Imperial College London

ASSESSING THE IMPORTANCE OF WATER FOOTPRINT INDICATORS IN CLASSIFYING CITIES USING SELF-ORGANISING MAPS

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1. INTRODUCTION

Increasing urban settlement and growing water consumption urged emphasis to be placed on better managing the water resources. The water footprint, as a consumption-based indicator of water use, has become popular in measuring water sustainability in recent decades. This project assessed the importance of water footprint indicators amongst other common urban indicators in cities clustering based on data collected form 65 major U.S. cities. Self-organising maps are employed to depict the cities' similarities in a multidimensional space.

2. WATER FOOTPRINT AS WATER USE INDICATOR

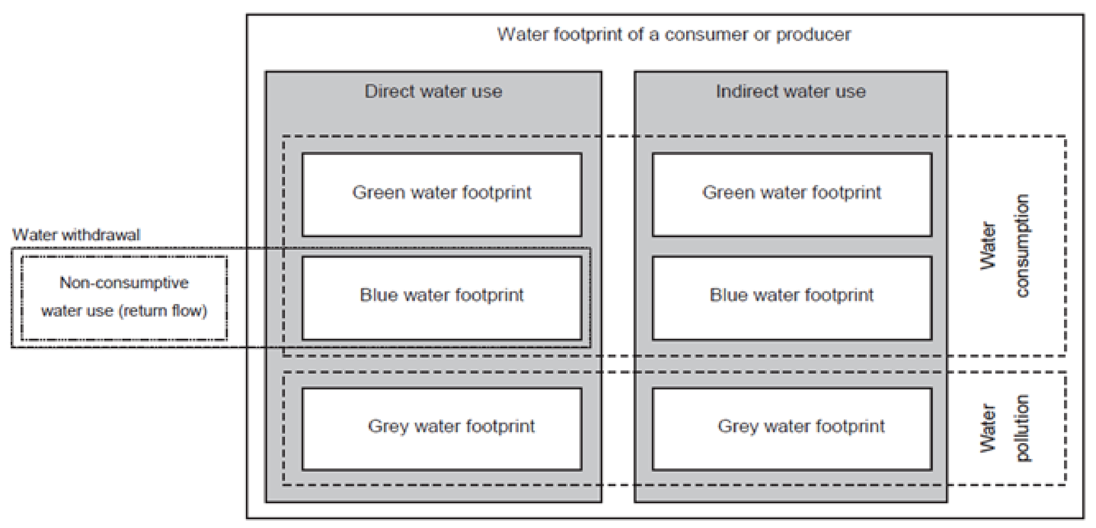

Figure 1: Schematic representation of the WF components

Water footprint (WF) measures human's appropriation of freshwater resources, typically in terms of volume of water consumed or polluted per unit time. It accounts for both **direct** (domestic water use) and **indirect** (water required to produce industrial and agricultural products) water use (Fig. 1). Compared with traditional water use indicators, it can provide additional information which links human consumption to the place and time of production, taking into account *all the water used at different stages along the whole supply chain*.

3. SELF-ORGANISING MAP (SOM)

SOM models are 2D rectangular or hexagonal grids, which map data patterns from the input space onto an output space, comprised of an n-dimensional grid of neurons or units. Topological relationships are preserved; patterns in the input space that are close together will be mapped to neighbouring units in the output space, vice versa (Fig. 2). The method employed in this analysis is adapted from that primarily developed by Kohonen (2001), performed with the R modelling platform which emphasises on results visualisation.

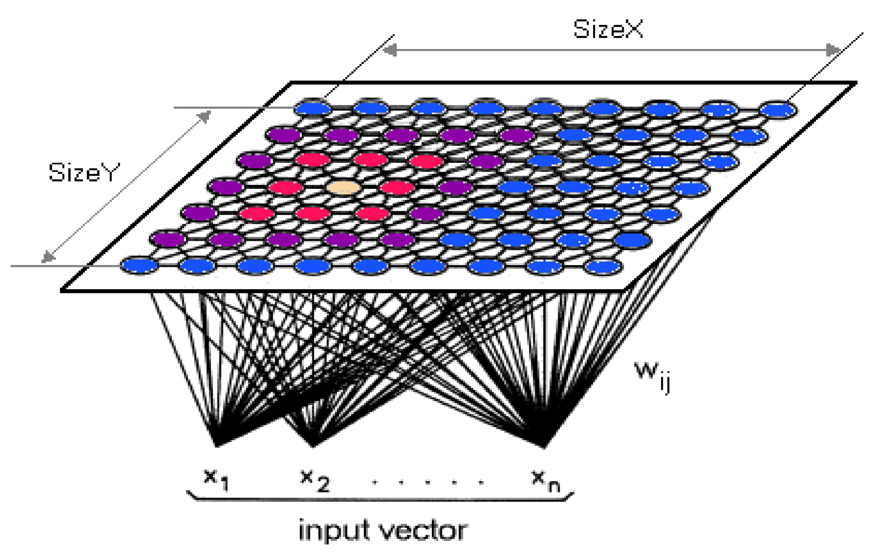

Figure 2: Illustration of the training of a Self-Organising Map

4. DATA SET AND METHODOLOGY

Non WF Indicators	WF Indicators
Area	Total Agricultural WF of Consumption
Population	Total Agricultural WF of Production
Total Consumptive Commercial Water Use	Total Industrial WF of Consumption
Total Consumptive Domestic Water Use	Total Industrial WF of Production

Table 1: Indicators used for city clustering

In total eight indicators are assessed (Table 1). To identify the influence of WF indicators in grouping cities, three main classification case studies are used as base analysis:

- Case I: Non-WF Indicators Only
- Case II: WF Indicators Only
- Case III: All Indicators

Further testing are carried out by adopting different indicators combinations in order to assess the sensitivity of cities classified under the same cluster group.

Literature Review → Data Processing → SOM Training → Clustering with Different Indicator Combinations → Identifying Similarities in Cluster Categories → Ranking Analysis and Geographical Mapping

5. RESULTS AND CONCLUSIONS

Six major clusters are identified for Cases I, II and III (Fig. 3(a)-(c)). Results from base cases and further testing of indicator combinations show that cities are classified mainly by WF indicators.

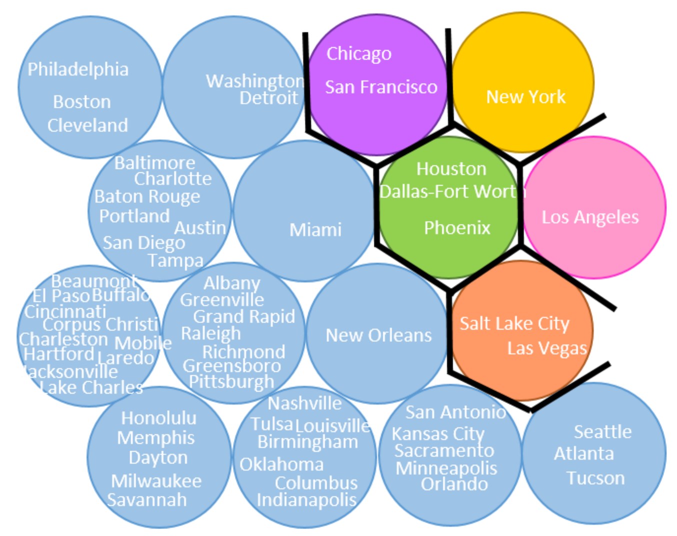

Figure 3(a): SOM Training Result for Case I

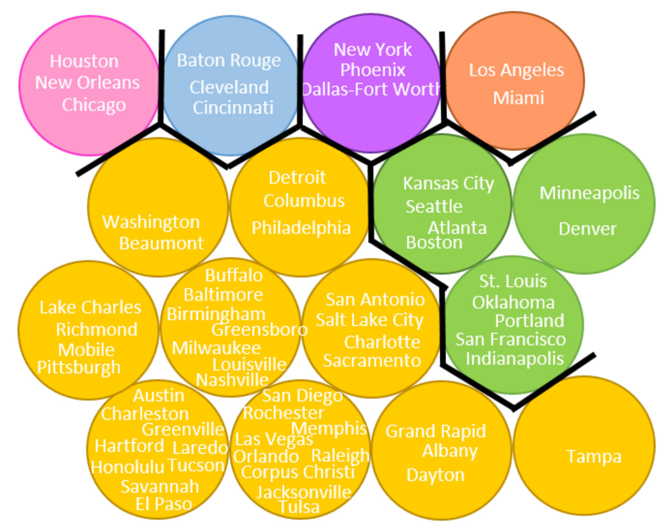

Figure 3(b): SOM Training Result for Case II

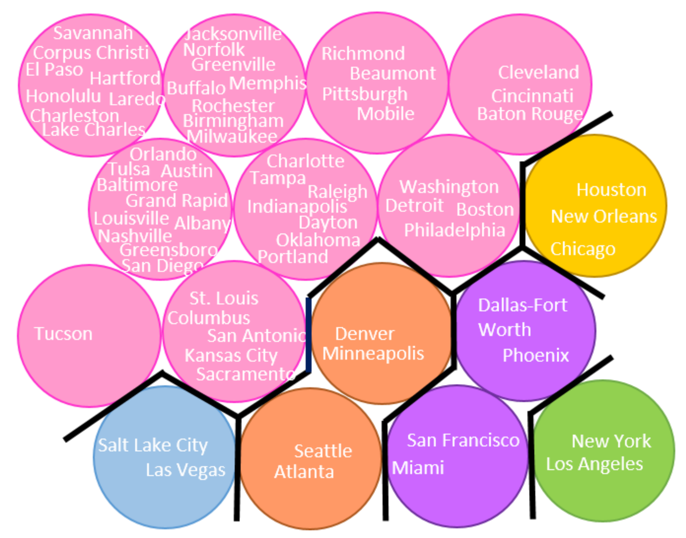

Figure 3(c): SOM Training Results for Case III

CITIES RE-GROUPING

Based on the characteristics of each clusters, the cities are re-grouped into five new categories (Fig. 4).

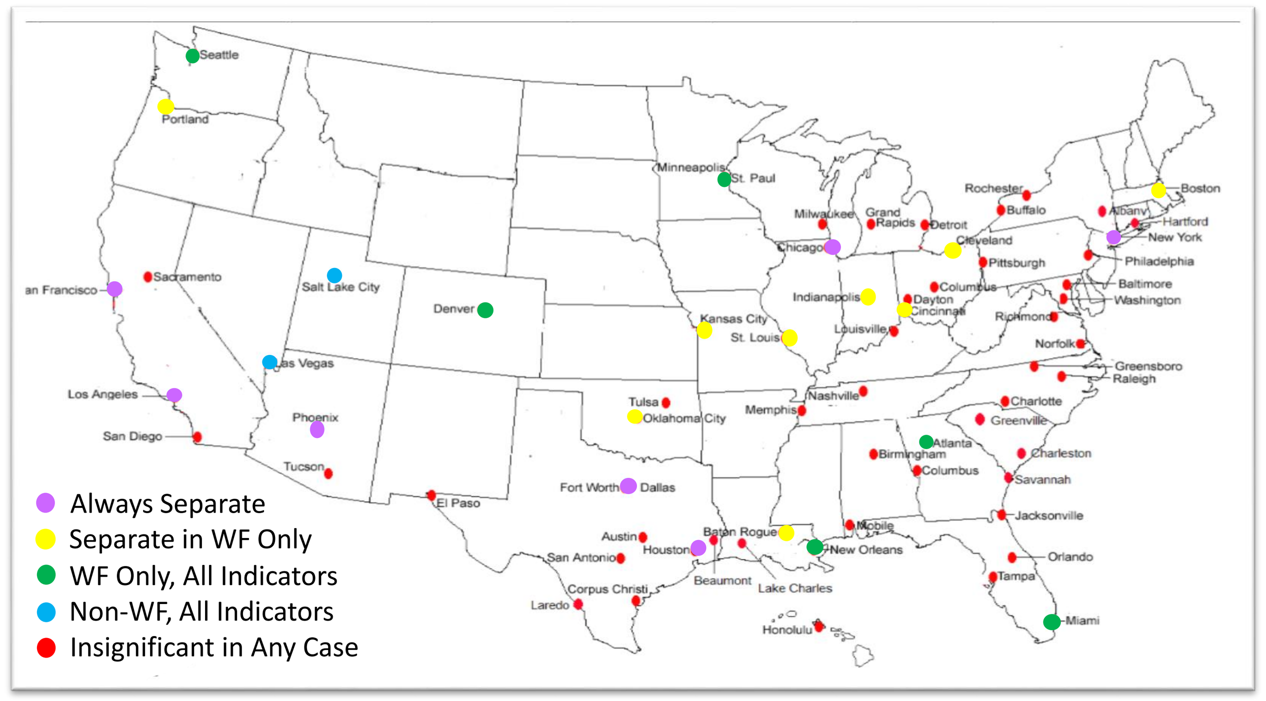

Figure 4: Re-grouping of cities based on clusters characteristics

Ranking the cities by each indicator show that *WF indicators have greater influence than direct water use indicators*, with the following properties:

Agricultural WF > Industrial WF

WF of Consumption > WF of Production

Further geographical mappings suggested that these patterns might be influenced by U.S. spatial **rainfall data**, **land use** and **population density**.

In addition, mapping of the five categories show that they greatly overlap with the 11 U.S. megaregions (Fig. 5) which are defined by:

- Environmental Systems
- Infrastructure Systems
- Settlement Patterns and Land Use
- Economic Linkage
- Shared Culture and History

WF dominated cities mainly lie in agricultural /industrial-oriented regions, whereas the rest fall into service-oriented area, mostly with small overall WF.

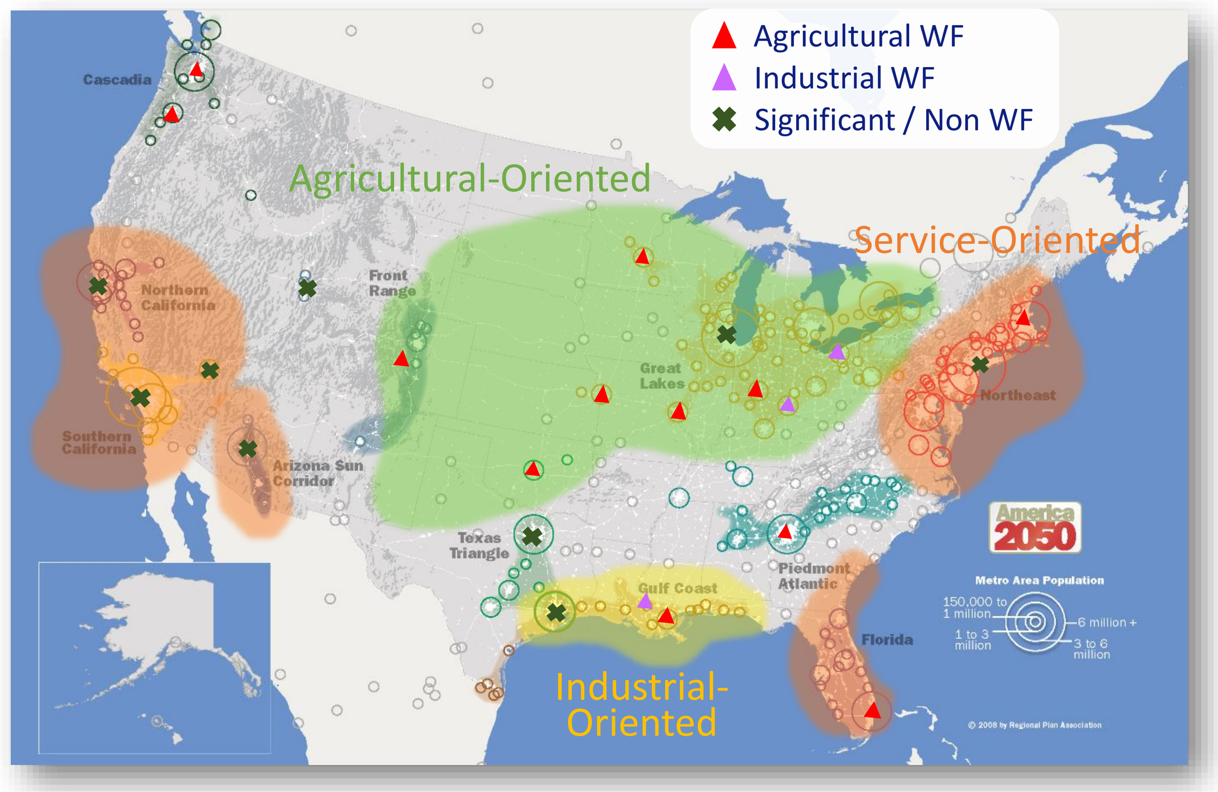

Figure 5: 11 U.S. megaregions proposed by Regional Plan Association (2016)

It is thus believed that:

Economic functions of cities determine their water use, i.e. individual WF behavior → WF indicators could provide reasonable indications to a nation's different regional functions and form the basis of policy decisions

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Regional Plan Association (2016). Megaregions. Available at: http://www.america2050.org/content/megaregions.html#more