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# Blue, Green, and Grey Water Quantification Approaches: A Bibliometric and Literature Review

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**Abstract:** An array of methodologies to quantify blue, green, and grey water have emerged in recent years and are still evolving rapidly, as are efforts to come up with reliable indicators of human appropriation of freshwater resources. This study provides an overview of recent blue, green, and grey water quantification approaches by analyzing publications extracted from the Web of Science database utilizing the Network Analysis Interface for Literature Studies (NAILS) bibliometric analysis tool, covering the period 2000-2018. A steep increase in the number of blue, green, and grey water publications was observed from the year 2009, with the United States and China among the top contributing nations. Blue, green, and grey water quantification approaches used in the analyzed publications were broadly categorized into Water Footprint Assessment, Life Cycle Assessment, and Hybrid methodologies. The Water Footprint Network was the most influential hub in terms of providing the most productive and cited authors. "Water footprint" and "virtual water" were unsurprisingly the trendiest and most cited keywords associated with the sample of analyzed publications. The study provides important insights that are helpful in understanding the diversity of techniques that have been applied to quantify blue, green, and grey water in recent assessment studies.

**Keywords:** *virtual water, water footprint, water scarcity, bibliometric analysis*

Water is a critical input to most human economic activities. Growing human populations and increasing economic production and consumption activities call for comprehensive freshwater analytical frameworks that cover all water resource components, including water stored in the soil that limits food production potential (green water), surface and groundwater resources (blue water), and freshwater used to assimilate waste (grey water) (Postel et al. 1996; Falkenmark 2000; Falkenmark and Rockström 2006; Hoekstra 2011). Closely related to blue, green, and grey water components are the concepts of "virtual water" and "water footprint." Virtual water refers to water used for the production of a commodity (Allan 2003), whereas water footprint is a measure of consumptive and degradative freshwater water use associated with all goods and services consumed by one person or the whole population of a country (Hoekstra 2003; Hoekstra and Chapagain 2008). Thus, whereas virtual water refers only to the volume of water embodied in a commodity, the water footprint indicator broadens the scope of this definition by including spatio-temporal aspects: where and when the embodied water is being used (Hoekstra et al. 2011). Allan (2011) also used the term "virtual water trade" to refer to the amount of water embedded in traded commodities. A key distinction is that virtual water focuses primarily on blue and green water quantity, but water footprint goes a step further to highlight environmental impacts of water use (grey water footprints), in addition to blue and green water footprints (Ridoutt and Pfister 2013). A comprehensive water footprint therefore not only assesses a nation's consumption of blue water (blue water footprint) and consumption of green water (green water footprint) (Hoekstra 2017), but also accounts for indirect water consumption through import of water intensive commodities produced in other geographic locations and imported through virtual water trade. Because of this interrelatedness, blue, green, and grey water components are often quantified as part of water accounting approaches that assess virtual water content and water footprints.

## Water Accounting Approaches

Analytical frameworks that quantify blue, green, and grey water are evolving with the emergence of water footprint assessment as a new research field (Hoekstra 2017). In certain studies, these frameworks have been classified into two broad categories of Water Footprint Assessment (WFA) methodologies, and Life Cycle Assessment (LCA) methodologies (Jefferies et al. 2012; Vanham and Bidoglio 2013). WFA is a volumetric approach developed by the Water Footprint Network, but the LCA approach owes its origin to the LCA community (Hoekstra et al. 2011; McGlade et al. 2012; Postle et al. 2012). A fundamental difference between the approaches is that LCA focusses on products, and water sustainability is just one area of focus among others. In contrast, WFA focusses on water management covering products and consumption patterns of individuals at different spatial scales (Jefferies et al. 2012; Boulay et al. 2013). For a more comprehensive assessment of parallelisms, contrasts, and synergies between LCA and WFA, see Jefferies et al. (2012) and Boulay et al. (2013). Some schools of thought have broadly classified water accounting methods into the two general categories of bottom-up and top-down approaches, as shown in Figure 1 (Feng et al. 2011; Yang et al. 2013).

### WFA Approaches

Most WFA methods are indeed a mix of bottom-up and top-down techniques, encompassing methods such as modelling crop water requirements and aggregation of water requirements of various primary and secondary commodities over space and the supply chain (for example, Hoekstra and Hung 2002; Hoekstra and Chapagain 2007; Hoekstra and Chapagain 2008; Hoekstra et al. 2011). Further, WFA uses waste assimilated by freshwater to determine the grey water footprint, adds water volumes without weighting with water scarcity or pollution indicators, and is a geographically explicit indicator that shows location in addition to water use volume and pollution (Hoekstra 2009).

### LCA Approaches

LCA methods include a mix of largely bottom-up approaches used to assess environmental impacts of a product or service over its whole life cycle (Yang et al. 2013). In general, LCA involves an analysis stage such as setting goals and scope,

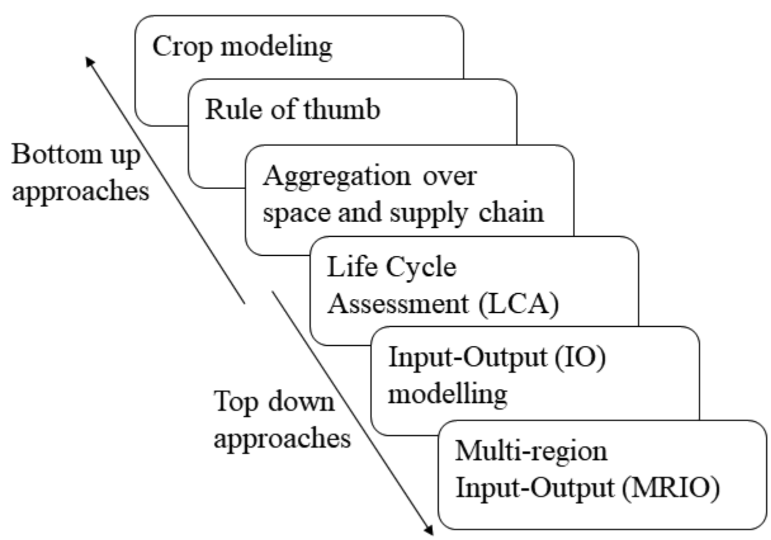


**Figure 1.** Water accounting methods and approaches. Adapted from Yang et al. (2013).

life cycle inventory, life cycle impact assessment, and interpretation (Vanham and Bidoglio 2013). Examples of LCA-based methods include relative blue water scarcity (Harris et al. 2017), and system-based tools (Al-Ansari et al. 2015). LCA-based methods have been used for applications ranging from assessing environmental impacts of food crops and livestock production, to dairy farming and energy use assessment (Vora et al. 2017).

**Other Major Water Accounting Approaches**

Other major approaches that have been widely used to quantify human appropriation of freshwater are based on input-output (IO) modelling, where relationships are determined between direct and indirect water consumption by commodities. Contrary to WFA methods, the virtual water content of intermediate inputs in IO modelling is attributed to the virtual water content of the final product. IO techniques can be applied as individual tools of analysis or in the context of LCA, and have evolved into standalone research fields that have been used to analyze systems ranging from a small factory to the entire world economy and its supply chain effects (Ridoutt et al. 2009; Steen-Olsen et al. 2012; Boulay et al. 2013). Widely applied IO modelling techniques include multi-region input-output (MRIO) analysis and environmentally-extended input-output (EEIO) analysis. MRIO analysis uses a top-down approach to account for environmental pressures through complex supply chains (Steen-Olsen et al. 2012; Mubako et al. 2013; Huang et al. 2017), but the two major goals of EEIO, according to Kitzes (2013), are: 1) assessment of hidden or indirect environmental impacts of downstream consumption activities and, 2) quantification of environmental impacts associated with commodities traded between countries. The technique has been applied in impact evaluation studies that involve water, global carbon, and biodiversity, among other natural resource systems. For a comprehensive overview of the EEIO conceptual framework as well as an evaluation of the approach's strengths and limitations in environmental applications, readers are again referred to Kitzes (2013).

Great strides have been made in recent years to quantify virtual water and water footprints at various spatial scales. However, Yang et al. (2013) claim that most of these assessments have focussed mainly on blue water, and there is a consequent weakness of conceptual frameworks that quantify green and grey water. The objective of this article therefore is to review blue, green, and grey water quantification approaches from recent years. First, blue, green, and grey water literature is identified through a database search. This is followed by a bibliometric analysis and structured review of water quantification approaches that have been applied in recent studies. The article ends by highlighting how an understanding of blue, green, and grey water quantification approaches could result in better comprehension of how production and consumption decisions impact freshwater resources.

## Methods

Blue, green, and grey water quantification approaches were assessed using bibliometric analysis, followed by a systematic literature review. Bibliometric analysis is a well-established meta-analytical technique that provides a rapid and quantitative way to handle large amounts of literature, and is a pathway to better understanding of research in any particular field of study (Kolle et al. 2015; Feng et al. 2017; Geissdoerfer et al. 2017).

A variety of data analysis tools and guidelines are available to conduct bibliometric analyses, for example Microsoft Excel, BibExcel, BibTex, and Pajek. However, even the most frequently followed guidelines are often not sufficient alone (Petersen et al. 2015), and there is always need to combine or update techniques. For this study, bibliometric analysis was performed using the Network Analysis Interface for Literature Studies (NAILS), an open source exploratory analysis software toolkit that provides a rapid visual overview and deep insight into any field of inquiry (Knutas et al. 2015). The NAILS toolkit uses literature records obtained from the Thomson Reuters Web of Science core collection, a comprehensive database containing high quality records (Gao and Guo 2014; Hajikhani 2017; Zhang et al. 2017). The records were uploaded to the analysis system via a web interface after typing in the keyword search terms "blue green grey water." A systematic literature review must be preceded by a predefined search strategy for studies (Kitchenham 2004); keyword selection criteria, for example, the "Population, Intervention, Comparison, Outcomes, Context" (PICO and PICOC) frameworks (Kitchenham and Charters 2007; Moher et al. 2009; Petersen et al. 2015), in addition to inclusion and exclusion criteria for weeding out studies that are not applicable to the research questions (Petersen et al. 2008). For this bibliometric analysis however, the formulation of keywords and search for studies was straightforward and guided by the "blue, green, and grey water" focus of this special issue of the Journal of Contemporary Water Research and Education. Only a few records were retained from a preliminary search for the period prior to the year 1999, so the more recent period 2000-2018 was used as the analysis time frame in NAILS to get insight into the following key aspects in relation to literature on blue, green, and grey water quantification approaches: 1) type and geographic distribution of recent publications; 2) number of articles produced; 3) top 25 contributing authors; 4) 25 most popular and most cited journals; and 5) top 25 most popular and cited keywords. Detailed insights from this exploratory data analysis in NAILS were then used to prioritize blue, green, and grey water quantification literature for further structured review. This study differs from a bibliometric study on the water footprint by Zhang et al. (2017) in terms of the period of analysis, keywords, and the analytical tools used. For a comprehensive overview of literature review methods focusing on other specific areas of expertise, readers can visit Budgen et al. (2008) for mapping studies in software engineering, Arksey and O'Malley (2005) for scoping studies and their rigor, transparency, and applicability in mapping areas of research in social policy and social work, and Grant and Booth (2009) as well as Levac et al. (2010) for scoping studies in healthcare research. The literature analysis workflow used in this study is provided in Figure 2.

## Results and Discussion

### Type of Publications and Geographic Distribution of Blue, Green, and Grey Water Literature Analyzed

The study period yielded 167 journal articles, 22 proceedings papers, 5 reviews, 2 editorial materials, and 1 letter from the Web of Science core collection. After removal of duplicate records, a total of 192 publications from 59 countries were analyzed. The word cloud in Figure 3 shows that the majority of publications were contributed by the United States and China. These two countries had a share of 15% and 13% of the total number of relevant publications, respectively. Figure 3 also reveals that the contributing countries are a mix of developed and developing countries from all world regions, indicating that blue, green, and grey water issues are globally important. The more prominent contributing countries, mapped in larger letters in the word cloud are to a large extent part

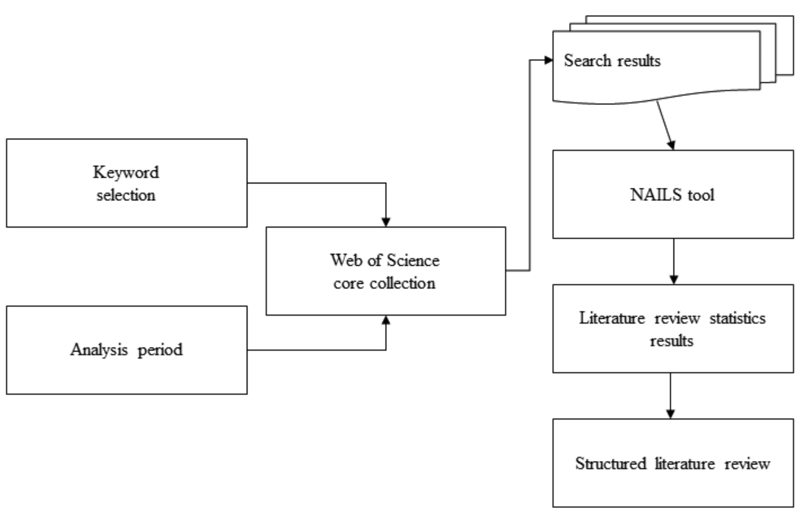


**Figure 2.** Workflow for bibliometric analysis of blue, green, and grey water quantification literature.

of developed or more industrialized countries. This unsurprising result is in agreement with findings of recent bibliographic studies in other academic fields of inquiry (for example Kolle et al. 2015; Kolle and Thyavanahalli 2016; Chen et al. 2017; Feng et al. 2017; Geissdoerfer et al. 2017; Hajikhani 2017; Zhang et al. 2017) where most publications tend to originate from more developed countries due to better access to more research resources.

### Number of Articles Produced

Figure 4 shows the number of recent blue, green, and grey water articles published each year during the analysis period 2000-2018. The general trend shows a steep increase in the volume of publications from 2009 onwards, with the greatest number of publications in 2017. The increasing trend of publications relating to blue, green, and grey water quantification from the Web of Science database indicates that this is still a growing field of inquiry.

### Top Contributing Authors

Figure 5 provides details for the top 25 contributing authors (Figure 5a) and the most cited authors (b) in the field of blue, green, and grey water literature for the analysis period. The results are listed by lead author only. The top two most productive authors from the Web of Science database for the 2000-2018 analysis period were Mekonnen M. and Herath I., while Mekonnen M. and Hoekstra A. were the most important authors in terms of number of citations (Figure 5b). Most cited authors in the top 25 rank, for example Mekonenn, Hoekstra, Chapagain, and Aldaya have current or previous associations with the Water Footprint Network (waterfootprint.org/), indicating that this is one of the most important hubs conducting research related to blue, green, and grey water quantification work in recent years through water footprint assessments.

### Most Popular and Most Cited Journals

In Figure 6 the 25 most important journals are sorted by number of published articles and the number of citations. The top two most important publications were "Journal of Cleaner Production" and "Ecological Indicators" (Figure 6a), but the top two most cited publications were "Hydrology and Earth System Sciences" and "Proceedings of the National Academy of Sciences" (Figure 6b). These results provide insight into the top journal publication counts in terms of importance to blue, green, and grey water literature.


**Figure 3.** Word cloud of blue, green, and grey water literature contribution by country.

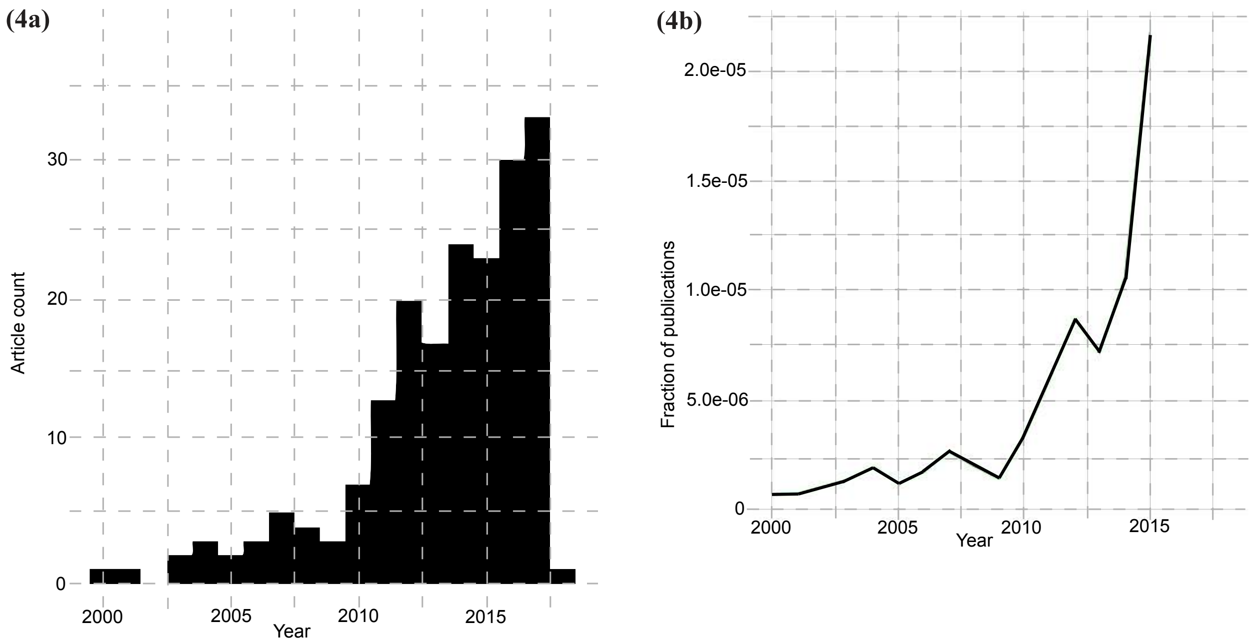


**Figure 4. (a)** Article citation count by year published, and **(b)** relative volume of publications.

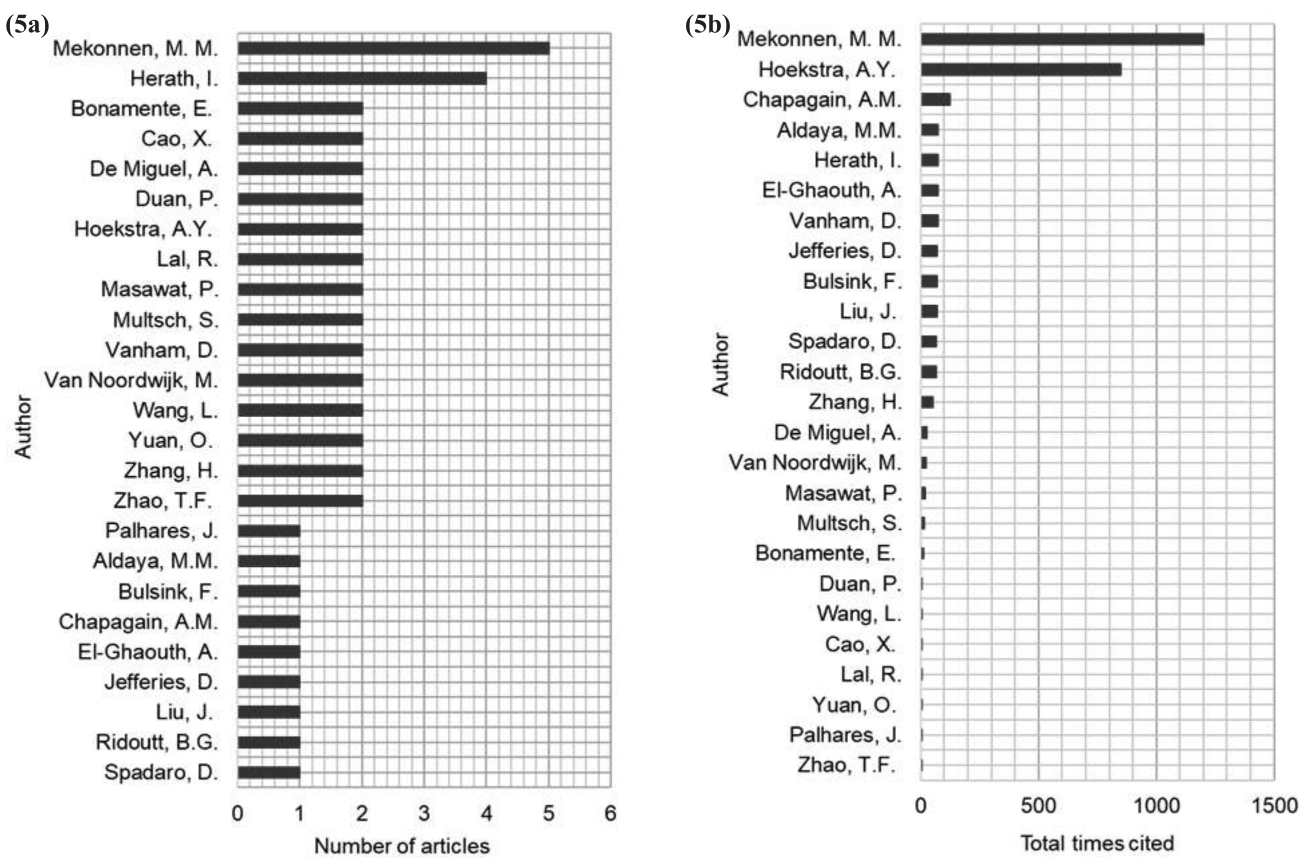


**Figure 5. (a)** Productive authors according to their blue, green, and grey water publication count, and **(b)** most cited authors in the field.

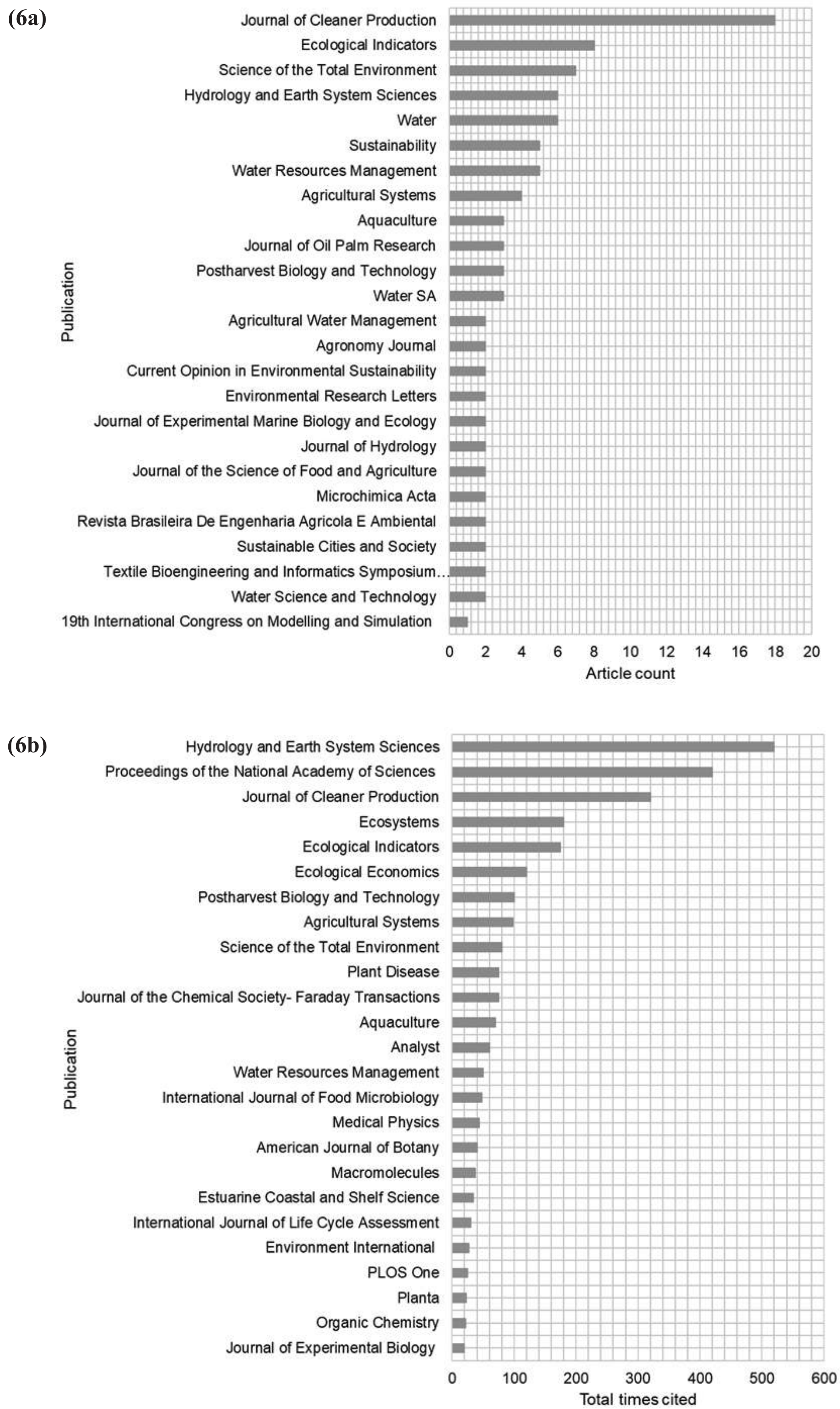


**Figure 6. (a)** Most popular publications by article count, and **(b)** most cited publications in relation to their activity in publishing blue, green, and grey water relevant articles.

### Most Popular and Cited Keywords

Figure 7 provides a list of the most popular and most cited keywords in relation to analyzed blue, green, and grey water literature, sorted by the number of articles where the keyword is mentioned, and by the total number of citations for the keyword (Knutas et al. 2015). "Water footprint" is the most popular keyword associated with blue, green, and grey water for the analysis time frame 2000-2018, followed by "virtual water," "water scarcity," and "sustainability" (Figure 7a). "Water footprint" is also the most cited keyword, followed by "water pollution," "sustainable consumption," and "virtual water trade" (Figure 7b). These keywords provide major insights into the combination of words and "hot topics" that are associated with blue, green, and grey water, and were instrumental in guiding the prioritization of the original 192 Web of Science publications in NAILS to a trimmed list of top 25 publications that were then used for further literature review (Table 1).

### Approaches for Blue, Green, and Grey Water Quantification

Figure 8 highlights the ranking results for the major blue, green, and grey water assessment frameworks associated with the final 25 publications reviewed in this study, as well as the scale of analysis. The summary is for the most important 25 out of the 192 records downloaded from the Web of Science core collection for the 2000-2018 analysis period. The publications are ranked using importance criteria that include in-degree, total citation count, and page rank scores (Knutas et al. 2015).

Among the broad assessment frameworks used to quantify blue, green, and grey water, the WFA methodology is the most popular framework applied, accounting for 16 out of 25, or 64% of the top 25 publications, followed by LCA (24% of the top 25 publications) (Figure 8). The remaining 12% of publications were grouped into a broad category called "Hybrid," which included a combination of WFA and LCA, and other

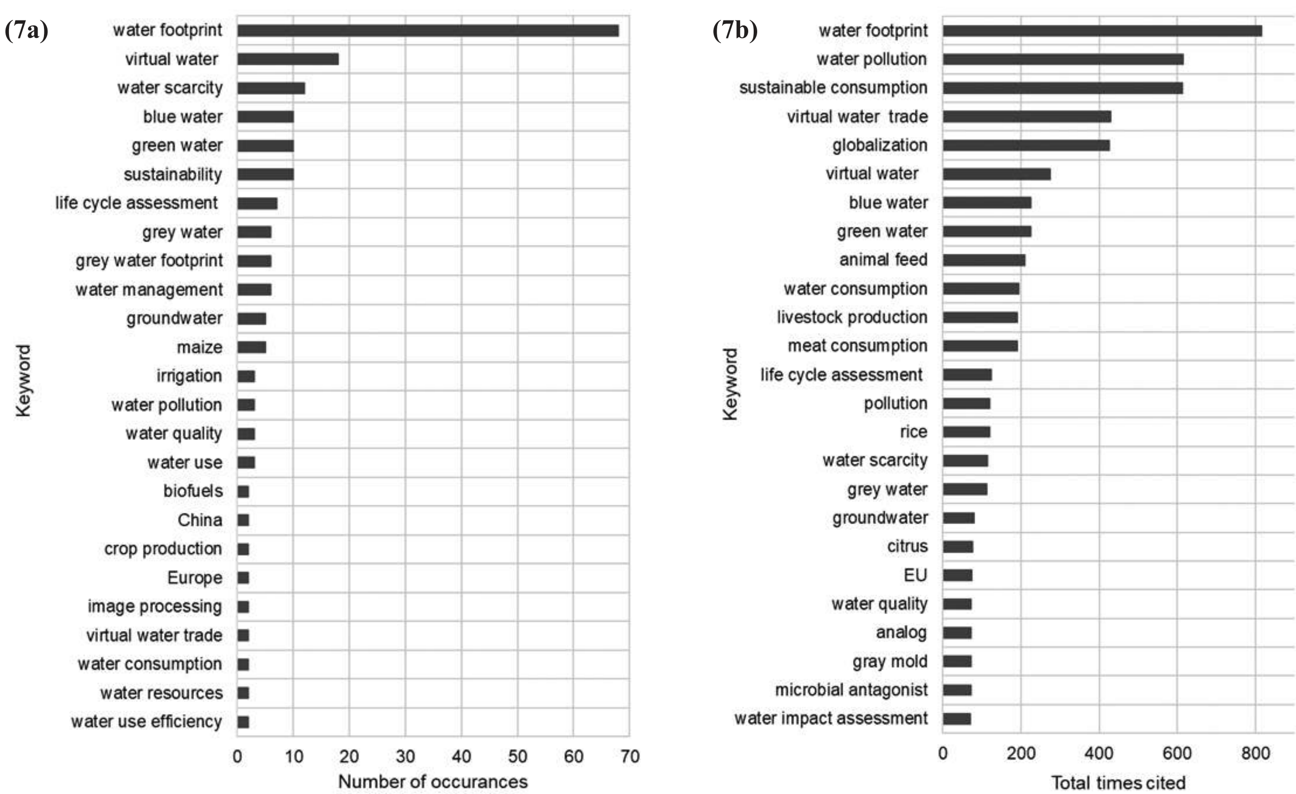


**Figure 7. (a)** Most popular, and **(b)** most cited keywords from the analyzed blue, green, and grey water publications.

**Table 1.** The 25 most important papers included in the 192 records downloaded from the Web of Science ranked using the NAILS toolkit.*

| Rank | Year | Study Region / Country | Scale / Location | Focus: Blue, Green, or Grey Water | Broad Study Approach / Assessment Framework | Specific Techniques Used | Reference |
|---|---|---|---|---|---|---|---|
| 1 | 2011 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | Grid-based dynamic water balance model, CROPWAT model | Mekonnen and Hoekstra (2011) |
| 2 | 2011 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | International trade, spatially explicit domestic production | Chapagain and Hoekstra (2011) |
| 3 | 2010 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | Spatially explicit, production & consumption perspective | Mekonnen and Hoekstra (2010) |
| 4 | 2012 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | International trade, production & consumption perspective, spatially explicit | Hoekstra and Mekonnen (2012) |
| 5 | 2012 | Global | Global | Blue, Grey | Water Footprint Assessment | Production systems, feed composition | Mekonnen and Hoekstra (2012) |
| 6 | 2013 | New Zealand | Local/ Marlborough, Gisborne | Blue, Green, Grey | Life Cycle Assessment | Water balance, hydrological perspective | Herath et al. (2013a) |
| 7 | 2012 | India, Ukraine | Local/ Coonoor, Zaporizhia | Blue, Green | Water Footprint Assessment, Life Cycle Assessment | Water accounting, environmental impact assessment | Jefferies et al. (2012) |
| 8 | 2010 | Italy | Local/ Puglia, Sicily, Emilia-Romagna | Blue, Grey | Water Footprint Assessment | Consumption perspective | Aldaya and Hoekstra (2010) |
| 9 | 2013 | China | Local/ Beijing | Blue, Green, Grey | Water Footprint Assessment | Interannual variability | Sun et al. (2013) |
| 10 | 2013 | European Union | Region/ European Union | Blue, Green, Grey | Water Footprint Assessment | Consumption perspective | Vanham et al. (2013) |
| 11 | 2010 | Australia | Region/ Australia | Blue, Green, Grey | Water Footprint Assessment, Life Cycle Assessment | Consumption perspective | Ridoutt et al. (2010) |
| 12 | 2012 | New Zealand | Local/ Waikato, Canterbury | Blue, Green, Grey | Water Footprint Assessment, Stress-weighted Water Footprint, Life Cycle Assessment | Catchment-specific characterization, sustainable aquifer yield, environmental impact assessment | Zonderland-Thomassen and Ledgard (2012) |

*The 25 most important papers is an analysis of records downloaded from the Web of Science. The analysis identifies the 25 most important authors, journals, and keywords in the dataset based on the number of occurrences and citation counts. A citation network of the provided records is created and used to identify the important papers according to their in-degree, total citation count, and page rank scores according to the procedure described in Knutas et al. (2015).

**Table 1.** The 25 most important papers included in the 192 records downloaded from the Web of Science ranked using the NAILS toolkit.*

| Rank | Year | Study Region / Country | Scale / Location | Focus: Blue, Green, or Grey Water | Broad Study Approach / Assessment Framework | Specific Techniques Used | Reference |
|---|---|---|---|---|---|---|---|
| 13 | 2014 | Italy | Local/Sicily | Green, Grey | Water Footprint Assessment, VIVA methodology | Production perspective, Tier III approach for grey water footprint | Lamastra et al. (2014) |
| 14 | 2015 | Spain | Region/Spain | Blue, Green, Grey | Water Footprint Assessment | Production systems, feed composition | de Miguel et al. (2015) |
| 15 | 2012 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | Production perspective | Gerbens-Leenes and Hoekstra (2012) |
| 16 | 2011 | New Zealand | Region/ New Zealand | Blue, Green, Grey | Water Footprint Assessment, Hydrological water balance method | Production perspective, water balance | Deurer et al. (2011) |
| 17 | 2013 | Romania | Region/ Romaina | Blue, Green, Grey | Life Cycle Assessment | Production chain analysis | Ene et al. (2013) |
| 18 | 2014 | Morocco | Region/ Morocco | Blue, Green, Grey | Water Footprint Assessment | Grid-based, spatially explicit | Schyns and Hoekstra (2014) |
| 19 | 2015 | China | Local/ Beijing | Blue, Green, Grey | Water Footprint Assessment | Logarithmic mean Divisia index (LMDI) decomposition method | Xu et al. (2015) |
| 20 | 2013 | Nepal | Local/ Districts | Blue, Green, Grey | Water Footprint Assessment | Water balance model, nitrate pollution dilution | Shrestha et al. (2013) |
| 21 | 2013 | Netherlands | Local/ Noord-Brabant | Blue, Green, Grey | Life Cycle Assessment | Environmental impact assessment, model irrigation requirements | De Boer et al. (2013) |
| 22 | 2015 | Global | Global | Blue, Green, Grey | Water Footprint Assessment | Production weighted average | Pahlow et al. (2015) |
| 23 | 2013 | New Zealand | Region/New Zealand | Blue, Green, Grey | Water Footprint Assessment, Life Cycle Assessment Hydrological water balance method | Consumption perspective, freshwater ecosystem impact method, freshwater depletion method | Herath et al. (2013b) |
| 24 | 2015 | South Africa | Region/South Africa | Blue, Grey | Water Footprint Assessment | Direct water footprint | Haggard et al. (2015) |
| 25 | 2010 | Indonesia | Region/ Indonesia | Blue, Green, Grey | Water Footprint Assessment | National water-use accounting | Bulsink et al. (2010) |

*The 25 most important papers is an analysis of records downloaded from the Web of Science. The analysis identifies the 25 most important authors, journals, and keywords in the dataset based on the number of occurrences and citation counts. A citation network of the provided records is created and used to identify the important papers according to their in-degree, total citation count, and page rank scores according to the procedure described in Knutas et al. (2015).

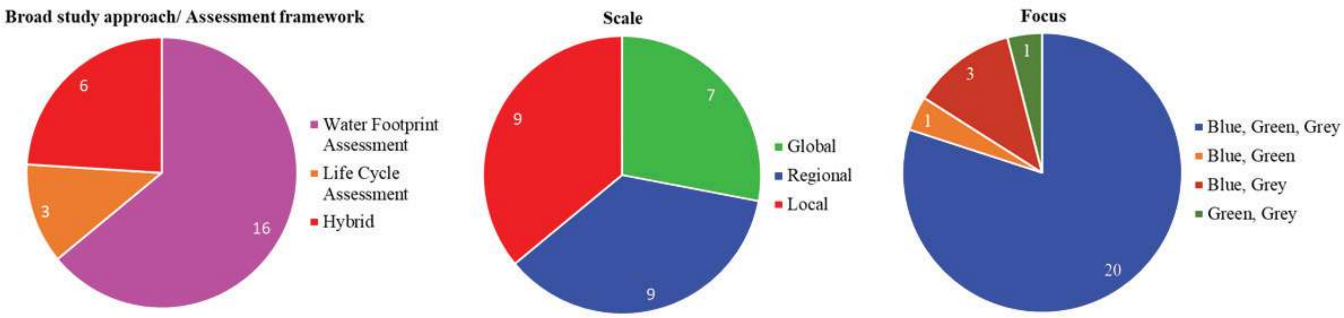


**Figure 8.** Summary of blue, green, and grey water quantification approaches based on the top 25 publications from the Web of Science core collection, 2000-2018.

frameworks such as stress-weighted WFA, the hydrological water balance method, and VIVA methodology (see Table 1).

In terms of spatial scale, 36% of the top 25 publications were conducted at regional level, defined in this study as national boundary or river basin, and a further 36% were at the local level, defined as any spatial scale below the river basin level, such as cities. The remaining 28% were global level studies in scope (Figure 8). This almost evenly distributed spatial scope indicates the applicability of current blue, green, and grey water methodologies across different spatial scales from global to local level.

Figure 8 also reveals that approaches used in 80% of the 25 top studies quantified all of blue, green, and grey water components within the same study, 3 out of 25 (12%) quantified both blue and grey water, and an equal proportion of 4% quantified a combination of blue/green and green/grey water, respectively. These results indicate the importance attached to partitioning blue, green, and grey water components by research communities who use the different assessment frameworks. A possible explanation behind this partitioning is the need to distinguish between the different opportunity costs and environmental impacts associated with each of the blue, green, and grey water components.

## Overview of Specific Blue, Green, and Grey Water Quantification Techniques Used

The outcome of this bibliometric analysis revealed a broad range of specific techniques used to quantify blue, green, and grey water. Examples of such unique techniques include crop water requirement computations using the CROPWAT model (Mekonnen and Hoekstra 2011); use of international trade data to assess virtual water flows (Chapagain and Hoekstra 2011; Hoekstra and Mekonnen 2012); use of spatially explicit grid-based dynamic water balance models (Mekonnen and Hoekstra 2010; Schyns and Hoekstra 2014); environmental impact assessment (Jefferies et al. 2012; Zonderland-Thomassen and Ledgard 2012; De Boer et al. 2013); livestock production systems and feed composition (Mekonnen and Hoekstra 2012; de Miguel et al. 2015); hydrological water balance techniques (Herath et al. 2013a); water footprint assessment from production perspectives (Deurer et al. 2011; Gerbens-Leenes and Hoekstra 2012) and consumption perspectives (Aldaya and Hoekstra 2010; Ridoutt et al. 2010; Vanham et al. 2013); interannual variability assessment (Sun et al. 2013); catchment specific aquifer characterization (Zonderland-Thomassen and Ledgard 2012); tier III approach for grey water footprint assessment (Lamastra et al. 2014); nitrate pollution dilution (Shrestha et al. 2013); index decomposition method (Xu et al. 2015); production weighted average (Pahlow et al. 2015); and national water use accounting (Bulsink et al. 2010).

## Scale and Scope of Commodities and Industries Assessed

Global level studies focused on commodities that ranged from major crops (Mekonnen and Hoekstra 2010, 2011; Chapagain and Hoekstra 2011); animal products (Mekonnen and Hoekstra 2012); energy crops (Gerbens-Leenes and Hoekstra 2012); and aquaculture (Pahlow et al. 2015), to the water footprint of humanity (Hoekstra and Mekonnen 2012). All these studies are associated with the WFA framework (Table 1).

The top ranked regional studies in Table 1 also covered a wide range of commodities and topics, including European diets (Vanham et al. 2013); fresh mango fruit in Australia (Ridoutt et al. 2010); kiwifruit in New Zealand (Deurer et al. 2011); wine production in Romania (Ene et al. 2013) and New Zealand (Herath et al. 2013b); various economic activities in Morocco river basins (Schyns and Hoekstra 2014); mining industry in South Africa (Haggard et al. 2015); and crop products in Indonesia (Bulsink et al. 2010).

Blue, green, and grey water quantification studies at the local level tracked the life cycle grape-wine production in New Zealand locations (Herath et al. 2013a); tea and margarine production in India and Ukraine (Jefferies et al. 2012); pasta and pizza margherita diets in Italian cities (Aldaya and Hoekstra 2010); crop production in Beijing (Sun et al. 2013; Xu et al. 2015); comparison of irrigated and non-irrigated dairy farming in climatically different New Zealand farming regions (Zonderland-Thomassen and Ledgard 2012); water use impacts of wine production in Italy (Lamastra et al. 2014); the pig sector in Spain (de Miguel et al. 2015); production of major primary crops in Nepal districts (Shrestha et al. 2013); and milk production in a Dutch province (De Boer et al. 2013).

The results in Table 1 demonstrate the utility of the NAILS bibliometric toolkit in providing a rapid but detailed analysis of freshwater literature, including the range of commodities and industries that are impacting freshwater resources in terms of blue and green water consumption, and grey water generation. These insights into blue, green, and grey water can improve the understanding of human appropriation of freshwater resources, and guide the implementation of the most appropriate water management measures as water consuming economic activities increase.

## Conclusion

This bibliometric and literature review study provided an overview of current approaches that have been used to quantify blue, green, and grey water for the period 2000-2018. The scales of assessment are evenly distributed between global level focused studies, intermediate national and river basin levels, and the microscale level, focused approaches used to assess urban areas, individual economic sectors, and dietary styles. The spatial scope and diversity of commodities and industries assessed varies widely, indicating that blue, green, and grey water quantification approaches are still evolving. The study found that the WFA methodology is the most influential approach that has been applied in recent studies to quantify blue, green, and grey water. This study also highlighted the close association between blue, green, grey, virtual water, and water footprint assessments. It is therefore clear that most virtual water and water footprint assessment frameworks also quantify blue, green, and grey water. The results also show that there is an array of rapidly evolving approaches that can be broadly categorized into WFA, LCA, and other Hybrid approaches that include a mix of other major approaches that are standalone research areas. Each major approach tends to employ one or more specific analysis techniques, such as the more spatially and temporally explicit water accounting methods. The United States and China were found to be the leading contributors of blue, green, and grey water publications. Global distribution of publications highlighted the obvious worldwide importance of blue, green, and grey water issues. The growing body of knowledge on blue, green, and grey water issues was demonstrated by the exponential increase of publications during the studied period, particularly from the year 2009 onwards. The Water Footprint Network is one of the most important hubs in blue, green, and grey water assessments, contributing the greatest number of most cited and most productive authors. The most prominent journals in terms of importance to blue, green, and grey water literature were the *Journal of Cleaner Production* and *Ecological Indicators*, while "water footprint" and "virtual water" were unsurprisingly the most popular and cited keywords associated with blue, green, and grey water. The bibliometric indicators in this study have been calculated using only research papers extracted from the Web of Science database. Although this is a major research database, it should be noted that there are other often most cited papers that were not accessible through the NAILS-Web of Science toolkit coupling that was used. Nevertheless, the use of a rapid bibliometric analysis toolkit still provided important insights to help better understand the diversity of techniques that have been applied in blue, green, and grey water quantification approaches in recent years.

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