Title: The Effect of Photovoltaic Nanomaterial Roofing on Harvested Rainwater Quality

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Abstract:

The global freshwater crisis has greatly motivated the investment in rainwater harvesting systems. The implementation of these systems to combat the worldwide water shortage is developing concurrently with the installation of photovoltaic roofs. The materials of this renewable energy technology have evolved from silicon wafers to more economically feasible and effective nanomaterials. Since the type of roofing material used for rainwater harvesting has been shown to affect the quality of the harvested rainwater (Chang et al., 2004), the use of solar roofs as catchment systems may pose a health risk to these consumers by altering the water quality as well as by releasing hazardous nanomaterials into the harvested rainwater. The main goal of this research is to investigate how nanomaterials from a solar roof can affect the water quality of harvested rainwater via a lab-scale roof coated with Cu_2ZnSnS_4 (CZTS) or "solar paint," which is a type of nanomaterial used for solar energy capture. With an understanding of how harvested rainwater quality can be affected by nanomaterials found on photovoltaic rooftops, it can be determined if such materials are sources of contamination in harvested rainwater.

Background on Regional Water Problems and Nanomaterials:

Global freshwater resources are diminishing as the human demand grows. According to the World Bank, world-wide demand for water is doubling every 21 years. In fact, by 2050, the United Nations estimates that without major changes, more than 2 billion people will live in water scarce areas (Glenn, 2006). In Texas, historical groundwater extraction exhibits an increasing trend for the last 65 years as a result of economic and population growth. This pattern is predicted to continue until the year 2050 when this groundwater resource will dry up (Loáiciga et al., 2000). Due to the recognition of the water shortage crisis, many regions in the United States, including Texas, are looking to rooftop rainwater harvesting to supplement their freshwater resources.

Rainwater harvesting can be incorporated with a solar energy capture system to alleviate both the water and energy crisis. In 2008, I worked with a team from the Columbia University Urban Design Studio to design a system, called a "tech tree," which functions to capture rainwater and generate electricity with solar panels to water lawns at public parks in East Harlem, New York. That project sparked my curiosity as to how the materials used in the solar panels might affect harvested rainwater quality. The proposed research will allow me to assess the feasibility of such an integrated system and how this system can impact the environment.

The replacement of silicon solar cells with films coated with nanoparticles, which are more effective photocatalysts, has allowed for the decreasing cost of photovoltaic technology. Due to these reduced costs, the use of solar cells at the household level is rising. Concurrently, rooftop rainwater harvesting systems are also increasing at the household level to combat regional water shortages. As a result, the presence of nanomaterials from these photovoltaic roofs may alter the water quality of captured rainwater; this could pose an environmental health risk to humans if this water is used for potable purposes and a risk to aquatic life in surface waters if this water is used for nonpotable purposes like irrigation.

Nanomaterials may alter the water quality of the harvested rainwater (i.e., pH, concentration of metals), but the presence of nanoparticles themselves in the harvested rainwater can also pose a threat to human health. Past research has been done to investigate the effects of nanomaterials on humans. One study found that exposing human lung epithelial cells to silica nanoparticles containing iron, cobalt, manganese, and titania causes oxidative stress (Limbach et al., 2007). Another study determined that nanoparticles can serve as effective carrier molecules in the human body, providing toxic chemicals direct access to the brain (Oberdörster et al., 2005). Thus, consumption of rainwater harvested from a photovoltaic rooftop might pose a health risk. **To our knowledge, no one has studied the impact of a photovoltaic rooftop on harvested rainwater quality, and that is the subject of the proposed research.**

Nature, Scope, and Objectives of the Research:

To better understand the effects of photovoltaic roofing material on harvested rainwater, this research will investigate how nanomaterials from a photovoltaic surface can affect the water quality of harvested rainwater via lab-scale roofs coated with a type of nanomaterial that is used for solar energy capture. With this understanding, a system in which rainwater harvesting is integrated with solar energy capture can be engineered to take full advantage of both the available regional water and energy resources.

The proposed research project focuses on nanomaterials used in photovoltaic cells, which have the potential to contaminate rainwater in the rooftop collection system by changing the water quality and releasing nanoparticles into the captured rainwater. A lab-scale roof coated with nanomaterials that are used for solar energy capture will be built. This lab-scale roof will be coated with Cu_2ZnSnS_4 (CZTS), an emerging nanomaterial called "solar paint," which is used to produce low-cost thin film solar cells (Katagiri et al., 2009).

CZTS nanocrystals will be made using a mixture of 0.52 g of $Cu(acac)_2$, 0.29 g of zinc acetate, 0.18 g of $SnCl_2$, 0.13 g of S with 40 mL of 70% octadecanoic acid in a 100-mL three-neck flask on a Schlenk line. Gasses are removed from this mixture under a vacuum for two hours. Then, nitrogen gas is used to remove any other gases in the mixture for 30 min at 110°C. The mixture is then heated to 280°C for one hour and allowed to cool to room temperature. The newly formed nanocrystals are precipitated using ethanol and dewatered using centrifugation. Unwanted byproducts and incomplete nanocrystals are removed using redispersion in chloroform followed by centrifugation at 8000 rpm for two minutes. The purified nanocrystals are then washed three more times using solvent precipitation with ethanol. The resulting CZTS nanocrystals can then be deposited on the lab-scale roof by spray coating using a 20 mg/mL toluene dispersion (Steinhagen et al., 2009).

These lab-scaled nanomaterial coated roofs will be set up on 1 ft^2 stands angled at 18.4 degrees in the laboratory to mimic runoff from rooftops (Figure 1). Samples of freshly collected rainwater will be recirculated over the surface of the roofs for one hour. After the exposure of the rainwater to these roofs, the runoff will be analyzed for several water quality indicators: pH, conductivity, dissolved organic carbon, total solids, turbidity, selected metals, nitrite/nitrate, and total and fecal coliform. The presence of nanoparticles in the rainwater will be assessed using transmission electron microscopy. All of these measurements will be performed in the Environmental and Water Resources Engineering laboratories at the University of Texas at Austin. The concentrations of the contaminants and the presence of nanomaterials will be compared to the concentrations of these contaminants in the control, which is the initial sample of rainwater without exposure to the nanomaterials.

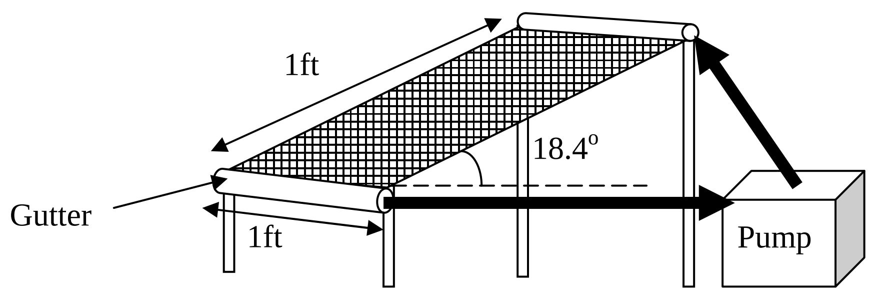

Figure 1: Lab-Scale Roof

After completing the tasks outlined above during the project year, I expect to continue research in the area of the effect of nanomaterials in engineered water systems. For instance, I plan to examine how the aging of these photovoltaic cells can affect harvested rainwater quality.

Results Expected from this Research:

With the improvement and cost-effectiveness of photovoltaic systems occurring alongside diminishing freshwater resources, it is critical to have a better understanding of how nanomaterials in these solar cells can affect the water quality in rainwater from rooftop harvesting systems. The results of this research will quantify the water quality that can be expected in rainwater harvested from a photovoltaic surface. These data will be compared to other data being generated in our laboratory with more conventional roofing materials (i.e., asphalt fiberglass shingle, Galvalume® metal, and concrete tile). Thus, the results of this project will allow us to evaluate if integrated photovoltaic/rainwater harvesting systems have major water quality drawbacks.

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