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EXPLORING FOG HARVESTING IN EUROPE: CHARACTERISTICS AND GUIDELINES FOR A SUSTAINABLE CITY MODEL

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ABSTRACT

Water availability affects the economy, social relations and environmental security in regions. As groundwater supplies are diminishing, and global water demand is increasing (United Nations, 2015), new nature-based technological solutions are highly desirable. Recently, the water scarcity crisis is also starting to affect Europe. In order to relieve the stress on traditional fresh water resources, fog-collection technologies stand as a promising alternative solution. Thus, this study developed the Nebula Project to maximize the ecology of system boundary processes and offer fog harvesting as sustainable opportunities in the Switzerland Alps and Northern Italian region. The project is used to inform policymakers understand tailor nature-based sustainable solutions in cities, based on their unique geography, climatic conditions, and social characteristics. Active involvement of citizens is fundamental for the functioning of those systems, especially if combined with promotion strategies, data gathering systems and gamification processes.

Key Words: fog harvesting, urban metabolism, water consumption awareness and education platform

1. INTRODUCTION

The increased risk of a global water drought has already been well documented by a series of authors (Wada et al., 2011; WWAP, 2015). Climate changes are exacerbating these conditions through indirect effects on the whole hydrological cycle (Gleeson et al., 2012). Although water scarcity has different causes according to the region's environment and state of economic development, there is no unique solution for this crisis but a set of measures and practices, from the policy level to physical interventions. Without a change in water resource management, 68% of the world's population will be living with medium to high water stress levels (Pfister et al., 2009).

While Europe is regarded as having sufficient water resources, water scarcity and drought is an increasingly frequent phenomenon, as many Mediterranean countries (included Spain and Italy) are yearly using up 20% or more of their long-term supplies, with impacts on hydropower, agriculture, manufacture and tourism (Arnell, 2004). Unfortunately, even regions traditionally known as water-abundant, are now being affected, more specifically around the northern Italian and Swiss Alps, which now face water availability fluctuations due to raising temperatures, glaciers melting and changes in the seasonal distribution of precipitations (Blanc and Schadler, 2014).

As the world's demand for fresh water is growing, collecting water from fog masses could represent an alternative solution to help relieve the stress on conventional, over-exploited water sources (Domen et al., 2014).

1.1.Fog water harvesting and the SDGs

Equity and sustainable development in fog collection is essential. The United Nations Sustainable Development Goal 6 (SDGs), and Goal 14 (UN, 2015), are calling for access to safe water, sanitation and water under the sea for all by the year 2030. The goals support the efforts in water scarce countries and regions to go beyond conventional resources and tap unconventional water supplies to narrow the water demand supply gap. Among average water resources, the potentiality to collect water from the air, such as Fog Harvesting (FH), is by far an unexplored science. Fog water collection is a low maintenance and sustainable option that can supply fresh drinking water to communities where fog is in abundance (Fernandez, 2018) already implemented around the world (Batisha, 2015).

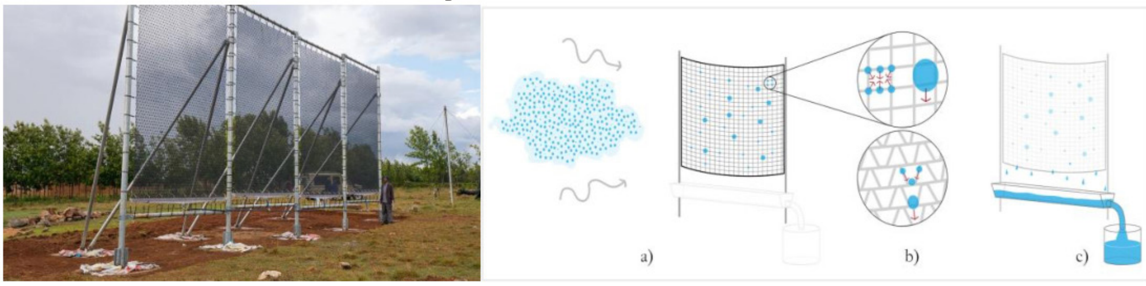
Despite technology development and demonstrated benefits, there are certain challenges to fog collecting, including the lack of supportive policies, educational expertise, community involvement and awareness, especially in developed countries. To supply this void, this study investigates two European regions to assess potential fog water harvesting application scenarios: the Swiss Plateau (Switzerland) and Po Valley (Italy). Moreover, it proposes a solution to adapt these nature-based mechanism solutions to semi-urban environments not only to provide an additional source of water in these regions, but to promote sustainable development education on water behaviours and water conservation awareness using Information and Communication Technology (ICT) platform and machine learning.

2. A GUIDE TO FOG CHARACTERISTICS AND COLLECTION

Fog is a low-lying cloud (Schemenauer and Cereceda, 1994) that forms when sufficient air humidity meets temperatures slightly close to the dew point, as water molecules group around condensation nuclei, commonly present in the atmospheric air (Vipul et al., 2016). A common meteorological phenomenon of valleys, islands, hills and mountains of temperate climates, fog can be found around the world in many different ecosystems - many of whom rely on fog moisture to exist (Fessehaye, 2013). Despite forming through different processes, only a handful of fog types are currently known as suitable for water harvesting. In particular, advection fog occurs when warm air masses from the ocean meets colder, humid continental air masses. Orographic fog tends to be formed when air masses move upwards on mountains, meeting a colder temperature. Radiation fog: forms under calm weather conditions, when temperature inversion in valleys and water bodies condense an already highly humid air into fog.

Topography is a major influence on fog onset and formation, as it might facilitate fog formation in one place and difficult in the other, within few kilometres apart. Although it is not easy to predict fog formation, some site evaluations and methods do exist and were proposed by several authors, including Schemenauer, Cereceda and Osses (2015). Besides topography, other indicators documented as impacting fog harvesting performance are: global and local wind patterns, Liquid Water Content (LWC), temperature range, relief, altitude, distance from coastline and crestline and upwind locations. Wind is the leading factor in traditional water collection.

A large number of FH projects worldwide have used advection and orographic fog for water collection, for different purposes (Batisha, 2015). These devices are constituted by a frame and a strained, porous mesh that intercepts air water droplets. As the wind moves fog moves through the mesh Fig.1(a), some of its water droplets get caught on its surface, merging into larger drops (b) that falls to a gutter through gravity, being directed to a reservoir for storage or treatment (c) (Morichi, 2017). In the Chugungo FH project in Chile, the LFC yielded an average of 3L/day per m^2 of mesh area. (Schemenauer, Cereceda and Osses, 2015). In Oman, magnitudes of 30L/m^2/day were achieved, and in a particular day, it amounted for 70 L/m^2/day. Cost-wise, an LFC can be very cheap to buy and build, but its price may vary according to the materials used: a 1m^2 collector can cost around 300 USD if made of aluminum. In a project conceived for Eritrea, 20 LFC costed a total of 28.193 USD (Vision Eritrea Financial Report, 2008).



[Figure 1] (left) Fog collectors in Tanzania; (a-c) Scheme of fog collection process (right). (www.aqualonis.com; Morichi, 2017)

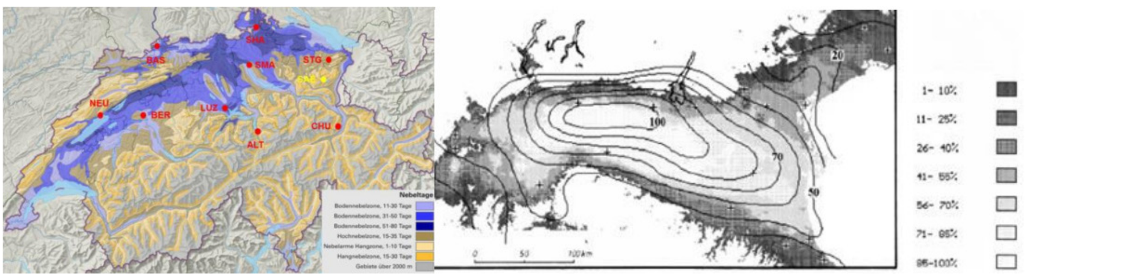
3. METHOD

Cities are faced with the challenges of traditional and outdated methodological water management monitoring tools as cities continue to grow in size, density and complexity. First, the study aims to use available open source public and private water consumption data from the area of Switzerland and Italian Alps communities to develop a data driven water management ICT platform network. The Nebula Project, four phase study, employs computational methods and machine learning algorithms (artificial neural networks, random forest) to improve the performance by mechanizing the acquisition of knowledge from experience. In addition, the Project provides a sequence of phases from the identification of hot-spot opportunity areas within specific characteristics and boundaries, climatic assessment analysis, educational and awareness campaign, real-time data methods, a community reward-based system, and system distribution approach (see Figure 3).

4. FOG-INTENSE HOTSPOTS IN EUROPE: THE CASE STUDY OF SWITZERLAND AND ITALY

Although advection fog is widely preferred as the ideal fog for water collection through standard fog harvesting techniques (Schemenauer, Cereceda and Osses, 2015), radiation fog appears to be more consistent, predictable (Scherrer and Appenzeller, 2014) and uniform compared to advection fog. Strongly present in Europe, particularly in the Po Valley (Fuzzi, 1993; Mariani, 2008) and the Swiss Plateau (Wanner, 1979; Bendix, 2002; Scherrer and Appenzeller, 2014), this fog type often shrouds vast portions of these regions for many hours, starting from early evening and persisting until late morning (Bendix, 2002; Mariani, 2008). The lack of strong winds (Mariani, 2008) in the region is a major obstacle for traditional FH systems. Despite requiring an innovative approach to tackle the issue, the potential of water production is very consistent. At the spatial scale, satellite imagery maps on Fog Low Stratus (FLS days) have been produced, by comparing spatial daily observations with local station data (Cermak et al., 2009). In Italy, a number of fog harvesting projects have already been proposed in the Po Valley (Calixto, 2018; Morichi, 2018). According to Bendix, (1994), fog is often the subject due to the large amount of toxic smog phenomenon found in cities, which is a major environmental hazard to be considered during the implementation and intervention of fog harvesting.

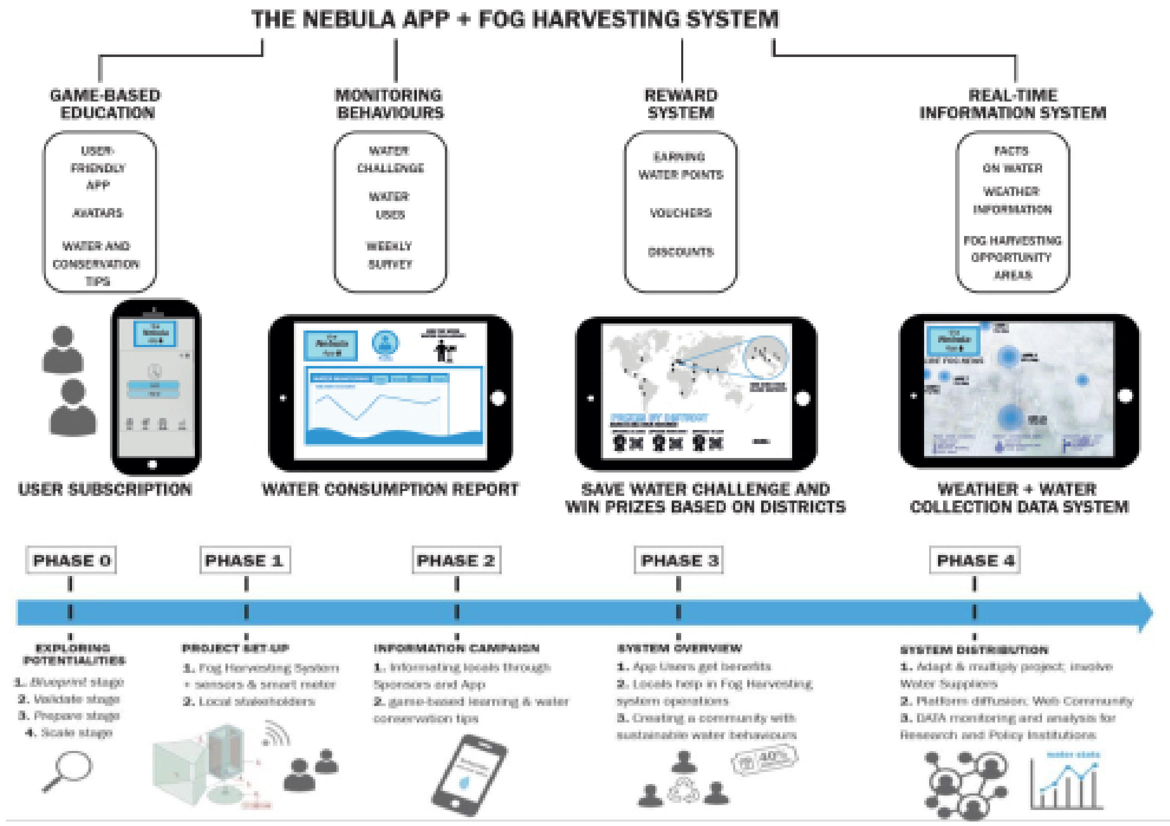
Both Italy and Switzerland are faced with water availability threats. In Italy, it has become increasingly difficult to meet water demands, in particular in summer season, with subsequent economic damage to agriculture (Swedish Commission, 2007). The country is expected to experience a 25% increase in water stress in the present century and a reduced availability of resources affecting drinking water supply, irrigation and hydropower generation in the Po Valley. This will lead to an increased soil dryness and increased frequency of droughts in the areas of plains (Wada et al., 2011). In Switzerland, most alpine glaciers will have disappeared by 2090 if current temperature trends are not inverted (Schaefli et al., 2018). Precipitation in the Alpine region of the country is likely to suffer distribution unbalance, as summertime rain is expected to decrease by 60% and to increase in winter. Also, concern is directed towards water-sensitive regions like Valais, Ticino or the Central Plateau, where the unclear effects of climate change drags concern about water shortages (Blanc and Schadler, 2014).



[Figure 2] (left) Map of fog in Switzerland (Credits: MeteoSwiss, 2017) and (right) fog incidence in the Po Valley, north of Italy. (Credits: Bendix, 1994)

4.1 The Nebula Project

This study developed the Nebula Project, a water management smart systems awareness communication ICT system + App smartphone platform, shown in Figure 3. The platform promotes sustainable urban water use and conservation, using practical suggestions and advocacy using real-time data and machine learning techniques -- connection to a virtual community. The smart meter allows water management and monitoring, the gamification process involves users (citizens, local governments, universities, companies, industries, institutions) and provides them with data, tools, consumption behavioural tips, educational kits, conservation advice, recover strategies, mitigation and fog harvesting opportunities. Platform users have the opportunity to participate in water reduction programs and receive rewarding prizes that can be used or exchange with other users within their community. Users that are interested to implement and employ the Nebula Project in their community, the system provides a replicable set of guidelines: (i) blueprint, (ii) validate, (iii) prepare, and (iv) scale. The blueprint stage provides a thorough climatic, socio-economic, policy, and topographic analysis investigation to identify the platform's feasibility within a specific environment and indicator conditions. The validate stage provides an evaluation assessment on fog harvesting hot spot opportunity areas based on short/long term fog and humidity presence. The prepare stage prepares a feasibility network diffusion model with required sensors, server, and satellite imagery data to prototype using a radius fog buffer scan with specific implementation and monitoring criteria. The scale stage is the final stage where the collaboration of public/private stakeholders takes place and users scale the network to their needs. Moreover, a combined use of ICTs with human interaction enhances public exposure to environment messages. The platform provides an excellent way to educate users about the environmental impacts of their actions and provide them with the tools needed to conserve and preserve water (i.e. home, school, work, and school).



[Figure 3] The Nebula Project: (top) Water Awareness Gamification Platform Scheme; Progress timeline for Platform scaling-u (bottom) (Gloria Morichi)

5. CONCLUSION

In contrasts, to current data models, mainly based on physical principles, the machine learning approach platform model focuses more on the macro-description of the behaviour of the system, calculating the association of the outputs with the system inputs. Increasing levels of automation related to pattern recognition and statistical inference to improve the performance of water management by evaluating and analysing regularities in training data. Second, using gamification approaches to engage an array of stakeholders by means of a cooperative network to develop a smart water management tool though gamification can develop awareness on the consumption behaviours.

Identifying FH opportunity areas using real time data, and monitoring lifestyle patterns by developing an ICT platform using machine-learning technique provide water utilities an effective tool for the monitoring of water management and promote and optimize water efficiency. The platform uses gamification user friendly criteria to attract all types of users from children, elderly, people with disabilities, students and academics and many more. The *Neb-*

ula Project would not only help relieving local water stress but also, with active involvement of citizens, contribute monitor their water-related behaviour and correct unsustainable lifestyles with gamification processes and pay-back reward systems. Smart water management tools through natural resources monitoring, alternative resource evaluation and education campaigns are fundamental for cities to help achieving the SDGs.

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