

Sustainable Water Consumption in Building Industry: A Review Focusing on Building Water Footprint



Bhagya Nallaperuma, Zih-Ee Lin, Jithya Wijesinghe, Amila Abeynayaka, Safa Rachid, and Selim Karkour

Abstract Sustainable water consumption has become a primary concern of the building industry. The water footprinting assesses the freshwater use and associated effects on local and global freshwater resources plus ecosystems therein. This review elaborates two extensively adopted water footprinting approaches, Water Footprint Network (WFN) and ISO 14046 Life Cycle Assessment (LCA), discussing their methodologies and perspectives of analyses with special regard to the building industry. An appraisal of water footprints of common building materials is presented in this study with glimpses of the hotspots of freshwater consumption along their supply chains. Further, it advances its water footprints appraisal into the use phase/case study level referring to the real-world applications of the building industry. The importance of comprehensive water footprint analysis covering the complete life cycle of buildings, the inclusion of allied environmental impacts into analyses, influence of building type/structural design/site-specific variables were highlighted under this discussion in support of the dependable judgment of freshwater appropriation performances. Ultimately, the review dedicated a segment to set a futuristic view into the matter featuring sustainable freshwater consumption, economic and developmental interests, challenges faced by the industry, prioritization and compromise of freshwater uses of the building industry.

B. Nallaperuma (✉) · Z.-E. Lin · J. Wijesinghe · A. Abeynayaka · S. Rachid · S. Karkour
Beyond Borders of Life Cycle Assessment (2BLCA), Shinjuku-ku, Tokyo 169-0075, Japan e-mail: bhagya@gwu.ac.lk

B. Nallaperuma · J. Wijesinghe
Department of Indigenous Medical Resources, Faculty of Indigenous Health Sciences and Technology, Gampaha Wickramarachchi University of Indigenous Medicine, Kandy Road, Yakkala, Sri Lanka

Z.-E. Lin
Graduate Institute of Environmental Engineering, National Taiwan University, Taipei 10617, Taiwan

A. Abeynayaka
Institute for Global Environmental Strategies (IGES), 2108-11 Kamiyamaguchi, Hayama, Kanagawa, 240-0115 Japan

S. Rachid
Mining Environment and Circular Economy, Mohammed VI Polytechnic University (UM6P), Lot 660 —Hay Moulay Rachid, 43150 Ben Guerir, Morocco

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2023
R. Dissanayake et al. (eds.), *12th International Conference on Structural Engineering and Construction Management*, Lecture Notes in Civil Engineering 266,
https://doi.org/10.1007/978-981-19-2886-4_56

1

19 **Keywords** Water footprint · Building industry · Water footprint network · Life
20 cycle assessment · Building materials · Sustainable water consumption

21 **1 Introduction**

22 Freshwater sustains the life on earth and reinforces the course of civilization accom-
23 panying agriculture, industrial processes, urban development and almost all human-
24 induced activities [27]. Sustainable management of freshwater resources stands to
25 satisfy the changing demands placed on water resources, at present and on into the
26 future without system degradation [14]. The water footprint (WF) is a concept devel-
27 oped within the water resources research community by way of an assessment tool
28 of sustainability of freshwater appropriation [9].

29 Water footprinting appraises freshwater use and its related effects from the
30 consumption of goods and services [9, 20]. The assessment of water consumption is of
31 paramount importance as freshwater resources are currently under greater pressure
32 worldwide. Climate change, speeded-up industrialization, extensive urbanization,
33 population growth and associated higher standards of lifestyle dynamics are aggra-
34 vating the crisis of freshwater resources [2]. During the twentieth century, the growth
35 of global water consumption was twice as the population growth and at this junct-
36 ure, many of the comprehensive policy agendas focused on increasing the limited
37 availability of freshwater to meet ever-growing and competing demands [28].

38 The constructions sector, especially the building industry's contribution to the
39 total freshwater withdrawal is sizable as per the accounts documented. The World
40 Bank [25] reports that around 19% of total water is withdrawn by the industrial sector
41 in which the construction industry is among the top water consumers [7]. Abd El-
42 Hameed et al. [1] report that the built environment globally consumes 20% of water
43 and the green buildings can possibly reduce usage by almost 40%. Along the value
44 chains, the water consumption profiles of different materials vary greatly during
45 raw material extraction, processing, manufacturing, transportation and construction.
46 Besides, both direct and indirect water uses have to be accounted for along their
47 supply chains to explore the critical points of water efficiency's interests [17]. As
48 the building construction is supported by complex supply chains involving many
49 a manufacturing sector, comprehensive quantification of water footprints is diffi-
50 cult and intricate [5, 18]. Therefore, the need for metric(s) with methodical proto-
51 cols to quantify the volumetric water use and/or potential environmental impacts
52 related to the water use was of prime importance, and the international consensus
53 for such metric(s) was well appreciated in facilitation of comparative analyses of
54 water consumption performance assessments of products or processes in the sphere
55 of building industry.

56 This review bids to present a landscape analysis of water footprinting discussing
57 the developments and salient points with regard to sustainable freshwater consump-
58 tion in the building industry. The literature was surveyed in Google Scholar by
59 the keywords and the resourceful articles were pooled perusing the abstracts of the

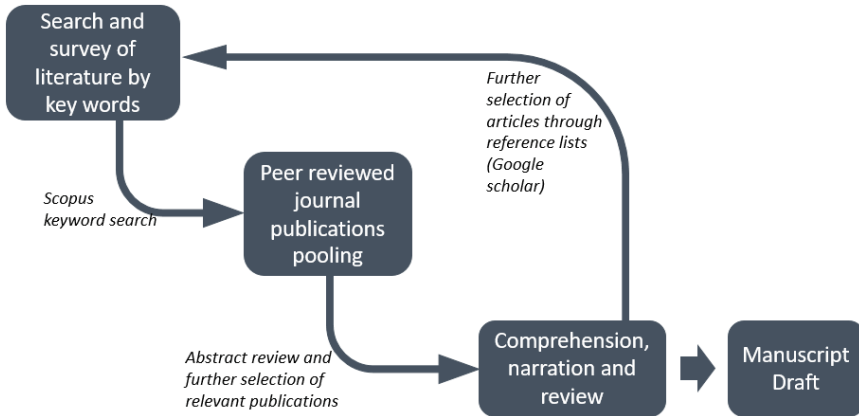


Fig. 1 The iterative operationalization of developing this review study

60 search results. Thereby, twenty-nine articles were selected as the primary reservoir
 61 of information for this review. This process was iterated as the narration of the review
 62 develops. Figure 1 illustrates the operationalization of this work.

63 2 Water Footprint Analysis in the Building Industry

64 At the outset, it is worth briefly review the two widely applied water footprinting
 65 approaches proposed by two different communities, the Water Footprint Network
 66 (WFN) and the Life Cycle Assessment (LCA). Both these methods are broadly
 67 similar standing for the computation of freshwater use and its impact. The WFN
 68 considers water footprinting as a volumetric approach (total volume of freshwater
 69 used by an individual/community/business activity), focusing on water productivity.
 70 It views freshwater as a limited global resource, and the environmental relevance
 71 of both consumptive (green and blue waters) and degradative (gray water) fresh-
 72 water uses are accounted referring to the sustainability limits, environmental needs,
 73 efficiency of use and equitability of global freshwater resources [9]. Berger and
 74 Finkbeiner [4] define this approach as a volumetric water footprinting method since
 75 it determines the freshwater appropriation on an inventory level.

76 On the other hand, the LCA quantifies potential environmental impacts related
 77 to a particular freshwater appropriation going beyond the primary reporting of the
 78 volumetric water use [20]. The LCA approach extends the freshwater use assess-
 79 ment to the consequences resulting from water consumption (impact-based water
 80 footprinting) through weighting and characterization pertinent to the case of interest.
 81 Moving beyond the volumetric water use accounting (inventory level/LCI—life cycle
 82 inventorying), the LCA approach works on life cycle impact assessment (LCIA)
 83 based on freshwater scarcity/water quality/vulnerability of ecosystems/sensitivity

84 of the population to human health damages [4]. This integration of freshwater use
85 into life cycle assessments by the LCA community has formulated the international
86 standard on water footprinting in ISO 14046.

87 Although the WFN and LCA approach manifest differences in their terminolo-
88 gies and communications, they share common fundamental principles in freshwater
89 accounting. Both approaches intend for water efficiency, water productivity and envi-
90 ronmental well-being giving complementary inputs to the system improvements.
91 Further, both methods account for volumetric water use following the life cycle
92 approach with nearly similar steps. Still, in contrast to the WFN's viewpoint (fresh-
93 water is deemed as a limited global resource), the LCIA of LCA approach adopts a
94 damage-oriented analysis of local freshwater use [20]. Having all in mind, the WFN
95 and LCA approaches should be regarded not as competing water footprinting tools,
96 but as complementary methods. Thus, the approach/es should be fittingly adapted
97 for the intended purpose.

98 The establishment of a transparent and replicable approach to quantify fresh-
99 water use in building industry entirely depends on the quality of available data. The
100 embodied water demand of a particular product/process of the building industry is
101 the overall freshwater need of manufacture/delivery covering both direct and indirect
102 water uses. Though the direct water component of a product/process is straightfor-
103 wardly assessed, the indirect water accounting is a hard task as it involves the fresh-
104 water use of all the processes along the upstream supply chain in which the main
105 product moved through utilizing resources and raw materials [1]. The supply chain
106 dispersion of the building industry moves across the national borders. Even though
107 it observes variations of international building WFs among different countries, the
108 supply chains of the building industry is highly dispersed going beyond country
109 borders [21]. Therefore, the higher degree of sector disaggregation and the avail-
110 ability of corresponding fine resolution data throughout the supply chain nexuses
111 become key determinants over the dependable quantification of water use in the
112 building industry.

113 The process boundary of the water footprint analysis is another principal aspect
114 in the evaluation of the material, technology and structural design alternatives in the
115 field of the building industry. For instance, the water use performance of a building
116 construction should be appraised referring to its practical applications of durability,
117 water footprints of maintenance, repair, demolition/treatment/disposal (end-of-life),
118 post-construction use phase water footprints, water footprints of material transporta-
119 tions, water footprints of compatible and complementary materials (e.g., stainless
120 steel/glass fiber reinforcements for concretes with seawater and/or marine aggre-
121 gates), gray water footprints related to effluents [2, 8, 23]. Thus, the establishment
122 of comprehensive reasoning for a particular water-efficient alternative will only be
123 rationalized by cradle-to-grave water footprint analyses. Moreover, the case-specific
124 interests have to be duly inventoried and the associated water footprints should be
125 well accounted for to secure the interpretational accuracy of individual case anal-
126 yses. The case-specific water footprints of raw material extraction and processing,
127 sources of energy used, mode of labor employed, soil characteristics of the construc-
128 tion site (influencing the load resisting structures of buildings), technologies adopted

129 in different unit operations should be carefully surveyed throughout the supply chain
 130 network [1, 5, 11].

131 3 Appraisal of Water Footprints at the Construction 132 Materials Level

133 In this section, a review on appraising water footprints of common building materials
 134 is presented based on the published work. A water footprint analysis of blue and gray
 135 waters for most common types of steel, cement and glass has been reported by [8]
 136 adopting a combined approach of LCA and WFN, and their findings are shown in
 137 Fig. 2.

138 Among the materials studied, steel records the top WF values with leading figures
 139 in both blue and gray WF components. In a cradle-to-grave LCA analysis of Ultra-
 140 High-Performance Concrete (UHPC) in comparison to Conventional Concrete (CC),
 141 [23] also have reiterated the predominance of steel's WF. The alloyed steel leaves
 142 the highest WF with a predominant blue WF for energy used. This is attributed to
 143 the relatively large electricity demand for ferronickel melting in the alloying process
 144 [8]. Further, the substantial gray WF values of steels and Portland cement are caused
 145 by the heavy metal (Cd, Hg, Cu) laden effluents of their manufacturing processes.
 146 Specifically, Cd is the critical pollutant responsible for the gray WFs of alloyed steel,
 147 unalloyed steel and Portland cement. These WF estimations at the material level
 148 are supported by a study [3] that has reported embodied water volume of building
 149 materials per unit floor area basis. Those estimations are comparable to the data
 150 presented above recording values for steel, cement and bricks as 25, 0.5 and 0.1
 151 kl/m^2 , respectively. Moreover, [3] has assessed both water use during the construction
 152 phase and embodied water use of building materials as 2 and 25.6 kl/m^2 , respectively.

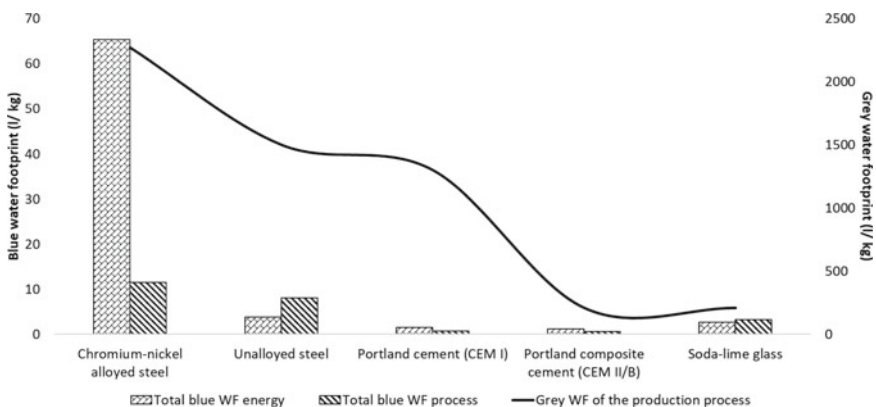


Fig. 2 Blue and gray WFs of common building materials pertaining to the direct production process, energy inputs of the production process and pollutant effluent of wastewaters [8]

153 This assessment stands with the study of [11] as they have recorded the extents of
 154 direct water consumption of on-site constructions and indirect water consumption of
 155 off-site processes (energy use, material production, transportation, food, water use
 156 for equipment and machinery, etc.) as 2.26% and 97.74%, respectively. Therefore,
 157 it can be deduced that the building industry exerts comparatively less pressure on
 158 local freshwater resources while its greatest impact is on national water resources
 159 or beyond (Fig. 3). This matter would be very much insightful in the determination
 160 of the water footprinting approach for case studies. To be specific, for the off-site
 161 freshwater use quantifications of the building industry, the WFN approach can be
 162 generally recommended whereas LCA water footprinting fits most for the on-site
 163 operations of building constructions.

164 In [8], the total blue WF of the process represents the direct blue water use by the
 165 material excluding water use for transportation. The blue WF of energy is a sizable
 166 predictor of the water use performance of each material as it ranges from 32 to 85%
 167 of the total blue WFs. Thus, the WF of the energy source of material manufacturing
 168 becomes a critical determinant of the overall blue WF of construction materials.
 169 The WFs of energy sources corresponding to this study have been tabulated below
 170 (Table 1), and the relative variation of blue WF ranges implies the significance of
 171 the choice of energy source over the total blue WF of the material. This claim is
 172 further supported by [11] as they have weighted >50% of the total WF of building

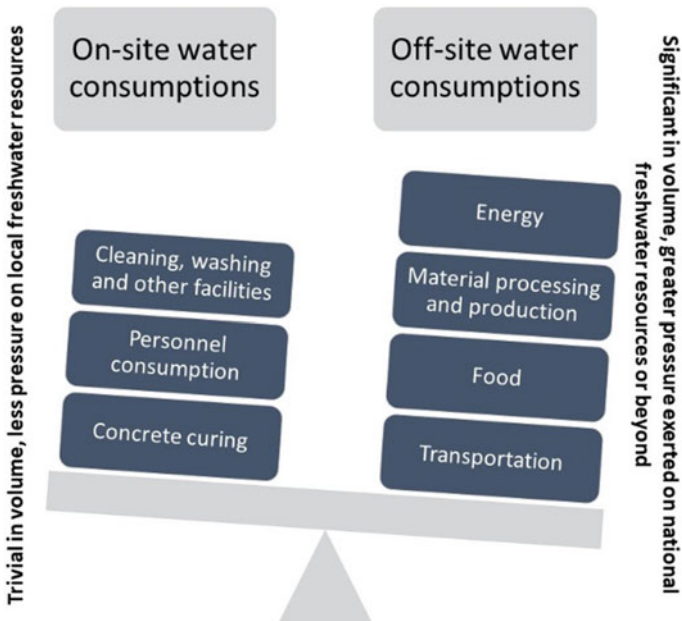


Fig. 3 On-site and off-site water consumptions of building industry and their relative pressure exerted on freshwater resources

Table 1 Ranges and median values of blue WFs of energy sources reported by [8]

Energy source	Blue WF range (l/GJ)	Blue WF median value (l/GJ)
Diesel	28–376	80
Light fuel oil	19–259	55
Heavy fuel oil	10–133	28
Natural gas	0.6–18	2.2
Coal	6.6–228	15–39
Hard coal cokes	42–321	52–82
Electricity	4241	

173 construction to its material use in which >50% of WF is of the energy used for
174 manufacturing and processing.

175 If the energy sources of building material manufacturing and processing can be
176 inclined toward alternatives with lower WFs (solar/wind/geothermal energy) it can
177 be improved the water use performances of most of the common building materials.
178 At the same time, the industry should seek new technologies to relieve higher WFs
179 spotting critical points of freshwater efficiencies along its supply chains: reusing
180 and recycling of materials, effluent treatment before discharge, encouraged rain and
181 stormwater use in material manufacturing and processing, replacement of freshwater
182 with seawater where workable (cooling activities), improved concrete curing tech-
183 nologies with lower WFs, promotion of local purchases of building materials to
184 minimize the WF of transportation, etc.

185 4 Appraisal of WFs at Use Phase/Case Study Level

186 Moving forward from the WF analysis at the construction materials level, a review
187 of water footprinting at the case study level is presented here based upon available
188 literature. The study of the complete life cycle of buildings includes not only extrac-
189 tion and processing of raw materials, production, transport and on-site construction
190 activities. It extends to the analysis of use, reuse and maintenance, recycling, and final
191 disposal phases as well [15, 16]. Thus, environmental performances of a building
192 construction should be comprehensively appraised through a systematic method-
193 ology (LCA based on ISO 14040 and ISO 14044) to produce inputs for well-judged
194 sustainability assessments of natural resources [1, 23].

195 The importance of the inclusive analysis of building construction is exhibited
196 in a WF assessment of Ultra-High-Performance Concrete (UHPC) in comparison
197 to Conventional Concrete (CC) done by [23]. At the level of the materials, UHPC
198 shows nearly three times higher WFs compared to CC for both ready-mix and precast
199 concretes (from raw material production to construction site) (Fig. 4). Nevertheless,
200 the UHPC design (a bridge design) compared to its corresponding CC design had a
201 WF around 30% lower (Fig. 5). Further, as UHPC is superior to CC in compressive

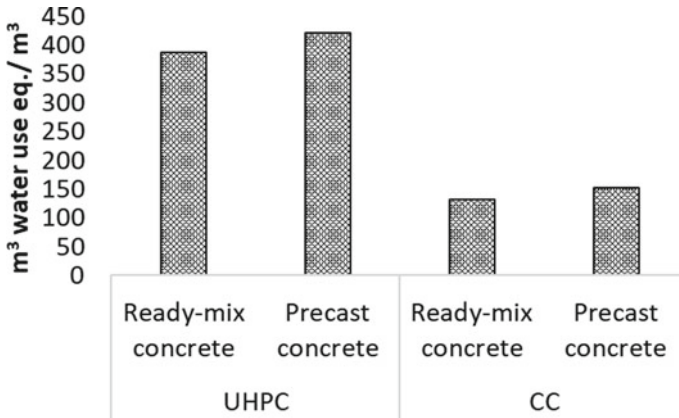


Fig. 4 Water footprints of ultra-high-performance concrete (UHPC) in comparison to conventional concrete (CC) [23]

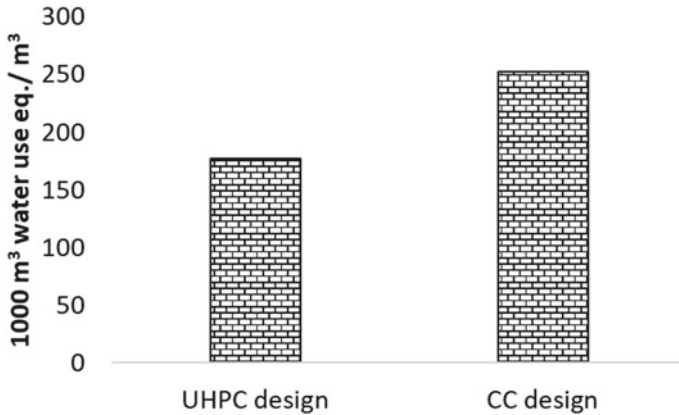


Fig. 5 Water footprints of two bridge designs of ultra-high-performance concrete (UHPC) and conventional concrete (CC) [23]

202 and tensile strengths, it is anticipated that the UHPC’s end-of-life (EoL) phase would
 203 leave a relatively higher WF (especially of demolition) compared to the CC. Besides,
 204 the WF analyses should reach out to emerging sustainability-oriented applications in
 205 the sphere of building construction. For instance, in urban mining as a key approach
 206 of circular economy, the materials flow reverse bringing in new dimensions of process
 207 boundaries (e.g., concrete manufacturing from recycled aggregates in EoL-to-gate
 208 boundaries) [19].

209 From the perspective of overall environmental impact, the WFs of building
 210 constructions should be appraised in tandem with other environmental footprints
 211 entailed (carbon footprint, energy footprint, material footprint, ecological footprint).

212 These environmental footprints do not always follow congruous patterns mutually.
213 As per [21], no collinearity of WF with energy and carbon footprints was observed in
214 environmental footprints associated with the construction sector of India, Italy, South
215 Africa, and the UK. Further, in an environmental assessment of recycled concrete, the
216 material footprint had a clear improvement though the water use remained without a
217 significant saving [19]. This claim was confirmed in a cradle-to-gate assessment of
218 environmental footprints for different design alternatives of building elements using
219 recycled aggregates for concrete production [22]. Still, a contrasting finding was
220 documented in the environmental assessment of UHPC compared to CC where all
221 the footprints of carbon, material and water for UHPC recorded comparatively higher
222 figures at the construction materials level [23]. At the same time, all the three foot-
223 prints of UHPC had comparatively lower values than CC at the case study level (for a
224 bridge design case study) of the same study. To cut short, it can be observed case-wise
225 discrepancies of the way WF is left with other environmental footprints. Therefore,
226 drawing recommendations for the practical applications of building construction
227 becomes a multi-faceted phenomenon extending beyond materials level and case
228 study level assessments of mere WF analyses.

229 Viewing the case study level from a different perspective, [5] carried out quan-
230 tification of WFs of buildings in China considering the variable of building type.
231 Its results divulge how the scale of heavy structural designs that directly depend
232 on water-intensive steel and cement consumptions be predictors of their embodied
233 WFs. Thereby, the public buildings preceded residential buildings in WFs while
234 the urban residential buildings having 55–130% greater WFs in comparison to the
235 rural residential buildings. Figure 6 shows the factual evidence of water withdrawals
236 (surface and groundwater withdrawals) and water consumptions (permanent water
237 withdrawals as no longer available for any other use) for the thirteen building sub-
238 sectors studied under that analysis. Moreover, [11] assessed the effects of structural
239 parameters of residential buildings on the WFs. The work declared WF mitigation
240 recommendations by way of: concrete structures over steel structures, short struc-
241 tures over tall structures, composite slabs over steel deck and compute precast slabs,
242 and building sites with dense soils over building sites with soft soils.

243 5 Challenges and Futuristic View

244 Even amidst the global pandemic, the developing economies, especially in Asian and
245 African regions are in a healthy economic revival in terms of their Gross Domestic
246 Product (GDP) growth rates [24]. Around one-third of the top twenty-five devel-
247 oping economies suffers with either lack of basic access to water for the majority of
248 their populations (Eritrea, Ethiopia, Uganda) or higher baseline water stress (Turk-
249 menistan, Syria, Egypt, San Marino, China) [10]. These countries undergo intensive
250 infrastructure development projects that probably exert substantial impacts on the
251 national freshwater resources. This crisis gets compounded with the outward-bound
252 virtual waters related to the building industry in these developing economies. For

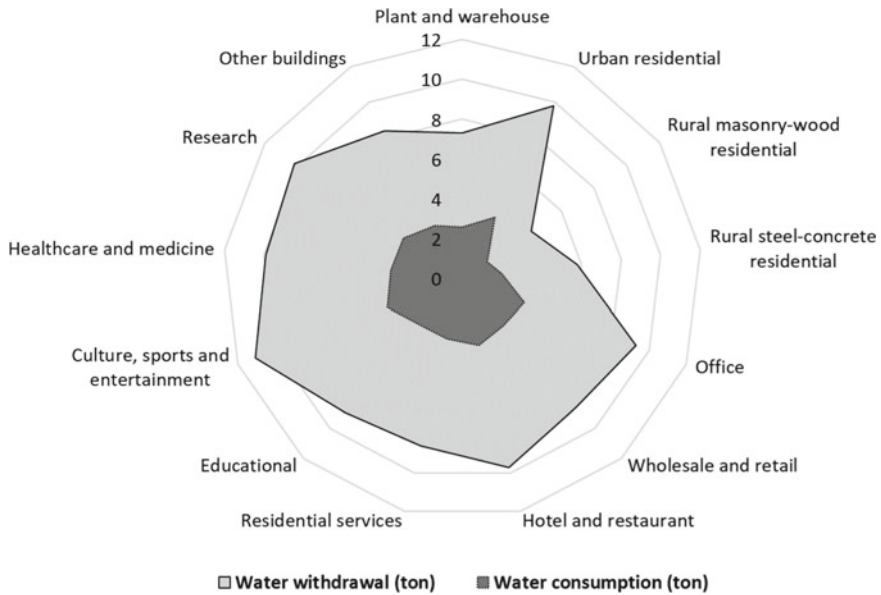


Fig. 6 Water withdrawal and water consumption values estimated per 1 m² of building area in China [5]

253 instance, having a swelling building industry China is one of the countries with
 254 the most deficient per capita water resources of which the spatial distribution is
 255 highly uneven [13]. Further, China extensively exports virtual waters via building
 256 materials and other inputs of the construction sector putting extra pressure on local
 257 freshwater resources [21]. Thus, alleviation of this crisis through mindful freshwater
 258 appropriations is a crying need that ought to be placed top in sustainable manage-
 259 ment practices. Along with the collective effort toward Sustainable Development
 260 Goals (SDGs) intended to be achieved by 2030 and mid-century climate goals, the
 261 building industry’s role is decisive due to its significant contribution to the global
 262 environmental burden. Therefore, to overcome the challenges posed by irreconcil-
 263 able demands of environmental, economic and social interests all the stakeholders
 264 of water handling (industry, academia, regulators and general public) have to seek
 265 water-efficient alternatives.

266 With special regard to the local context of Sri Lanka, a set of potential challenges
 267 can be anticipated in gearing water-efficient alternatives in the building industry. In
 268 the Sri Lankan construction sector, there are few inherent drawbacks that may pose
 269 challenges to the aspiring transition of sustainable water management. Low level of
 270 new technological development and transfer, poor documentation and communica-
 271 tion, reluctance in using innovative building materials and disadvantaged industry-
 272 oriented research and developments reported by [6] may probably loom by way of
 273 potential challenges.

274 These challenges are to be tackled in a participatory approach with all the key
 275 stakeholders of the industry through information, communication and education.
 276 At the same time, sustainable water management should be integrated into the
 277 water governance by the national government to regulate freshwater appropri-
 278 ations of the industry [26]. However, the industry demand for freshwater is to be
 279 compromised with other priorities of freshwater uses (e.g., freshwater demand for
 280 agriculture to assure national food security) [12]. Ultimately, the industry well-
 281 being should be secured under the developing economy of Sri Lanka through
 282 economic analysis of water-efficient alternatives (life cycle costing of water-efficient
 283 materials/technologies).

284 References

- 285 1. Abd El-Hameed AK, Mansour YM, Faggal AA (2017) Benchmarking water efficiency of
 286 architectural finishing materials based on a “cradle-to-gate” approach. *J Build Eng* 14:73–80
- 287 2. Arosio V, Arrigoni A, Dotelli G (2019) Reducing water footprint of building sector: concrete
 288 with seawater and marine aggregates. *IOP Conf Ser Earth Environ Sci* 323:012127
- 289 3. Bardhan S (2011) Assessment of water resource consumption in building construction in India.
 290 *Ecosyst Sustain Devel VIII* 144:93–102
- 291 4. Berger M, Finkbeiner M (2013) Methodological challenges in volumetric and impact-oriented
 292 water footprints. *J Ind Ecol* 17(1):79–89
- 293 5. Chang Y, Huang Z, Ries RJ, Masanet E (2016) The embodied air pollutant emissions and water
 294 footprints of buildings in China: a quantification using disaggregated input–output life cycle
 295 inventory model. *J Clean Prod* 113:274–284
- 296 6. De Silva N, Rajakaruna R, Bandara K (2008) Challenges faced by the construction industry in
 297 Sri Lanka: perspective of clients and contractors. *Build Resilience* 158
- 298 7. FAO (2021) AQUASTAT—FAO’s global information system on water and agriculture.
 299 Available at: <http://www.fao.org/aquastat/en/>. Accessed on 7 Sept 2021
- 300 8. Gerbens-Leenes P, Hoekstra A, Bosman R (2018) The blue and grey water footprint of
 301 construction materials: steel, cement and glass. *Water Res Ind* 19:1–12
- 302 9. Hoekstra AY (2016) A critique on the water-scarcity weighted water footprint in LCA. *Ecol*
 303 *Ind* 66:564–573
- 304 10. Hofste RW, Reig P, Schleifer L (2019) 17 countries, home to one-quarter of the world’s
 305 population, face extremely high water stress
- 306 11. Hosseinian SM, Ghahari SM (2021) The relationship between structural parameters and water
 307 footprint of residential buildings. *J Clean Prod* 279
- 308 12. IWMI (2021) IWMI in Sri Lanka :: IWMI. Available at: [https://www.iwmi.cgiar.org/about/
 309 where-we-work/asia/south-asia-region/sri-lanka/](https://www.iwmi.cgiar.org/about/where-we-work/asia/south-asia-region/sri-lanka/). Accessed on 7 Sept 2021
- 310 13. Liu S, Zhang F, Li K, Wang K, Shang B, Li D (2020) Analysis on research status of water
 311 footprint of ceramic tile (board). *IOP Conf Ser Earth Environ Sci* 526:012220
- 312 14. Loucks DP (2000) Sustainable water resources management. *Water Int* 25(1):3–10
- 313 15. Mannan M, Al-Ghamdi SG (2020) Environmental impact of water-use in buildings: latest
 314 developments from a life-cycle assessment perspective. *J Environ Manage* 261:110198
- 315 16. Marrero M, Wojtasiewicz M, Martínez-Rocamora A, Solís-Guzmán J, Alba-Rodríguez MD
 316 (2020) BIM-LCA integration for the environmental impact assessment of the urbanization
 317 process. *Sustainability* 12(10):4196
- 318 17. Matarazzo A, Gambera V, Suriano E, Conti MC (2017) Water footprint applied to construction
 319 sector. *Environ Eng Manage J (EEMJ)* 16(8)

- 320 18. Meng J, Chen G, Shao L, Li J, Tang H, Hayat T, Alsaedi A, Alsaadi F (2014) Virtual water
321 accounting for building: case study for E-town, Beijing. *J Clean Prod* 68:7–15
- 322 19. Mostert C, Sameer H, Glanz D, Bringezu S (2020) Urban mining for sustainable cities: envi-
323 ronmental assessment of recycled concrete. In: IOP conference series: earth and environmental
324 science
- 325 20. Pfister S, Boulay A-M, Berger M, Hadjikakou M, Motoshita M, Hess T, Ridoutt B, Weinzettel
326 J, Scherer L, Döll P (2017) Understanding the LCA and ISO water footprint: a response to
327 Hoekstra (2016) A critique on the water-scarcity weighted water footprint in LCA. *Ecol Ind*
328 72:352–359
- 329 21. Pomponi F, Stephan A (2021) Water, energy, and carbon dioxide footprints of the construction
330 sector: a case study on developed and developing economies. *Water Res* 194:116935
- 331 22. Sameer H, Mostert C, Bringezu S (2020) Product Resource and climate footprint analysis
332 during architectural design in BIM. In: IOP conference series: earth and environmental science
- 333 23. Sameer H, Weber V, Mostert C, Bringezu S, Fehling E, Wetzel A (2019) Environmental assess-
334 ment of ultra-high-performance concrete using carbon, material, and water footprint. *Materials*
335 12(6):851
- 336 24. The World Bank (2021) GDP growth (annual %)|Data. Available at: <https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG>. Accessed on 7 Sept 2021
- 337
338 25. The World Bank (2017) Annual freshwater withdrawals industry (% of total freshwater
339 withdrawel)-Sri Lanka. Available at [https://data.worldbank.org/indicator/ER.H2O.FWIN.ZS?](https://data.worldbank.org/indicator/ER.H2O.FWIN.ZS?locations=LK)
340 [locations=LK](https://data.worldbank.org/indicator/ER.H2O.FWIN.ZS?locations=LK). Accessed on 7 Sept 2021
- 341 26. UNDP (2021) What is water governance? Water governance facility—water gover-
342 nance facility. Available at: [https://www.watergovernance.org/governance/what-is-water-gov-](https://www.watergovernance.org/governance/what-is-water-governance/)
343 [ernance/](https://www.watergovernance.org/governance/what-is-water-governance/). Accessed on 7 Sept 2021
- 344 27. Vollmer D, Regan HM, Andelman SJ (2016) Assessing the sustainability of freshwater systems:
345 a critical review of composite indicators. *Ambio* 45(7):765–780
- 346 28. World Economic Forum (2021) On the Agenda/Water|World Economic Forum. Available at:
347 <https://www.weforum.org/agenda/archive/water>. Accessed on 7 Sept 2021
- 348 29. World Vision (2020) 10 worst countries for access to clean water|World Vision.
349 Available at: [https://www.worldvision.org/clean-water-news-stories/10-worst-countries-acc-](https://www.worldvision.org/clean-water-news-stories/10-worst-countries-access-clean-water)
350 [ess-clean-water](https://www.worldvision.org/clean-water-news-stories/10-worst-countries-access-clean-water). Accessed on 7 Sept 2021