 2,3 [16] |
| PVC profile | Coated | 1,350 | Negl. | 1.14 | 1.14 | 4 [17] |
| | Laminated | 1,350 | Negl. | 2.42 | 2.42 | 4 [18] |
| Softwood profile | | 550 | Negl. | 168.76 | 168.76 | 1 [19] |

Negl. = Neglected amount of water is used during local assembly

## 5.10. Sanitary Products

The water demands of 70-cm wide washbasins and floor pedestals reach 0.13 and 0.07 m$^3$ per unit respectively, while regular-sized toilets and flush tanks demand 0.12 and 0.07 m$^3$ of water per unit respectively. Mixers consume only 0.04 m$^3$ per unit. Acrylic showers consume a neglected fractional amount of water as figured in (Table 11).

***Table 11.*** *Manufacturing Water Demands of Assessed Sanitary Products.*

| Product | Specification | Density [kg/m$^3$] | Water consumption [m$^3$/ unit] | | | Factory # [EPD] |
|---|---|---|---|---|---|---|
| | | | Local | Imported | Total | |
| V.C. washbasin | Up to 70 cm | | 0.13 | | 0.13 | 1 |
| V.C. floor pedestal | W/ washbasins | | 0.07 | | 0.07 | 1 |
| V.C. toilet | Regular size | | 0.12 | | 0.12 | 1 |
| V.C. flush tank | W/ toilets | | 0.07 | | 0.07 | 1 |
| Acrylic shower | 80 x 80 cm | | Negl. | | | 2 |
| Fixture | Tap (mixer) | | 0.04 | | 0.04 | 1 |

V.C. = Vitreous Ceramic
Negl. = Neglected fractional amount of water

## 6. Weighting Issues in Local Green Building Regulations

In response to Egypt's need for a rating system for green buildings, benefiting from the experiences of earlier international adopters, the Housing and Building National Research Center has accordingly introduced The Green Pyramid Rating System. Water efficiency surpasses the other categories in GPRS, reaching 30% of its total score [20]. This is an evident indicator to the pivotal water efficiency measurements needed in Egypt.

Although the construction process is a large water-consumer, the 'Efficient water use during construction' requirement has evidently the lowest credit in ‘Water Efficiency’ category. Moreover, its detailed description mentioned: “Credit points are obtainable for demonstrating the use materials such as pre-mixed concrete for preventing loss during mixing” [20], cannot be a comprehensive criterion concerning the entire water embodied in building materials.

The mentioned description of the 'Materials fabricated on site' requirement in ‘Materials and Resources’ Category, which is: “A credit point is obtainable for demonstrating the use of building materials (such as bricks) that are fabricated on site” [20], cannot be a comprehensive rating criterion because resource control while fabricating a material on-site is not evaluated. However, pre-fabrication has been proved to be better in the terms of resource control and quality.

## 7. Conclusion

Water is intensively consumed during the processing, manufacturing and on-site installation of any building material, which was proved to surpass water used in operation and EOL. Accordingly, it is necessary to lower the use of finite water resources, and close all the loops of embodied material flows for building materials through reuse and recycling techniques.

Architects have the main responsibility in decisions associated with building material selection. Therefore, they should focus on water-efficient alternatives proved by the research, including:

a. Precast concrete for structural and non-structural applications.
b. Cement bricks for drywalls and wet brickwork.
c. Torched multi-layered Polyester-reinforced membranes for membrane waterproofing.
d. Marble tiles for durable flooring and cladding.
e. Ceramic tiles for wet flooring and cladding.
f. Acrylic paints for durable coating.
g. Tinted glass for non-clear view applications.
h. PVC profiles for doors and windows.

The research results should basically be considered a close approximation to the real embodied water demands of assessed materials. This is due mainly to the various broader assessment limits considered in the EPDs of materials analysed, beside the various boundaries of water consumption calculations in local factories surveyed. Therefore, it is essential to extend and adjust the existing water inventory databases of building materials to the properties of the related industries in Egypt, stimulating the local manufacturers to provide information based entirely on the real lifecycle demands of products using EPDs.

Regulations for the efficiency of embodied water should be considered in all green assessment tools and systems used for buildings in Egypt. Embodied water benchmarks from the research can be usefully used to develop a building certification program, conserving water for long-term usage highly recommended for any urban expansion with limited water resources.

Further studies can basically benefit from both the recommendations and findings of this research and expand its scope. Wider assessment and broader consideration of lifecycle water demands for building materials locally used in various building types are required to reach a more accurate resolution of the both on-site and embodied water consumption.

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