USING GOOGLE EARTH ENGINE FOR THE ANALYSIS OF FOG AND FOREST LANDSCAPE INTERACTIONS IN HYPER-ARID AREAS OF SOUTHERN PERU

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ABSTRACT:

Hyper-arid dryland ecosystems are particularly vulnerable to climate change and human influences, due to their dependence on advection fog as main water source. In these so-called ‘fogscapes’, human-induced fog collection represents a sustainable technology for fostering reforestation and, thus, increasing soil fertility and combating desertification. Along Atacama Desert coastal line, the effect of the Humboldt Current generates large scale fog events on the coastal belt, lasting from June to December, and the vegetation of the first hilly ridges (locally “lomas ecosystems”) may favour of the water content of fog. The University of Florence has set up a long-term research on fog collection associated to reforestation actions in two experimental plots in South Peru at the site of the Lomas de Mejia. 20 Large Fog Collectors were installed in 1996 to collect water from fog, for irrigating the trees and shrubs planted in the experimental plots. The irrigation lasted two years, then the established trees and shrubs were left to collect fog by themselves. The paper presents the results of a long-term remote sensing monitoring of the area, based on the use of Google Earth Engine platform. More than 20 years of NDVI time series for the two reforested parcels and portions of an external control area, were generated and analysed. NDVI time series analysis shows the evolution of the parcels from bare soil to vegetated portions and its development in time. Results show the important role of advection fog for inducing the re-vegetation of areas where forest was previously present, the significant increments of vegetation cover for the reforested parcels in time, encouraging the implementation of fog collection projects for land rehabilitation in areas with similar characteristics.

1. INTRODUCTION

As world population and demand for fresh water are increasing, new water resources are needed, especially in fragile and vulnerable ecosystems, particularly threatened by climate changes and human actions (Djuma et al., 2016). Fog water harvesting can represent a sustainable source of water in hyper-arid coastal areas, where rainfall and groundwater are limited or unavailable (Fessaye et al., 2014).

Fog collection is a water harvesting technique used in arid tropical and subtropical areas, characterized by low rainfall amounts but frequent fog events, due to local weather conditions (Schemenauer and Cereceda, 1991). This technique has been tested in the South Eastern part of Africa, Hawaii islands and in the South American coastal area, especially along the entire cost of Peru and the northern part of Chile (the world’s most arid regions). It takes inspiration from trees which can improve up to 25% the rain water income, by concentrating at their base (via throughfall and stem flow) the fog water which impacts and deposits on their canopy and trunk (Qadir et al., 2018).

Fog collected water can be used for human and animal consumption, subsistence agricultural activities, afforestation and environmental restoration, as in our case; it can supplement the average quantity of water per capita in these areas, where normally the water for human uses is carried in villages by trucks (Dodson and Bargach, 2015).

Concerning afforestation and environmental restoration, fog is particularly important because of its contribution of water, especially in the dry seasons or dry periods. Moreover, fog-collected water can be used for irrigation of seedlings and young plants that, otherwise, could not survive in so hard water deficit conditions (Certini et al. 2019). The objective of the irrigation is to support growth of tree and shrub seedlings and facilitate their establishment until they become able to sustain themselves by intercepting fog water (Valiente et al., 2011; Calamini et al., 1998).

The kind of fog suitable for being captured is the advection one: it forms when there is a strong horizontal advection of relatively warm moist air over cold water, as it often happens on regions characterized by strong sea surface temperature gradient, such as the Humboldt, Benguela and Labrador currents, and horizontal winds able to push the fog towards coastal mountains are present. As advection fog droplets have a diameter of some 10s μm, it is possible for the wind to move them (Cereceda et al., 2008). Fog collection is implemented by using vertical plastic meshes, supported by two wooden posts and exposed to the atmosphere; a part of water droplets carried by the wind deposits by impaction on these nets and, as they converge, they run down the meshes into underlying plastic gutters and then into storage tanks (Bresci, 1999).

These structures made by meshes and posts are called “fog collectors” (in Spanish called “atrapaniebla”). There are two main types of fog collectors: Standard Fog Collectors (SFC) have a mesh area of 1 m^2 and are used mainly in pilot experiments to evaluate the amount of water that can be obtained at given sites, and consequently to choose the most suitable areas for fog collection projects. They are equipped with a pluviometer and a meteorological station. Large Fog Collectors (LFC) have a mesh area ranging from 40 to 48 m^2 and are composed by two layers of mesh whose ribbons are 1 mm wide (Bresci, 1998) (Figure 1). Both the SFC and the LFC should be installed perpendicularly to the predominant wind direction for optimal performance (Schemenauer and Cereceda, 1994).

The University of Florence set up a project to study the influence of fog in Lomas ecosystem of Mejia (South Peru) and the possibility of restoring these areas through the plantations of trees and shrubs for their reforestation. A third of the plants was irrigated for 3 years, another third was

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irrigated for 2 years, while the remaining third received no treatment after the plantation. The experimental afforestation belonged to the project "Fog as a new water resource for a sustainable development of the Peruvian and Chilean coastal desert", funded by the EU from 1995 to 1998.

The present short communication proposes the analysis of the evolution of the two experimental afforested areas, by analyzing long-term time series of Normalised Difference Vegetation Index (NDVI), also comprehending an untreated nearby area. The analysis has been conducted using remote sensing images, through the new platform Google Earth Engine (GEE) (Gorelick et al., 2017).

Figure 1. A Standard Fog Collector and a Large one in the Lomas the Mejia

2. MATERIALS AND METHODS

2.1 Study Area

The study area of Lomas de Mejia is located in South-Western Peru, 17° 02' 10'' S and 17° 2' 37''S and between 71° 50' 00'' W and 71° 51' 00''W at an altitude of 823 m a.s.l., in the Department of Arequipa, province of Islay and district of Deán Valdiviva (Figure 2).

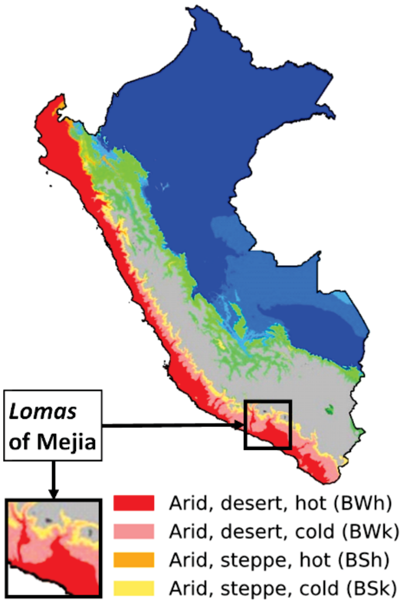

Figure 2. Location of the study area and climate zones of the Lomas of Mejia, processed from Beck et al., 2018.

The area has been deforested after the Spanish Colonization, leading to a severe desertification process (Belknap and Sandweiss, 2014).

From the twenty LFC installed, a PVC pipe (10 cm in diameter), was used to collect water falling from the mesh, stored in two reservoirs.

Two plots of 71 x 51 m, at 740 and 600 m a.s.l., respectively, and distant from each other almost 200 m, were afforested with 864 trees belonging to 5 species: two cohorts of native *Caesalpinia spinosa*, (seedings of 6 months and 12 months), *Prosopis pallida* and allochthones *Acacia saligna, Casuarina equisetifolia,* and *Parkinsonia aculeata*. The two plots were divided into two 51 x 33 m blocks, and each block into six 15 x 15 m parcels, separated by 3 m stripes in between (Figure 3).

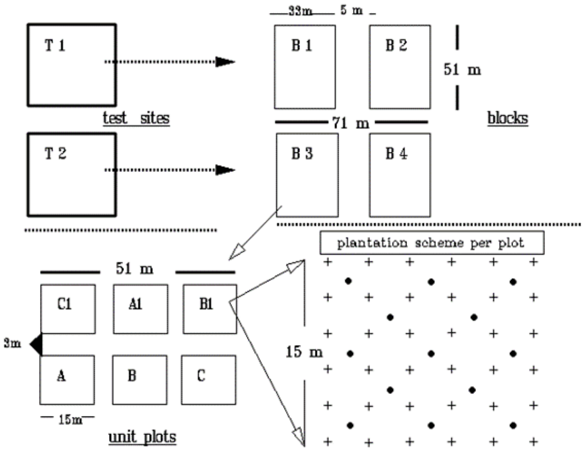

Figure 3. Scheme of the experimental plots in the Lomas de Mejia

The trees were planted in 1996 and, irrigated with fog water until 1998.

The evolution of vegetation in these 2 experimental plots (Figure 4) was observed and evaluated by analyzing NDVI time series, considering a smaller, vegetated target area, since the original framing was no longer visible after 22 years. An untreated control plot was also analyzed, as benchmark.

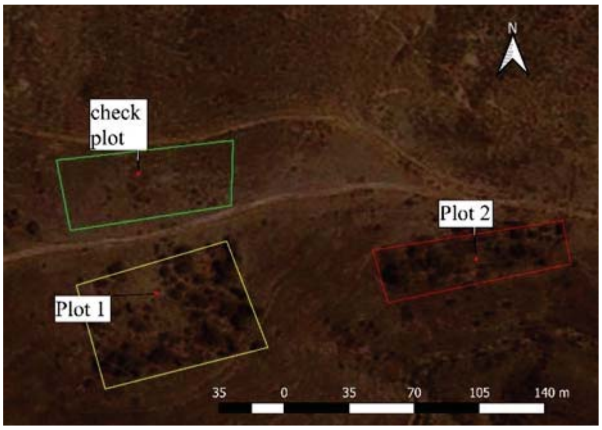

Figure 4. A view of the 2 target areas, representative of the experimental plots and the untreated area.

2.2 Remote sensing of afforested plots

NDVI is an indicator used to assess if the target of a remote sensing analysis contains green vegetation or not.

The index is based on the property of photosynthetically active vegetation of absorbing red radiation and reflecting infrared one. In its mathematical formulation, it can vary from -1 to +1 (Equation 1), while NDVI of vegetated areas can vary from 0 (bare or scarcely vegetated) to 1 (fully vegetated rainforest)

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \qquad (1)$$

Where:

- ρ_{NIR} is the reflectance of the target pixel in Near infrared wavelength (0.7 – 1.1 μm)
- ρ_{RED} is the reflectance of the target pixel in visible wavelength (0.4 – 0.7 μm)

Satellite data were downloaded through GEE, a cloud-based geospatial processing platform for environmental data analysis on planetary-scale. GEE grants access to many remote sensing datasets and processing algorithms, directly on Google servers. Moreover, it allows rapid integration and sharing of new algorithms and processing tools.

Landsat 5, 7 and Sentinel-2 satellite data were downloaded and processed through GEE online code editor. Landsat NDVI time series were obtained from "Landsat 5 TM 8-day NDVI Composite" and "Landsat 7 8-day NDVI Composite" Image Collections, processed at level 1 T.

Sentinel-2 NDVI time series were calculated from the bands available from the "Sentinel-2 MSI: MultiSpectral Instrument, Level- 1C" collection on GEE database.

Landsat 5 data were utilized to analyse NDVI Before and After the Afforestation (BA, AA), while Landsat 7 images were used to extend the Landsat time series after 2011 (when Landsat 5 satellite was dismissed). Sentinel-2 NDVI data are elaborated to compare them with Landsat time series (Table 1). In fact, while these latter have a resolution of 30 m, Sentinel-2 images have resolution 10 m. Images characterized by cloud cover were removed from the analysis.

Satellite	Before Afforestation (BA)	After Afforestation (AA)	Number of Images
Landsat 5	1984-1997	2011-2015	1110
Landsat 7	-	2012-2017	264
Sentinel-2	-	2016-2018	220

Table 1. Satellite data series considered for the NDVI time analysis

All data were analysed in terms of average of the NDVI on the pixels placed under the parcel shape, averaging the pixels cut by the parcel border of each target area. Temporal averages of these values were calculated for the periods BA and AA and compared.

Monthly averages of NDVI were also analyzed to check if there is a relation between the fog period and NDVI values increase.

3. RESULTS

The NDVI mean values for the two plots for the AA period are higher than those for the BA period (Table 2), including an increase also in the check plot for Landsat 7 AA period. This confirm the initial hypothesis of vegetation being self-capturing, once the irrigation was finished.

The analysis of monthly means of Landsat 5 NDVI time series values, here synthetically presented by averaging the values of the two plots, show an increase for the period September, October, November and December only for AA period. The same months for the BA period showed a slight variation (Figure 5).

Plot	Mean NDVI Landsat 5 (BA)	Mean NDVI Landsat 5 (AA)	Mean NDVI Landsat 7 (AA)	Mean NDVI Sentinel-2 (AA)
1	0.081	0.113	0.157	0.147
2	0.081	0.099	0.150	0.150
check	0.073	0.071	0.135	0.071

Table 2. Average NDVI values for the two experimental plots and the check plot

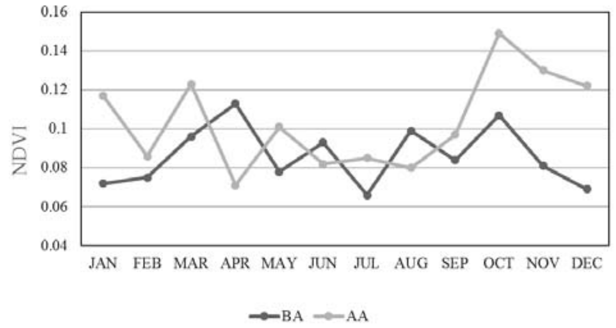

Figure 5. Mean monthly NDVI values from Landsat 5 data. Average value of Plot 1 and Plot 2.

The same temporal pattern is exhibited by the average of NDVI time series calculated with Sentinel-2 data, that showed a peak, but of lower entity, also for the check plot (Figure 6).

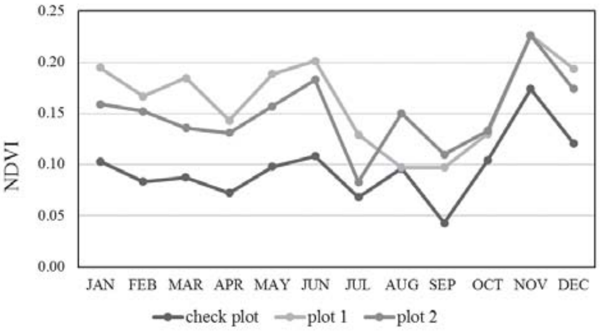

Figure 6. Mean monthly NDVI values for Sentinel-2 AA period in the two afforested plots and check plot after 2016

4. DISCUSSION AND CONCLUSIONS

The NDVI for afforested plots is about 0.1-0.2, the typical values for sparse vegetation and dry savannas. This is because a consistent part of the plots' surface is still uncovered by vegetation, while the alive individuals form low density groups.

The analysis of global averages of NDVI values (Table 2) showed a remarkable increase also in the check plot for the Landsat 7 AA period (2012 – 2017), that can be explained with the frequent occurrence of El Niño-Southern Oscillation (ENSO) in the period of analysis (NOAA, 2017), leading to higher precipitation, and thus to an increase of green cover and of the vegetation health status also in drylands.

Plot 1 has moderately higher NDVI values with respect to plot 2, because its higher altitude, allowing a major fog collection by the planted trees. This characteristic is robustly confirmed by the comparison with the time series of fog water collected by SFC installed in the study sites from 1995 to 1997 (Figure 7). From the analysis of SFC time series, the occurrence of fog from August to November is evident, explaining the increase of NDVI for the September – January period (Figures 5 and 6).

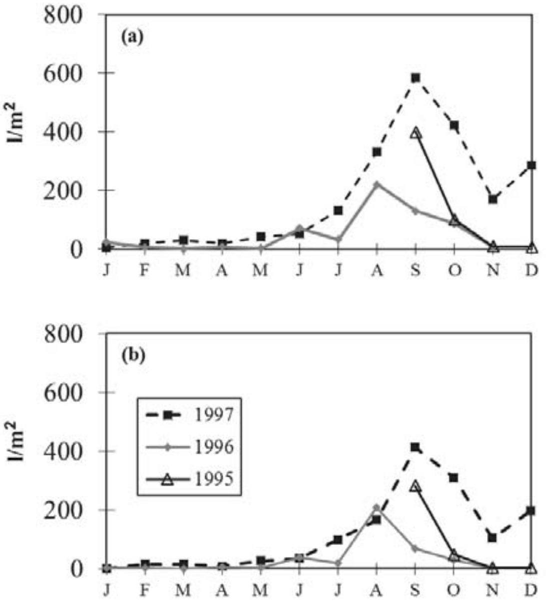

Figure 7. Total monthly SFC fog water (in liter per square meter) for the 1995-1997 period at the experimental plot sites (a) plot 1; (b) plot 2. (Bresci, 1999).

The present remote sensing analysis confirmed that an evident, even if scattered, reforestation is present and persisted in the area after the end of the project. Our results confirmed that the planted vegetation is sensitive to the occurrence of advection fog in autumn, exhibiting higher NDVI in the months from September to January.

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