Satellite Precipitation Metrics to Study the Energy-Water-Food Nexus within the Backdrop of an Urbanized Globe

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On emerging efforts to link satellite based precipitation data and other NASA data to support the Energy-Water-Food-Network nexus related to urban transitions and interconnections to agriculture.

Introduction

For the first time in history, the majority of the planet’s population lives in urban spaces and by 2025; this number could be greater than 65 percent. Such spaces are increasingly interconnected and actors within the climate system (Shepherd et al. 2013). The NASA Precipitation Measurement Mission program (PMM) has funded a coordinated research effort over the past decade to explore connections between urbanization and precipitation. This work has led to landmark discoveries and understanding related to the urban hydroclimate, flooding, and landcover-microphysical underpinnings of precipitation (Shepherd 2013, Jin and Su 2015, Walsh et al. 2014). The maturity of that work has now enabled a line of research addressing one of the most complex and societally-relevant challenges...
of our time: the Energy-Water-Food Nexus.

In a 2011 Global Risk report, the World Economic Forum (WEF) explicitly stated that natural resources were among the top three global risk clusters facing society. The report stated clearly that "Food production requires water and energy; water extraction and distribution requires energy; and energy production requires water. Food prices are highly sensitive to the cost of energy inputs through fertilizers, irrigation, transport and processing (Figure 1)."

The economy of this risk is manifested by the following numbers in the report: global projections for a 50 percent increase in food demand, 30 percent increase in water demand, and 40 percent increase in energy demand by 2030. Such demands are, in part, driven by urbanization and population increases.

Villamayor-Tomas et al. (2015) note that many frameworks have been used to study the Energy-Water-Food-Network (EWFN), however, there has been very little attention to the hydroclimate implications and interactions. Much of the attention has focused on greenhouse gas emissions, land use, resource management efficiency or societal facets. The complicated interconnections of Energy-Water-Food systems have emerged as critical areas of research. We approach EWFN from the perspective of NASA's Precipitation Measurement Mission (PMM).

Our motivation is to describe emerging efforts to link satellite based precipitation data and other NASA data to support the EWFN nexus related to urban transitions and interconnections to agriculture. As a part of our broader research portfolio, satellite-based precipitation estimates are being exploited to develop scientifically rigorous but stakeholder accessible metrics. The basic questions guiding the research are: Can precipitation per urban capita or per individual be quantified using PMM datasets? If so, can spatio-temporal trends in the metric be useful in the assessment of the EWFN capacities and vulnerabilities?

It is important to caveat that the focus on this emerging thread of research is the urban catchment scale. Most major urban areas have catchment basins that extend well beyond the city itself. Further, groundwater sources can augment water supply in an urban environment and broaden the catchment region as well. While the work herein focuses on precipitation contributions, it is not our intent to assume it is the only contributor to urban water supply budgets. Although Mitchell et al. (2003) did find that mean annual rainfall was three times greater than potable water for Canberra, Australia, a daily model was used to quantify the components of the total urban water balance of the Curtin catchment. They concluded that variations in climate (rainfall) were significant factors in the water balance components of an urban catchment. Precipitation is also vital to groundwater recharge, and the literature suggests that urbanization can actually increase recharge rates through the combination of precipitation, storm drainage, and infrastructure leakage (Lerner, 2002).

Metrics for Precipitation within the EWFN framework

The World Bank maintains a database of key indicators for countries related to agriculture, climate, and energy. Some of these indicators include: Cereal yield (kg per hectare), CO2 Emission, Electric Power Consumption, Improved Water Source, Urban (percent of urban population with access), Agricultural irrigated land (percent of total agricultural land), and so on. Many of the indicators are very much linked to the hydrologic cycle, particularly precipitation. A key goal is to utilize the now globally available, accurate precipitation data from the PMM program to index precipitation in a per capita, population, or areal basis.

The majority of the world’s population is now urban-bound. There is a certain budget of rainfall that falls on any given area or within accessibility of population centers. The implication of urban rainfall budgets takes on different character depending on the geographic perspective.

Two examples from different regimes illustrate such difference. In the United States, the city limits of Atlanta receives 106 billion gallons of water (via rainfall) in an average year. If the per capita water use is 40,150 gallons per year, it is clear that a large percentage of the population could be sustained by this stored rainfall (assuming no evaporation loss). Residents of urban centers in less-developed countries, which are often densely-packeded (e.g., India) have
limited access to potable water (Stout et al. 2015). In these cities, urban rainwater harvesting (RWH) and other concepts may be required.

Stout et al. (2015) illustrated that RWH for the purpose of providing irrigation to a small garden and allowing overflow to a drywell for groundwater recharge was concluded to be an approach to maximize benefits. They found that roughly 35 gallons of water per person were required in major cities like Dehli, Kolkata, or Bangalore and that RWH could provide roughly 20 percent of the indoor water demand. Capturing rainwater to provide three ecosystem services (water supplementation for indoor use, water supplementation for food production and groundwater recharge) also significantly reduced water bills (Figure 2). One goal of the research is to provide meaningful per year, per capita or per day metrics for different urban areas to truly understand needs of global cities.

So how are Atlanta, Georgia, and Indian cities like Dehli relevant in the narrative? In the United States, there are sufficient rain gauge or radar networks to provide precipitation data to conduct proper accounting of rainfall budgets. Stout et al. (2015) noted that fine scale precipitation data was virtually non-existent or inaccessible in India. Without satellite based estimates from the Tropical Rainfall Measuring Mission (TRMM), estimates of per capita or per household water availability or RHW contributions to the demand budget would have been impossible. Future analysis with Precipitation Measurement Mission (PMM) data also will provide seasonal precipitation metrics as many geographic regions like India are affected by monsoonal or other regional climate variations.

For perspective, the availability of rainfall data for many parts of the developing world, which is also experiencing rapid urbanization, is likely more similar to Indian cities than Atlanta, Georgia. Yet, to date, there is no operational database or indicator of precipitation per capita or given area (that the authors are aware of in the peer review literature) for the globe. At the same time, water scarcity is most acute in regions where precipitation estimates are lacking. A preliminary “Precipitation by Person” metric, developed by our team member at Texas A&M-Corpus Christie is the basis for further inquiry. Using 16 years of precipitation estimates from Tropical Rainfall Measuring Mission (TRMM), a robust high-resolution precipitation climatology on 0.1 by 0.1-degree grids is established over the tropics and the subtropics (Nesbitt and Anders, 2009). Combining with the Landscan global population dataset (Bhaduri et al. 2007), the geographical distribution of “precipitation per person” is derived over 36 degrees South and 36 degrees North. Figure 3 shows an example of precipitation per person (ton/year/person in a 0.1 by 0.1-degree space) over India. Future work will explore how this metric is related to water stress.

To expand the analysis to mid and high latitudes, some very preliminary global analysis (Figure 4) has been conducted using the Population Count Grid Future Estimates V3. FAO, Centro Internacional de Agricultura Tropical – CIAT, and CIESIN.

Twelve months of IMERG data (Integrated Multi-satellitE Retrievals for GPM, Hou et al. 2014) were employed. Rates were converted to totals for the period March 2014 to February 2015. The precipitation grid was resampled to match the population grid (2.5 feet, or about 4 km).

The precipitation/population map is certainly driven by population, but not only by population. If precipitation is somewhat homogeneously distributed over the region, population will define where boundaries will happen. If population is homogeneously distributed, precipitation defines the boundaries. Central Amazonia is depicted in blue/purple and so are parts of Northwest South America where population is much higher. At these places (particularly in Colombia) precipitation is also higher. Areas with very different population counts (Amazon, Indonesia, East Asia) show high ratios. Because of spatial variability in precipitation and population distribution, India is a great example of precipitation and population individually driving the results at different parts of the country.
Concluding Statements

Future work will seek to grid data on a common interface and then calculate as a standard per capita or per kilometer calculations (i.e., mean accumulated precipitation / by population or area). Ultimately, the intent would be to assess trends in the metrics to assess relative contributions due to changes in precipitation, population or urbanization.

We also will explore different approaches for characterizing our new indices. A population threshold will be explored (for instance, cells with more than 1,000 people per square kilometer) to see how resulting areas compare (more regional analysis). There is also potential to define dry and the wet side of water stress.

Once we have some working knowledge of the efficacy of the precipitation metrics, the work builds on recently published results quantifying ecosystem services from urban rainwater harvesting (RWH) in India using PMM data products (Stout et al. 2015). Current work is extending on this effort by asking questions like:

- What is the potential for precipitation-driven food production and other ecosystem services in cities and how do they vary spatially and temporally globally?
- How vulnerable is urban agriculture to hydroclimate variability and extreme events?

Complementing the spatial precipitation per capita metrics, a parallel and synergistic effort will conduct a hydrologic engineering analysis using TRMM/GPM precipitation data, specifically the 17-year, global, three-hour, 0.25 km TRMM (TMPA, Huffman et al. 2007) and new GPM observations (e.g., IMERG). The precipitation will be incorporated into a water balance analysis for a range of building scale RWH system configurations to estimate the amount of water that can be effectively captured for a range of building rooftop and demand sizes following the procedures we have used in the past (Steffen et al. 2013; Walsh et al. 2014, Stout et al. 2015).

Preliminary analysis of precipitation per population IMERG and population density estimates (no scales have been produced at this time as this is an experimental product). Purple and pink colors indicate high precipitation/population ratios. Yellow are low ratios. Image Credit: Co-author S. Bernardes
References


