Modeling Household Water Consumption in a Hydro-Institutional System – The Case of Amman, Jordan

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A transition to more sustainable water consumption patterns will likely require Jordan's water authorities to rely more strongly on water demand management in the future. We have developed an agent-based model of household water consumption in Jordan's capital Amman, in order to analyze the distribution of burdens imposed by demand-side policies across society. Amman's households face highly intermittent piped water supply, leading them to supplement it with water from storage tanks and private water tankers. We find that integrating these different supply sources into our model causes demand side policies to create winners and losers. This highlights the importance of a disaggregated perspective on water policy impacts, in order to identify and potentially mitigate excessive burdens.

Background:

Jordan faces an archetypal combination of increasingly high water scarcity, with a per capita water availability of around 150 CM per year significantly below the absolute scarcity threshold of 500 CM, and strong population growth, especially due to the Syrian refugee crisis (MWI, 2009; UNDP, 2006; MPIC and UN, 2013). This poses a severe challenge to the already strained institutions in the Jordanian water sector. Since the currently predominant supply enhancement solutions often rely on unsustainable abstraction rates (MWI, 2009), a transition to long-term sustainable consumption patterns will likely require them to be complemented with demand-side policies, such as water tariff increases. Most current tariffs do not fully cover capital costs and operation and maintenance costs, requiring subsidies of about 0.4 percent of Jordan's GDP across the whole water sector (Humpal et al., 2012). In these cases, the significant environmental costs are not covered at all.

However, while adequate pricing can improve the long-term sustainability and welfare contribution of the water sector, these efficiency effects are not immediately visible. In contrast, the often unequal distribution of the costs imposed by demand-side measures across society is much more tangible, potentially creating problems of equity and political feasibility. One solution to this is to estimate the costs which different policy options impose on different groups in society, in order to avoid or mitigate excessive burdens by adjusting policy choices or using countermeasures, such as lump sum payments.

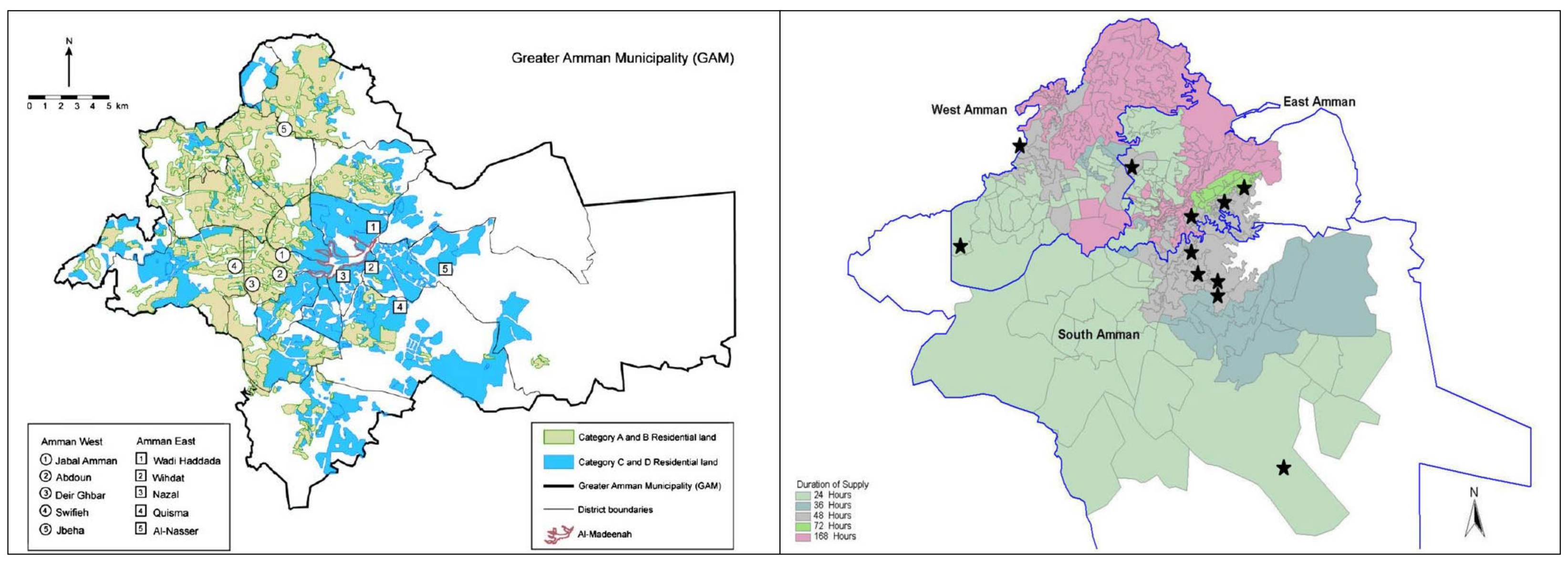

Figure 1: Greater Amman maps analyzed for model parameterization. Left: Residential land areas used to determine two different income classes in Potter and Darmame (2010). Right: Map of piped water supply durations (hours per week) from Gerlach and Franceys (2009).

We aim to assess the distribution of the impacts of various policy interventions across society in a case study of household water consumption in Amman. Piped water supply in Amman is characterized by a high degree of intermittency. This leads different households in Amman to adopt a variety of coping strategies, such as investing in in-house storage tanks or buying additional water from licensed or illegal private tanker operators. Thus, a comprehensive analysis of policy impacts needs to integrate various modes of supply. This especially entails a need to estimate the spatial distribution of tanker water consumption, for which data is sparse.

Methodology:

We have developed an agent-based model (ABM) that simulates water consumption by households of five districts and two income classes in Amman. The model is part of the Belmont Forum project "Integrated Analysis of Freshwater Resources Sustainability in Jordan", analyzing long-term policies for water sector sustainability by creating integrated agent-based and hydrological model of Jordan.

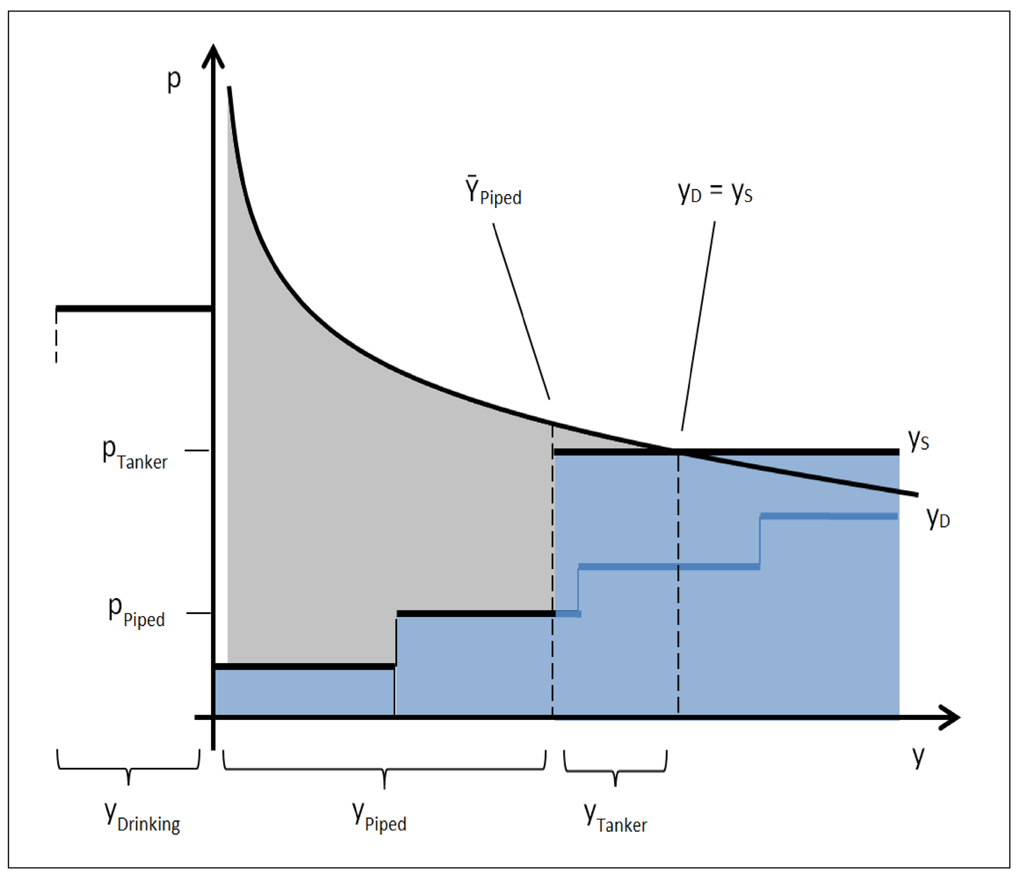

Figure 2: Illustration of the *tiered supply curve* model for one household buying a constrained quantity of piped water charged according to an increasing block tariff and private tanker water sold at a constant price, based on Srinivasan et al. (2010) (p = price, y = water quantity, D = demand, S = supply, $\bar{Y}$ = maximum individual piped water availability). Consumer surplus is marked in gray. Bottled water purchases are assumed to be constant.

In order to integrate the various supply modes into our ABM, we build upon a tiered supply-curve approach, developed by Srinivasan et al. (2010) for a similar case study in Chennai. This approach allows us to integrate household water originating from piped supply and water tankers, individual storage constraints, and system-wide piped water quantity constraints (see Figure 2). Data on the weekly piped water supply durations and the distribution of income classes across districts is derived via image analyses of published maps (see Figure 1). The model employs demand functions from the Jordanian household demand estimation literature (Salman et al., 2008).

Agents of the different districts and income classes compete for piped water, based on their weekly access to the piped water system and their storage capacities. Potentially remaining demands can be satisfied with more expensive tanker water supply. Policy burdens are evaluated based on the consumer surplus changes under different policy interventions, compared to a baseline scenario.

Results:

Testing the model in sensitivity analyses, the tiered supply curve approach leads to the expected quantity reductions in piped and tanker water consumption for increases in the respective prices. Also, the model is able to replicate an average tanker water consumption value of 0.05571 CM/Hh./day derived from Potter and Darmame (2010) quite closely, being only 3.8 % too high in the baseline scenario.

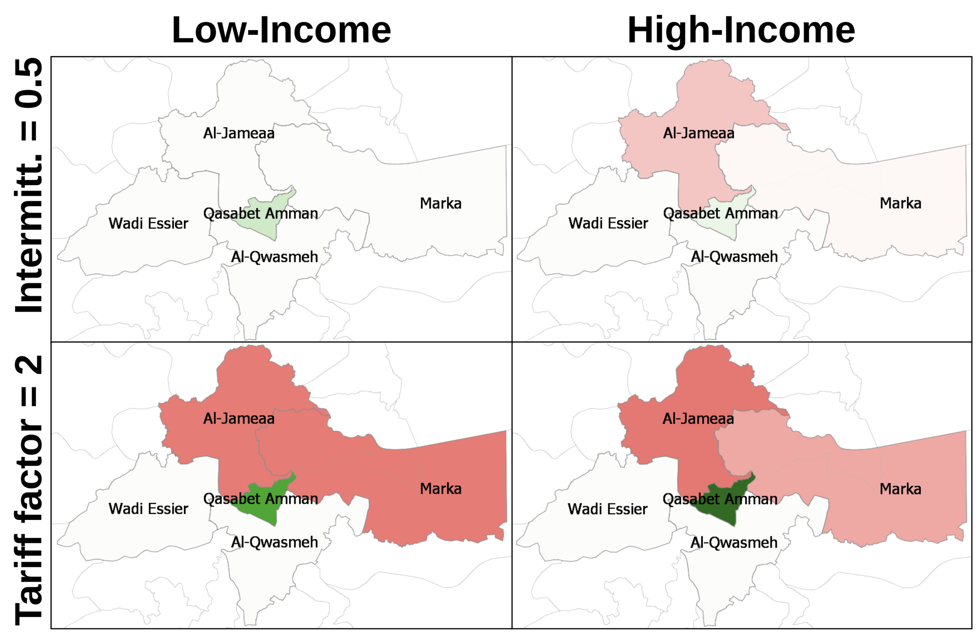

Figure 3: Consumer surplus deviations from the baseline due to changes in piped water and intermittency factors. Green = gain; red = loss; darker colors indicate higher values.

Regarding the analysis of demand-side policy impacts, the most striking consequence of our incorporation of the different weekly supply durations and coping strategies is that any proportional change across the whole tariff structure tested creates winners and losers among the different districts and income groups (see Figure 3). This can be explained by the fact that households relying on tanker water can benefit from price induced piped water demand reductions among those households, who do not face a binding piped water constraint.

Other notable results are that even seemingly unambiguous policy interventions, such as a reduction in system intermittency can have mixed impacts on different household groups. Furthermore, for most households, the storage constraint didn't become binding across the scenarios analyzed. In contrast, the total piped water constraint is always binding for some agents. This indicates a situation, where piped water pressure is reduced in parts of the system, preventing some agents from filling their storages to the degree they would prefer.

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