

Cracow , 22 October 2020

Dr hab inż. Paweł Ocloń, prof. CUT  
Cracow University of Technology  
Faculty of Enviromental and Energy Engineering  
Department of Energy  
Faculty of Energy and Enviromental Engineering,  
Al. Jana Pawła II, 31-864 Cracow, Poland

**The review of Doctoral Thesis**  
**entitled: *EXTENDED METHODOLOGY FOR WATER***  
***RESOURCES AND WATER-RELATED ENERGY ASSESSMENT ADDRESSING WATER***  
***QUALITY***  
***Authored by: Xuexiu JIA***

### **1. Thesis description**

The PhD Thesis consists of six Chapters, In Chapter 1 the scope of the thesis is presented with the research gaps as well as research aims and objectives. The dissertation aims to expand and refine the development of methodology and benchmark of consumption and impact on water consumption in terms of quantity and quality. Water-related energy use and emissions are also discussed as a continuation of water resource assessment. Water scarcity and quality degradation issues. The purpose of the research is

- a) facilitate the improvement of water use efficiency and reduce the impact on water consumption.
- b) a brief summary of recently reported water issues and a thorough literature review on the subject

The following research gaps are identified:

- a) Existing methods for assessing water resources mainly focus on volumetric measurement consumption. The impact of water consumption on water quality deserves more research, as water pollution becomes an important contributor to water scarcity.
- b) Decision tools are urgently needed for regional water management to deal with water scarcity. The final rating is only capable of delivering running water, water scarcity level, but in practice not able to target regional optimization of water use.
- c) Energy consumption and water related emissions should be determined to facilitate making decisions in the field of regional water resources management.

Extended Water Quality Resource Assessment Methods using the Water Footprint and Water Pinch Analysis is proposed and used in case studies both on a micro and macro scale.

The thesis consists of the following parts:

- a) Extended water footprint assessment methods to determine the water quality degradation impact of water use

b) Water Scarcity Pinch Analysis to minimise regional water scarcity and provide supporting information to decision making in regional water resource management.

c) An initial determination of the energy use and emissions in seawater desalination plants

In the Chapter 2 a literature review is carried out including Water resources assessments. Water resources assessments methods are compared including: Surface Water Supply Index, Water Stress Index, Water Resource Vulnerability Index, Critically ratio, Water Poverty Index, Water Exploitation Index, Water Stress Index, Grey Water footprint, Water Scarcity Index, Quantity Quality water Scarcity indicator. The definition, Indication and Remarks of the water resources assessment methods are listed in Table 2.1 Water Footprint Assessment is discussed in section 2.2. Table 2.2. provides a comparison of water resource assessment and design tools including: Water Footprint (WFP), Life Cycle Costing (LCC) and Water Pinch Analysis (WPA). Water Pinch Analysis is presented in section 2.3, and the Water-Energy Nexus is discussed in section 2.4.

In the Chapter 3 the extended water footprint assessment methods is presented. Section 3.1 proposed an extended approach to Water Availability Footprint (WAF) to quantify water availability. Based on the analysis of WF assessment methods, water quality is integrated into the assessment. Effective Water Availability (EWA) has been defined as the quantitative and qualitative extent of a certain body of water which meets the needs of a certain purpose of water use, and a WAF is proposed to determine the human water exploitation of water availability of water quality and quantity. A Water Quality Index (WQI) is proposed to quantify the contribution of water quality on EWA. The extension to water footprinting approaches is developed and implemented with a case study. Three outflows are set to present the impact of different water quality pattern on the result of WAF. The results showed that for the WAF calculated based on minimum WQI, systems with more average outflows have the lower WAF. The distribution of pollution levels has an impact on the water availability besides the actual pollutant concentration. Considering the WAF calculated based on average WQI, it indicated that the overall WQI is the only factor for WAF. The case study shows that the WAF calculated based on the concepts of minimum WQI, average WQI, and the blue WF is 1,600 m<sup>3</sup>, 1,277 m<sup>3</sup>, and 1,000 m<sup>3</sup>. The author noticed that the volumetric footprint is much less than the water footprints considering water quality, which may lead to misleading suggestions. The WAF considers water quality can reveal many issues neglected by the only-volumetric calculation of blue water footprint. The radar chart (Figure 3-4) of the WAF of multiple contaminants is effective to demonstrate the distribution of the pollutants, and provides more specific information for water users or managers in order to minimize the water use or improving water quality control.

Section 3.2 presents a Quantitative-Qualitative Water Footprint (QQWFP) which is developed to evaluate the negative impact of water use based on costs. The QQWFP is defined as the total cost of quantitative water consumption plus the cost of removing the contaminants generated during the water-using process. The QQWFP consists of two sub-indicators, Quantitative Water Footprint (WFqt) and Qualitative Water Footprint (WFql). This section considers the Monosodium Glutamate (MSG) plant to illustrate and validate the QQWFP method. The results showed that the WFql of producing 1 t MSG is 299.8 €, taking more than 99 % of the total QQWFP. The WFqt of

producing 1 t MSG is only 2.3 €, with a proportion of less than 1 % of the total QQWFP. MSG extraction and refining process are the two major critical process, with a QQWFP of 254.8 €/ t MSG (84 %) and 33.1 €/ t MSG (11 %).

Chapter 4 presents the Water Scarcity Pinch Analysis (WSPA) method and its implementations. Three case studies are presented outlining various supply minus demand, demand to supply ratio, water scarcity and minimal water scarcity. The case studies are carried out for various water supply profile and water demand profile. The calculations showed that the proposed WSPA identifies the water scarcity in terms of water quality together with quantity, and provides guidance information for regional water scarcity minimisation. In Case 1 and 2, WSPA identifies the water quality caused scarcity, which is overlooked by the conventional ratio-based. Case 3 showed that the WSPA covers both water quality and quantity scarcity, and results in minimal water scarcity. Water quality cascade can reduce water scarcity, and water quality upgrading by water dilution can minimise (in Case 1 and 3) and even eliminate the regional water scarcity (in Case 2). The overall results indicate that the proposed method has a high potential for water scarcity minimization in regional water resources management.

The novel contributions of this chapter includes:

- a) Account water quality together with quantity in water scarcity assessment
- b) Applying water quality categorisation in the WSPA is a critical improvement of the conventional WPA
- c) Applying the graphical Pinch Analysis to a macro level, which is more direct and evident than the conventional ratio-based methods
- d) Water Scarcity Pinch Analysis (WSPA) provides implications for water scarcity minimisation through maximising water use efficiency

Chapter 5 shows the initial determination of the national wide water-related energy consumption as well as its emissions in seawater desalination plants. The study presented in Chapter 5 investigated the energy consumption, GHG emission of the seawater desalination in China from 2006 to 2016, and the unit product cost in 2016. The key findings and conclusions are:

- a) The increased installed capacity of seawater desalination in years 2006 – 2016 caused the grow in the energy consumption from 81 MWh/y to 1,561 MWh/y. A corresponding GHG emission increase rate of 180% is observed. Tianjin has the largest GHG emissions, followed by Hebei and Shandong, with emissions of 4.1 Mt CO<sub>2</sub>eq/y, 2.2 Mt CO<sub>2</sub>eq/y, and 1.0 Mt CO<sub>2</sub>eq/y.
- b) The unit product cost (UPC) of seawater desalination is higher than other water supply alternatives, and it differentiates the desalination processes.
- c) Seawater desalination is now being highly promoted and implemented in China and is becoming a critical water supply alternative for cities with serious water scarcity. The cost, energy demand and GHG emissions are still considerably higher than surface water supply. There exists potential for energy consumption, GHG emission and cost reduction with the application of energy recovery units, the integration of desalination plants and renewable energies or low potential heat, as well as the development of new technologies.

The conclusions, novel contribution as well as future developments are provided in the Chapter 6.

## 2. Remarks and comments

The following remarks and comments to the author are provided:

1. What is a unit of  $F_1$ ,  $F_{2-1}$ ,  $F_{2-2}$  and  $F_{3-3}$  in Figure 3-4? The unit should be provided in the figure.
2. What means subscript  $q-q$  in Eq. 3-12?
3. In Figure 3-8 through which index  $i$  or  $j$  the summation occurs?
4. Please explain in more detail case studies 1, 2 and 3 in Section 4. Why those cases are considered and what are the major differences?
5. In Eq. (5-1) the summation indices should be provided for example  $\sum_{i=1}^n$
6. What are the values of  $EM_e$ ,  $EM_{in}$  and  $EM_{waste}$  used in Eq. (5-2)
7. Please explain in more detail how the Figure 5-9 is developed.
8. In y axis of Figure 5-1 there should be  $10^6$
9. Please explain how the results on Figures 4-1 and 4-12 are obtained?

## 3. Overall assessment

The major contribution of this PhD Thesis are:

- a) Quantifying the impact of water quality degradation into the existing water scarcity assessment frameworks
- b) Development of the Quantitative Qualitative Water Footprint (QQWFP) which uses the total cost of water consumption and cost of treating the contaminant generated during the water use process to determine the quality and quantity impact of water use. The method can also coverage multiple contaminants by accounting the total cost of treating different contaminants.
- c) initial assessment of the water-related energy consumption and GHG emissions in the seawater desalination plants in China during 2006-2016

A developed Quantitative Qualitative Water Footprint (QQWFP) method is a new tool that can be widely applied in Environmental Engineering. The QQWFP method, which uses cost as the quantification, can be easily applied by both water users (individual, industrial and regional) and water managers (e.g. the government organizations). The results can guide the users on adjust water use strategies (for example to reduce the water contaminants generation).

The objective of the Dissertation are fully achieved, and the thesis is written in a good English. What is also worth to be mention: the PhD student has very good publication achievements including the papers published in reputed journals such as:

- 1) Journal of Cleaner Production
- 2) Renewable and Sustainable Energy Reviews
- 3) Energies
- 4) Resources, Conservation and Recycling

5) Energy & Environment

6) Chemical Engineering Transactions,

7) Journal of Sustainable Development of Energy, Water and Environment Systems

Based on the discussed contribution I am fully convinced that the evaluated Dissertation is a valuable and novel contribution and I suggest awarding this PhD Thesis.

