The response of Groundwater-Dependent Ecosystems to drought in central Chile

Iongel Duran-Llacer1, Francisco Zambrano1, Víctor Gómez-Escalonilla Canales2, Pedro Martínez Santos2, Marcelo Aliagada Alvarado3, Lien Rodríguez-López4, Rebeca Martínez-Returetas5, and José Luis Arumí6

1Hémera Centro de Observación de la Tierra, Universidad Mayor, Santiago, Chile (iongel.duran@umayor.cl)
2Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, Madrid, España
3División de Hidrología, Región de Los Ríos, Dirección General de Aguas, Valdivia, Chile
4Facultad de Ingeniería, Arquitectura y Diseño, Universidad San Sebastián, Concepción, Chile
5Universidad de la Frontera, Temuco, Chile
6Centro de Recursos Hídricos para la Agricultura y la Minería (CRHIAM), Universidad de Concepción, Concepción, Chile

1. Background

Drought is recognized as a slow-onset natural hazard that originates from a deficiency of rainfall over a prolonged period and is also described as an inequality of water accessibility [1]. It is known as the global costliest climatic hazard that destroys the agriculture and ecosystem in terms of economy, society, and nature [2]. Drought is considered the main climate limitation that affects the hydrological cycle, agriculture, people, and ecosystems. Since 2010, central Chile has been experiencing an uninterrupted sequence of dry years that has been classified as a megadrought, which has conditioned major social problems [3,4]. This problem can't only affect agriculture, people, and access to drinking water in Chilean basins, but it can also affect the ecological integrity of ecosystems, particularly those known as groundwater-dependent ecosystems (GDEs) [5]. The mega-drought resulted in a diminished Andean snowpack, river discharge and reservoir volumes, groundwater levels, and difficulty for life systems for people across central Chile [3,4]. Previous research in the Aconcagua basin have investigated the drought relationship with water resources [3]. However, more exhaustive analysis related to ecosystems are need. Therefore, the main objective of this research is to examine the relationship between groundwater-dependent ecosystems and drought using satellite data in the Aconcagua basin in central Chile.

2. Materials and Methods

2.1. Conceptual scheme, study area and methodological scheme

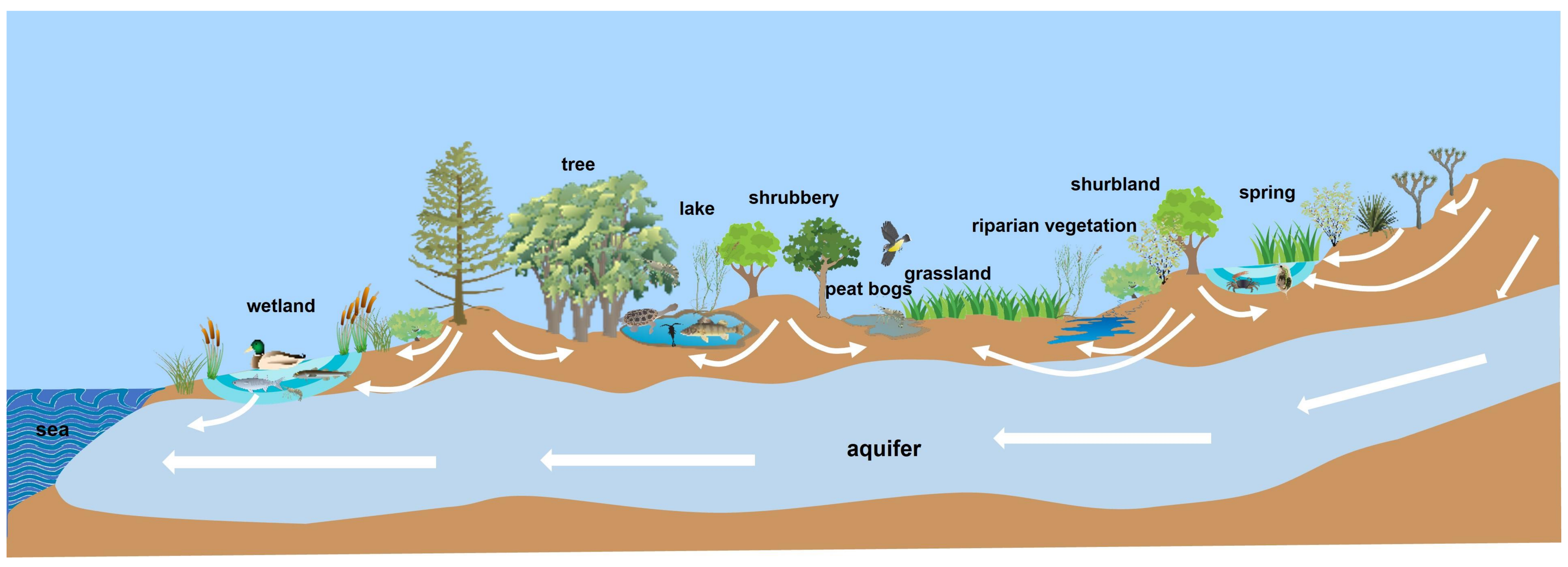


Fig.1 Conceptual scheme of Groundwater-Dependent Ecosystems (GDEs).

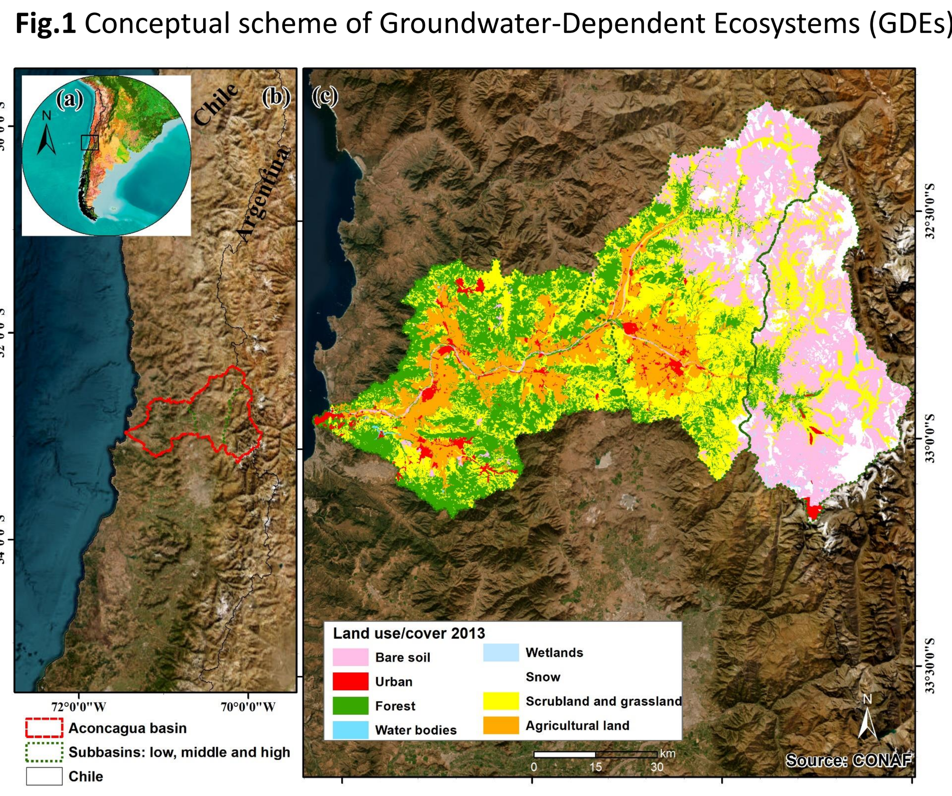


Fig.2. Aconcagua basin location and land use/cover in 2013.

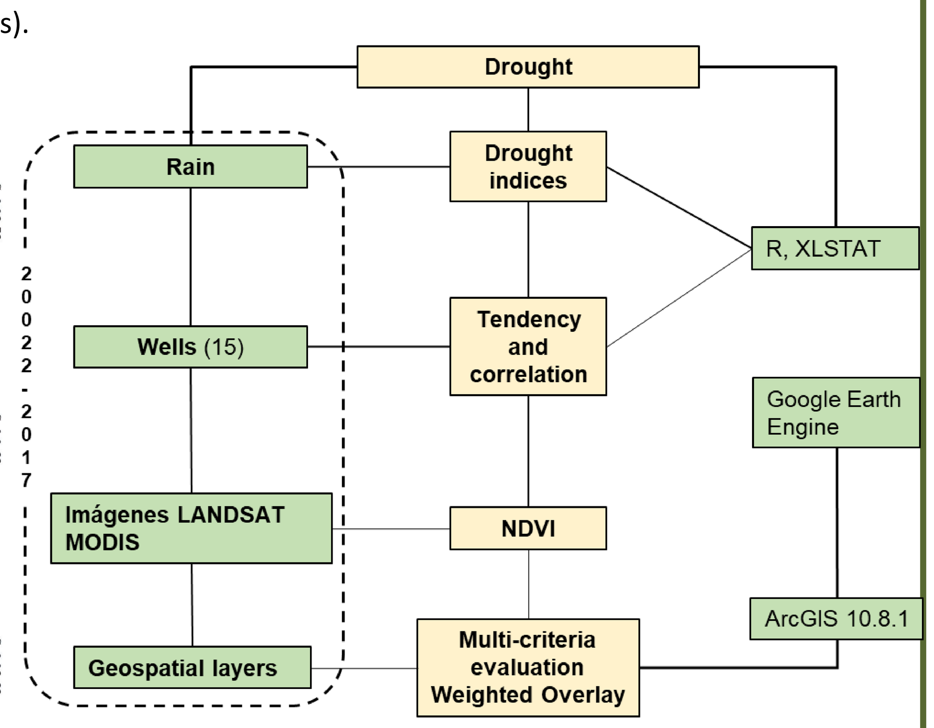
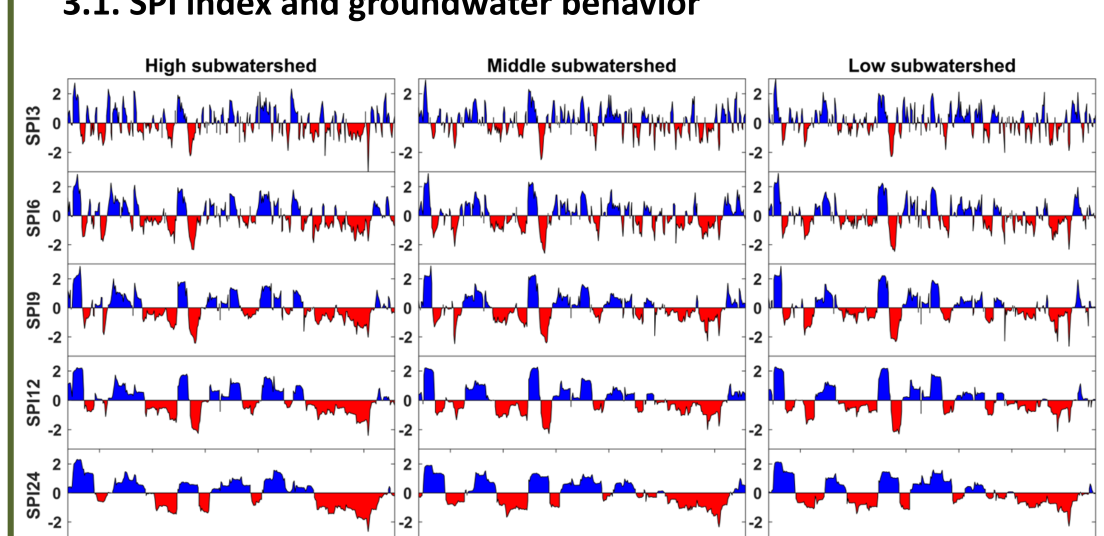


Fig.3. General methodological scheme.

The Aconcagua Basin (32.3° and 33°S) is located to center in the Valparaiso region, Chile (Figure 2). The landscape in the basin contains mountainous terrain with steep, narrow river valleys and the coastal plain is covered with sedimentary materials. The geological formations correspond to sedimentary, volcanic and sedimentary-volcanic sequences. In the Aconcagua Basin, the climate is subject to high intra- and inter-annual variability, considered as semiarid (1980–2010). Aconcagua river basin is the second most productive irrigated valley in Chile.

3. Results and discussion

3.1. SPI index and groundwater behavior



Fi.4. Temporal behavior of the SPI by subbasins.

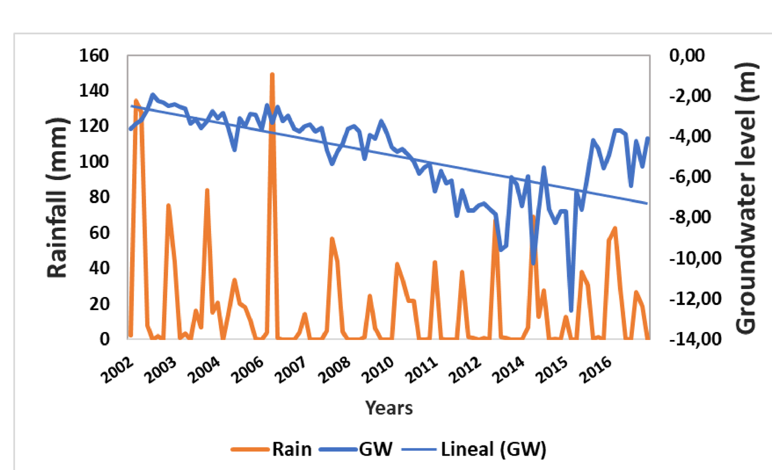


Fig. 5. Annual behavior of the groundwater level (GW) in wells and rain.

3.2. GIS multicriteria analysis and GDEs mapping

Geospatial parameters (14) calculated, normalized and reclassified were used. These data in a multicriteria analysis were used according to the methodology of Duran-Llacer et. al [5] to map the GDEs in two years 2001 and 2013.

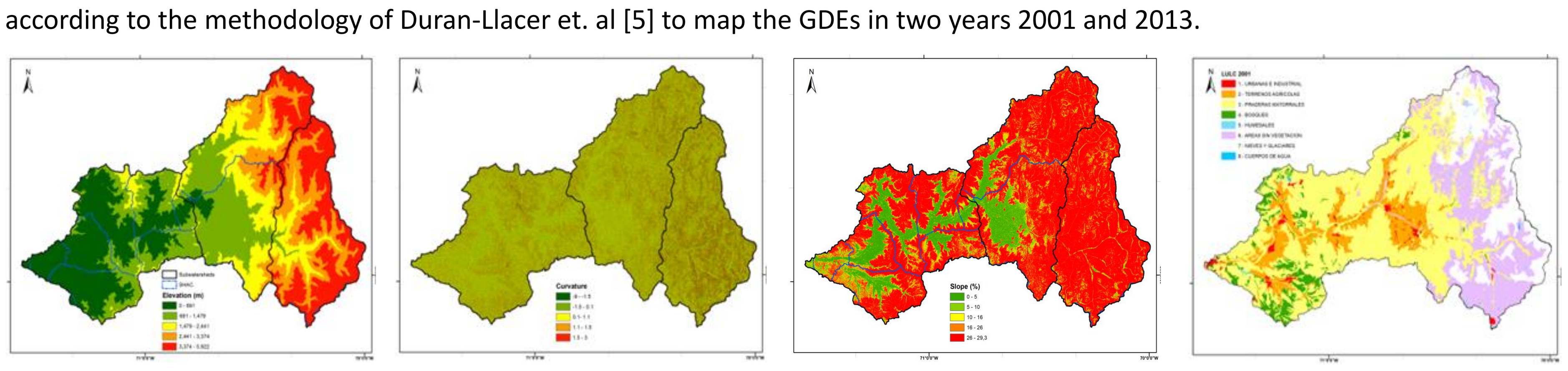


Fig. 6. Example of the 14 geospatial layers used (elevation, curvature, slope, land use/cover).

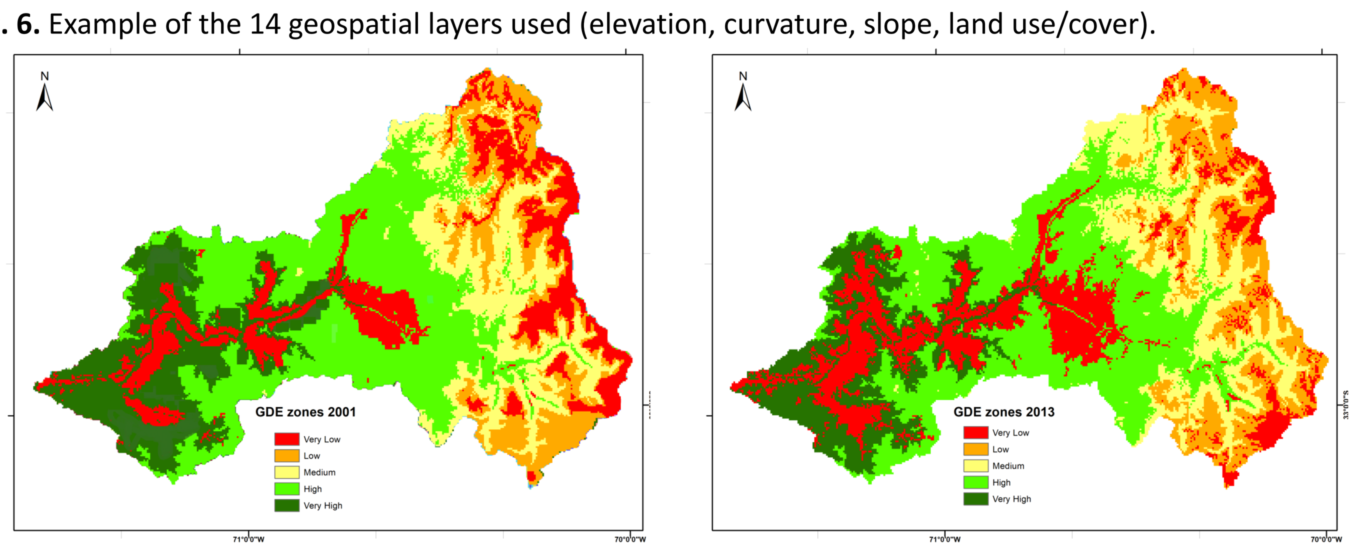


Fig. 7. GDEs zoning in 2001 and 2013.

Two maps were obtained in 2001 and 2013 of the GDEs from areas with very low presence to areas with a very high probability of finding these ecosystems. The very high zone was considered as GDEs and the persistent area between 2001-2013 for the temporal analysis was considered.

3.3. Analysis of SPI, NDVI, LST, rain, and groundwater in GDEs zones.

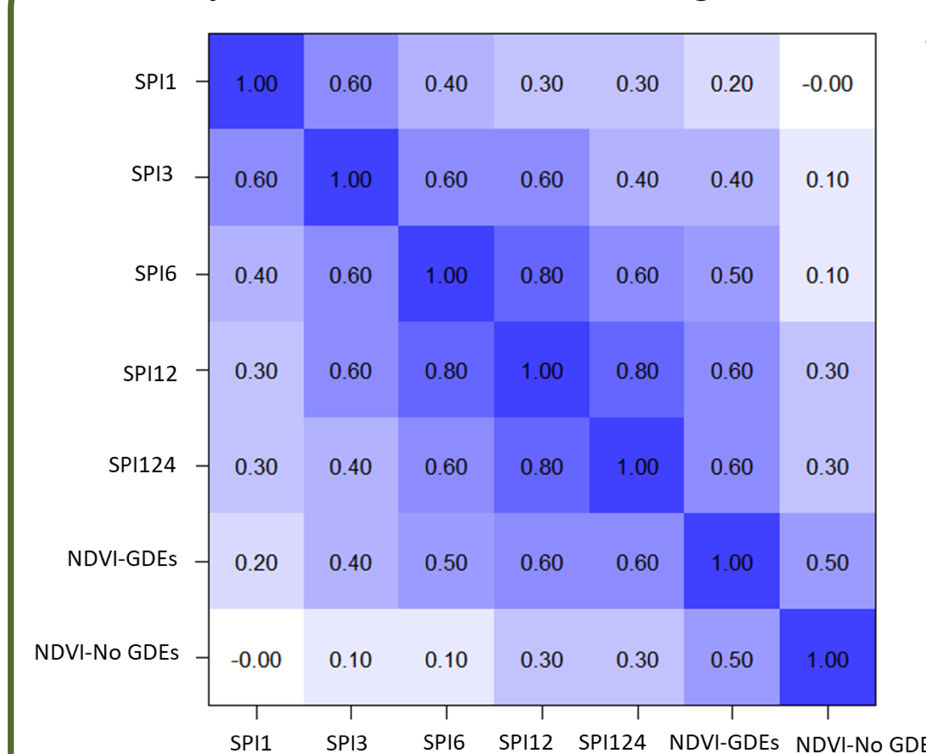


Fig. 8. Pearson correlation between SPI (1, 3, 6, 12, 24), NDVI-GDEs (NDVI of GDEs) and NDVI-No GDEs (NDVI of other areas) by subbasins.

Table 1. Trend analysis of average NDVI of GDEs by selected zones and SPEI tendency at annual level during 2002-2023. Test of Mann Kendall and Sen's Slope.

SPEI scale	SPEI		GDEs'zones	NDVI-GDEs	
	p-Value	Sen's slope		p-Value	Sen's slope
SPEI1	**0,049**	-0,009	**1**	**0,001**	-0,004
SPEI3	**0,047**	-0,012	**2**	**0,040**	-0,003
SPEI6	**0,029**	-0,020	**3**	**0,001**	-0,003
SPEI12	**0,001**	-0,028	**4**	**0,002**	-0,004
SPEI24	**<0,0001**	-0,047	**5**	**0,006**	-0,003

Trend analysis showed a statistically significant decrease in the NDVI of the GDEs across the basin (Table 1). In the rest of the basin (no-GDEs) it cannot be said that there is a trend, since the decrease was not statistically significant. Therefore, it can be stated that ecosystems have responded negatively to the drought. The SPI-SPEI values showed a statistically significant decreasing trend. For its part, groundwater also decreased significantly.

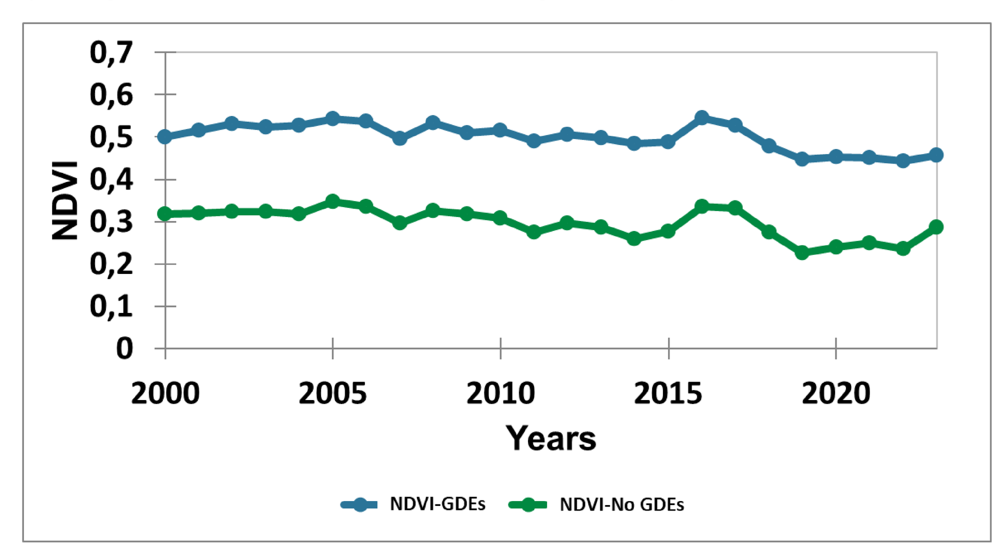


Fig. 9. NDVI of GDEs and NDVI in the rest of the basin (no-GDEs).

Fig. 10. Photographs taken at GDEs in the study area.

4. Preliminaries conclusions

- The SPI-SPEI at 12-24 months had a moderate correlation with the NDVI in the rest of the basin (no GDEs > 0.3) and high in the GDEs (>0.5).
- The Sen's slope was more pronounced in the GDE zones, and the trend was decreasing with respect to the NDVI.
- The GDEs zones were affected by drought processes, which demonstrates the need for sustainable management of these important ecosystems.

5. References

[1] Hui-Mean, F., Yusop, Z., & Yusof, F. (2018). Drought analysis and water resource availability using standardised precipitation evapotranspiration index. Atmospheric Research, 201, 102-115.

[2] IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Universersity Press.

[3] Duran-Llacer, I., Munizaga, J., Arumí, J.L., Ruybal, C., Aguayo, M., Sáez-Carrillo, K., Arriagada, L., Rojas, O., 2020. Lessons to Be Learned: Groundwater Depletion in Chile's Ligua and Petorca Watersheds through an Interdisciplinary Approach. Water 12, 2446. https://doi.org/10.3390/w12092446.

[4] Garreaud, R.D.; Boisier, J.P.; Rondanelli, R.; Montecinos, A.; Sepúlveda, H.H.; Veloso-Aguila, D. The Central Chile Mega Drought (2010–2018): A climate dynamics perspective. Int. J. Climatol. 2019, 40, 421–439.

[5] Duran-Llacer, I.; Arumí, J.L.; Arriagada, L.; Aguayo, M.; Rojas, O.; Rodríguez-López, L.; González-Rodríguez, L.; Martínez-Retureta, R.; Oyarzún, R.; and Sudhir, K. 2022. A new method to map groundwater-dependent ecosystem zones in semi-arid environments: A case study in Chile. Science of The Total Environment, 816, 151528, https://doi.org/10.1016/j.scitotenv.2021.151528.

Acknowledgments

- Authors appreciate the finnantial support of Project ANID/Postdoctoral FONDECYT/3230678.

CENTRO UM | HÉMERA Observación de la Tierra

Agencia Nacional de Investigación y Desarrollo — Gobierno de Chile

UNIVERSIDAD MAYOR