Quantifying the effects of land-use change and climate variability on water resources in the Pyrenees

International Soil and Water Assessment Tool (SWAT)
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Aarhus University, Deparment of Ecoscience, Denmark

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Soil & Water Assessment Tool SWAT

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EXCELENCIA MARÍA DE MAEZTU 2023 - 2027

1. INTRODUCTION

- Mountains provide half of the world's population with water resources
- Major changes have been observed in the variables and processes that shape the hydrological cycle
- In the Pyrenees there is a general decline in water resources which cannot be explained alone by climatic causes [1,2,3]

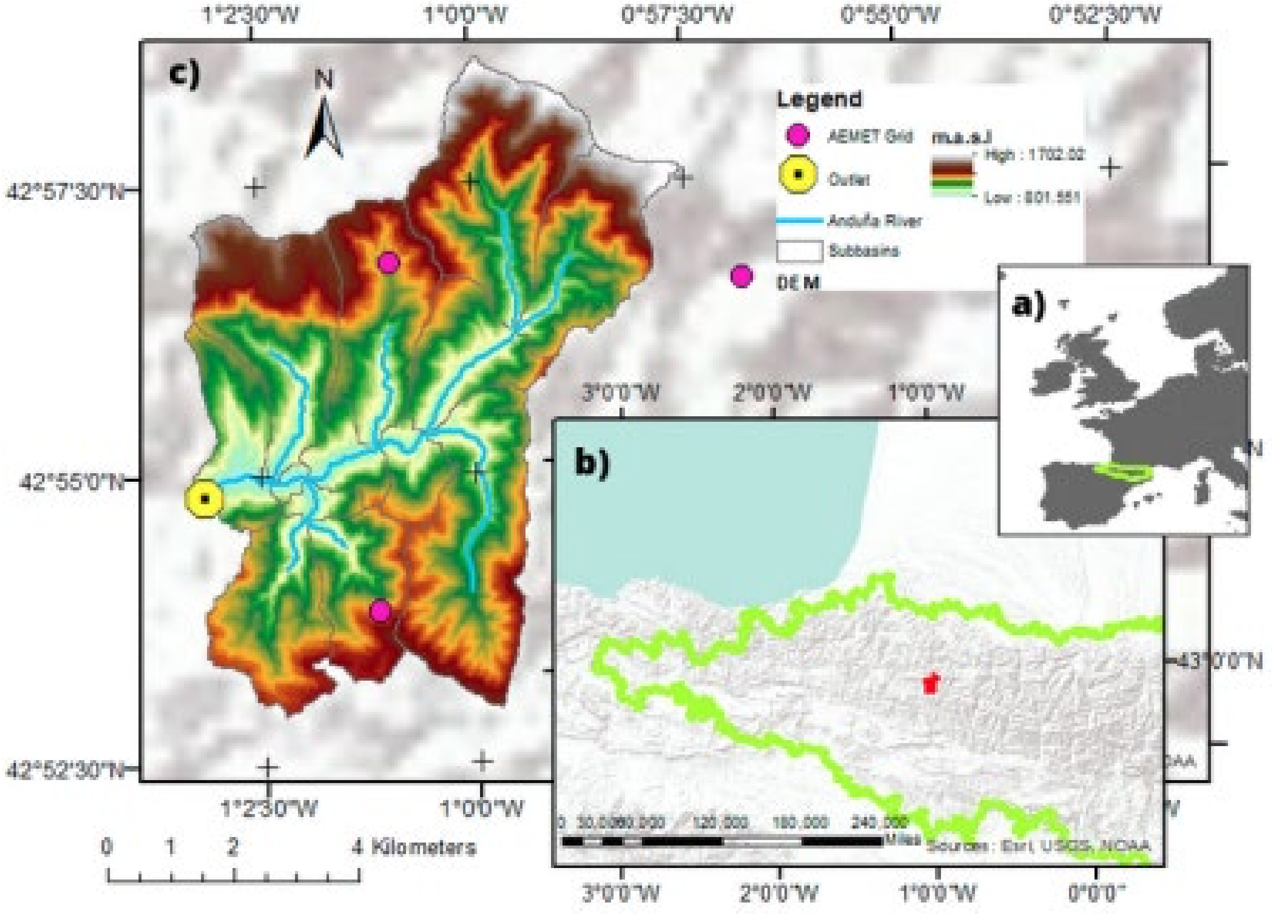
Climate variability | Land-use change

- This study quantifies independently the contribution of both of these factors

[1] Juez et al., 2022; [2] Lorenzo-Lacruz et al., 2012; [3] Martínez- Fernández et al., 2013

2. STUDY AREA: Anduña River basin

Figure 1. Location of the Anduña River Basin



- Located in the western Pyrenees, Spain (4,728.61 ha).
- <u>**Orographically complex**</u>
- Atlantic Climate
- Land-Use Evolution<u>**: Shift from agrarian to forest**</u> since 1956
- <u>**Giving rise to a land primarily occupied by forests**</u> (conifers and hardwoods)

3. DATA AND METHODS

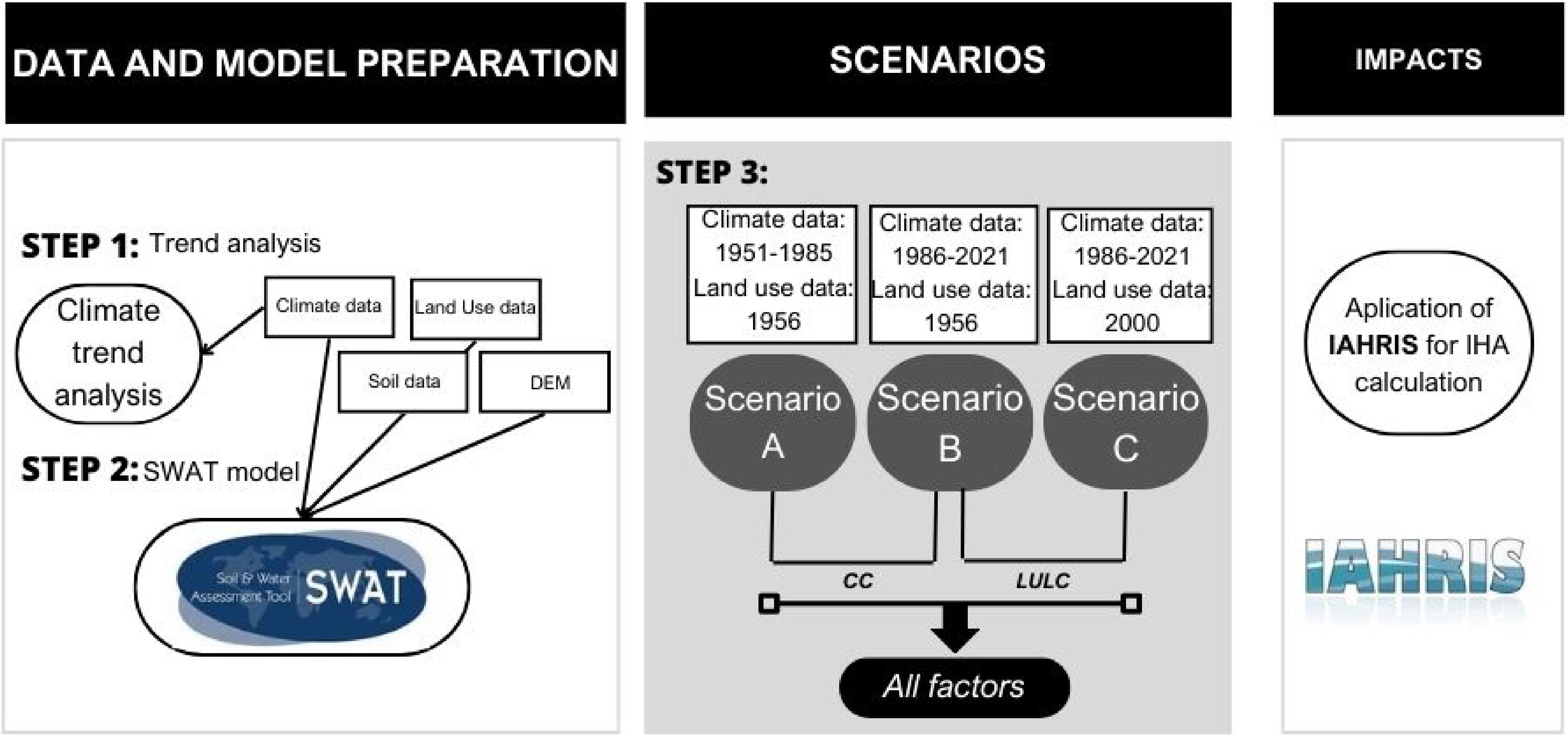


Figure 2. Flowchart of the methodology

3. DATA AND METHODS

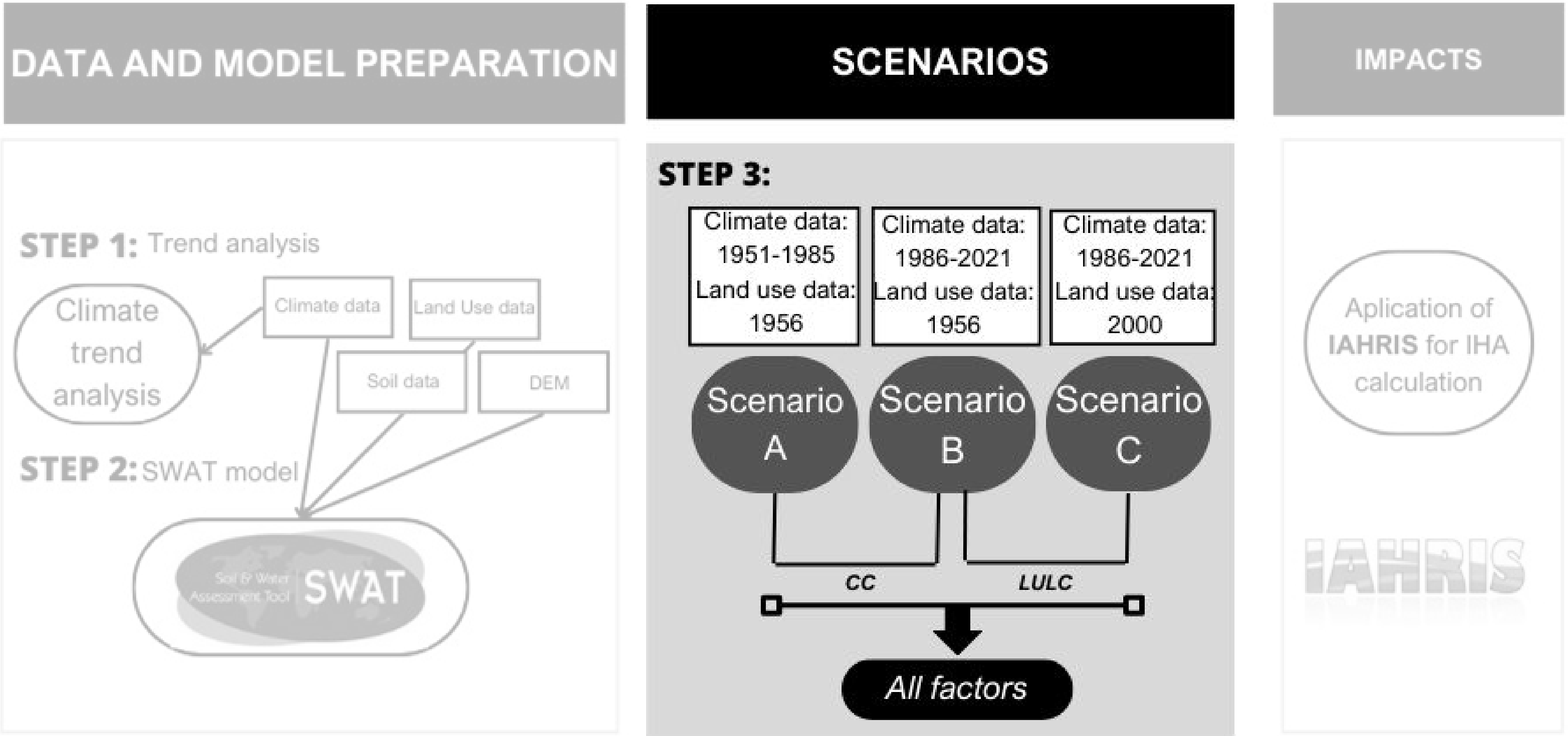


Figure 2. Flowchart of the methodology

3. DATA AND METHODS

3.1. Trend analysis of climate variables

- Climate variables: Maximum temperature, minimum temperature and precipitation
- Mann-Kendall trend test
- Significance assessed using the Z-test
- Sens' slope employed to estimate the magnitude of linear trends, providing a robust measure less sensitive to outliers.

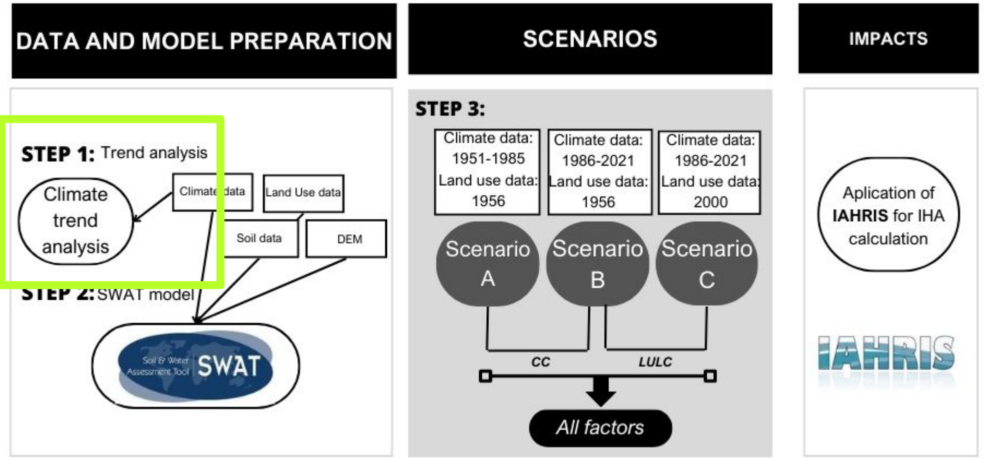


Figure 2. Flowchart of the methodology

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3. DATA AND METHODS

3.2. SWAT model

- Input Data for SWAT Model:
  - **DEM** data obtained from the Spanish Geographical Institute with a spatial resolution of 25 m x 25 m.
  - Harmonized World **Soil Map** used with a spatial resolution of 1 km x 1 km.
  - **Climate data**: Maximum temperature, minimum temperature, and precipitation data for 1951-1985 and 1986-2020 obtained from AEMET with a spatial resolution of 5 km x 5 km and daily temporal frequency.
  - **Land-use data**: Reference land-use maps from 1956 and 2000 obtained from the Government of Navarra regional sources.
  - **Discharge observations** of Izalzu outlet (CEDEX)

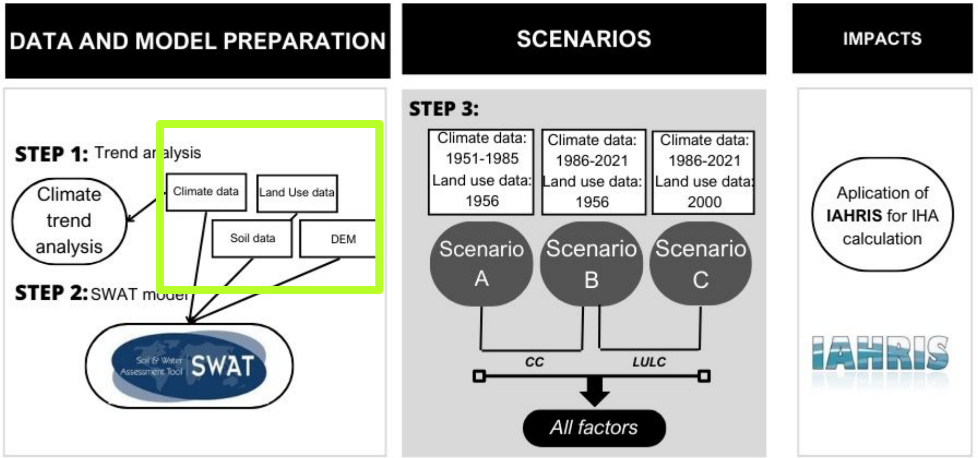

Figure 2. Flowchart of the methodology

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3. DATA AND METHODS

3.2. SWAT model

- Calibration and validation
  - SWAT-CUP → SUFI-2 algorithm
  - Sensitivity analysis (500 iterations)
  - Objective function: KGE
  - 1,000 iterations: 500 + 500

4

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad \mathrm{PBIAS} = \frac{\sum_{i=1}^{n}(O_i - S_i)}{\sum_{i=1}^{n}(O_i)} \times 100$$

$$\mathrm{R}^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}}\right)^2$$

$$\mathrm{KGE} = 1 - \sqrt{(r-1)^2 + \left(\frac{\delta_S}{\delta_O} - 1\right)^2 + \left(\frac{\bar{S}}{\bar{O}} - 1\right)^2}$$

Very Good
Good
Satisfactory
Unsatisfactory

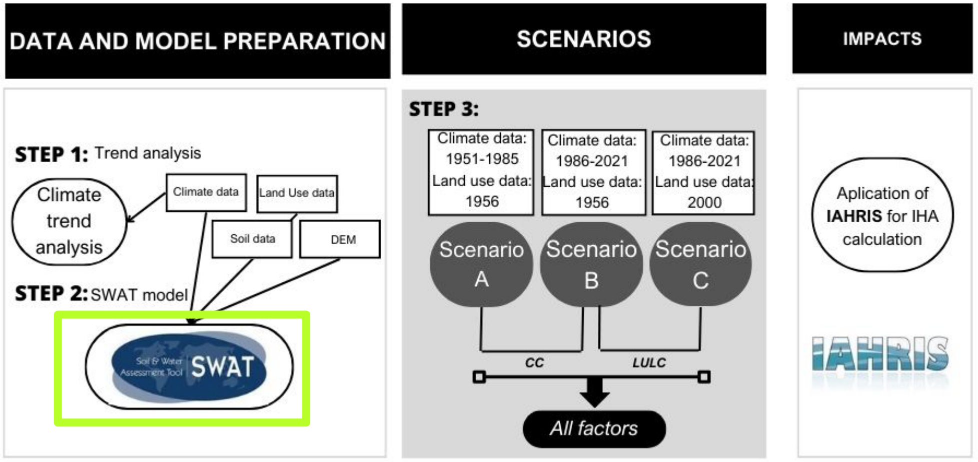

Figure 2. Flowchart of the methodology

[4] Moriasi et al., 2015

3. DATA AND METHODS

3.4. Indicators of hydrological alteration: IAHRIS[5]

- Provides information on the degree of alteration between a simulated and baseline scenario (Scenario A, B and C)
- Was developed in Spain to address the requirements of the European Water Framework Directive
- IAHRIS establishes the IHA related to the maximum extreme (floods), minimum extreme (droughts), and usual values

0 → Maximum disturbance

1 → No disturbance

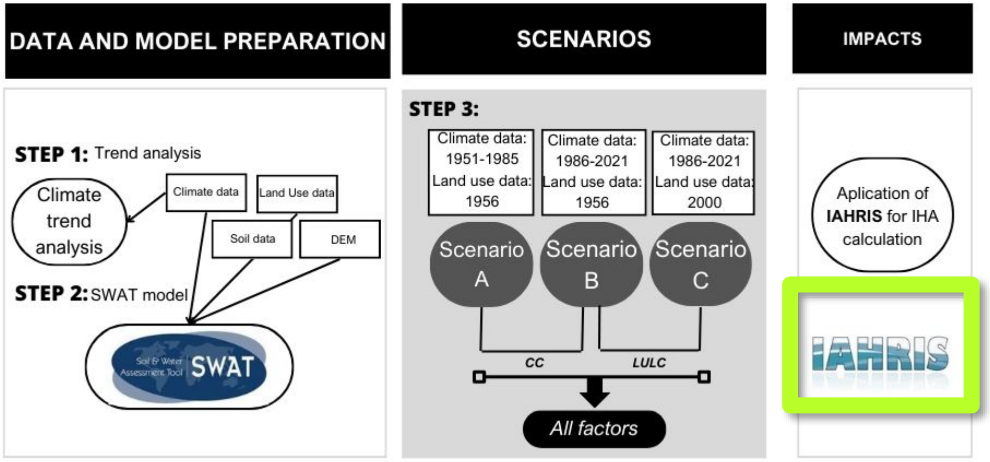

Figure 2. Flowchart of the methodology

- IGA: Index on Global Alteration

4. RESULTS

4.1. Trend analysis

	Precipitation			Maximum Temperature			Minimum Temperature		
	Test Z	Sig.	Q_i	Test Z	Sig.	Q_i	Test Z	Sig.	Q_i
jan	1.350		0.028	2.134		0.019	2.809	**	0.028
feb	0.715		0.012	1.107		0.018	1.817		0.022
mar	0.745		0.012	1.191		0.016	1.995		0.015
apr	0.645		0.008	2.144		0.028	1.936		0.014
may	0.735		0.008	1.698		0.024	1.886		0.016
jun	-0.139		-0.002	3.743	***	0.046	4.070	***	0.027
jul	1.489		0.009	3.703	**	0.041	3.946	***	0.025
aug	0.010		0.000	3.345	***	0.041	4.358	***	0.028
sep	-0.199		-0.002	0.893		0.012	0.655		0.006
oct	0.705		0.012	2.144		0.026	3.018	**	0.025
nov	1.201		0.024	1.152		0.013	2.422		0.022
dec	0.000		0.000 [6]	1.102		0.012	1.648		0.015
annual	1.896	**	0.009	4.735	***	0.028	5.490	***	0.021

Table 3. : Trend analysis results.

[6] Lemus-Canovas et al., 2019

4. RESULTS

4.2. Land-use change

Table 2. Land-use type data

Land Cover Type	Area Coverage km^2 (%) 1956	2000	Change (%) 1956–2000
Bare Soil	15 (0.3%)	23 (0.5%)	0.23
Broad-leaved Forest	1604 (33.2%)	1872 (38.8%)	6.71
Coniferous Forest Evergreen	334 (6.9%)	1331 (27.5%)	19.62
Mixed Forest	171 (3.5%)	347 (7.2%)	5.61
Pasture	2101 (43.5%)	1075 (22.3%)	-22.60
Shrub	607 (12.6%)	183 (3.8%)	-9.88

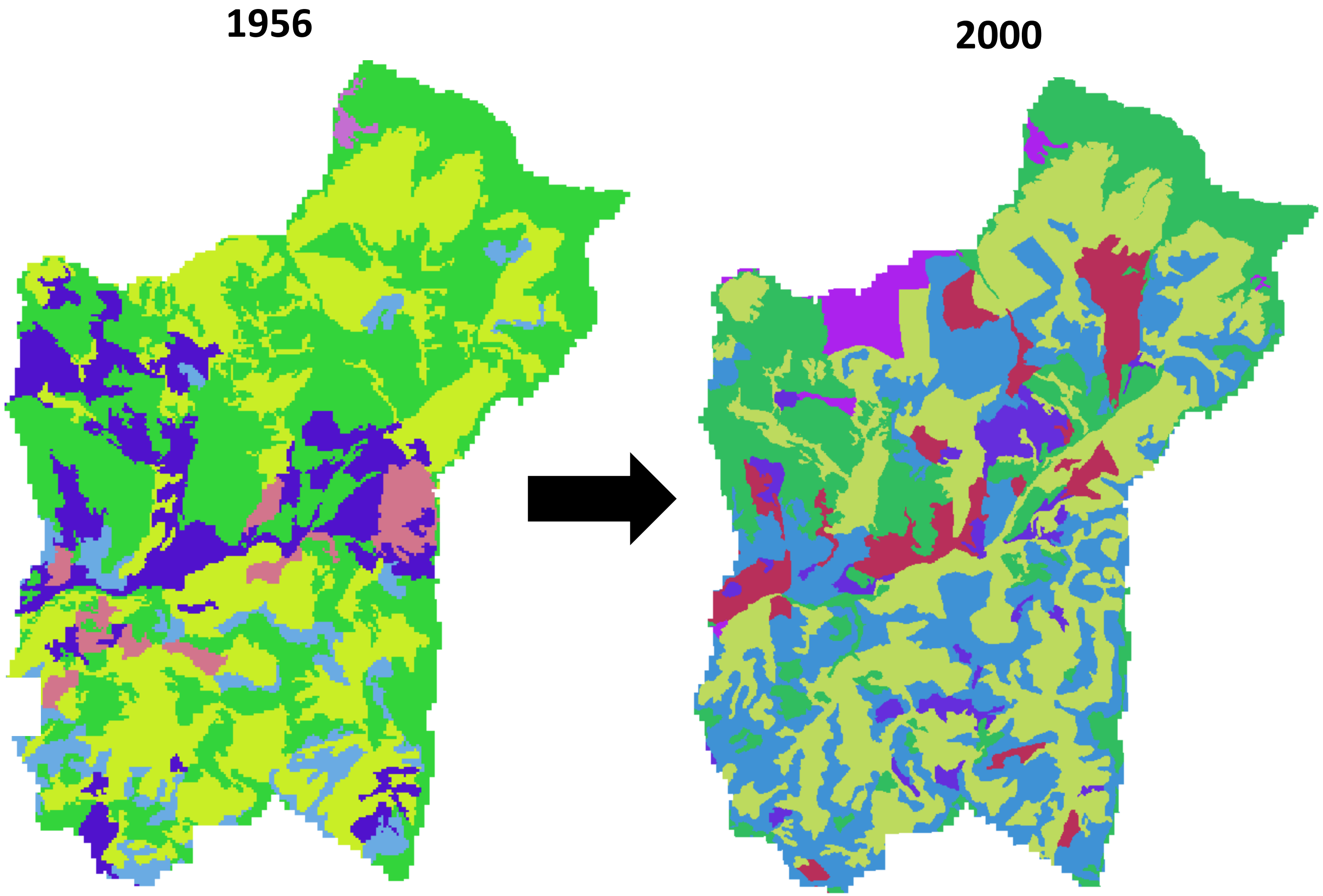

Figure 3. : Land-use change tranformation.

4. RESULTS

4.3. Calibration and validation

Table 3. Calibration parameters code, description, initial calibration range and final optimal value

	Parameter	Description	Calibration Range	Adjusted Value
Parameters derived from the Sensitive analysis	*Esco*	Soil evaporation compensation factor	0 – 1	0,7543
	Epco	Plant uptake compensation factor	0 – 1	0,7325
	Cn_2	Initial SCS runoff curve number condition II	±20 %	-19.88
	A_{wc}	Available water capacity	±20 %	12.04
Parameters selected from literature	*Snofalltmp*	Snowfall temperature (ºC)	-5 – 5	0,491
	Snomelttmp	Snowmelt base temperature (○C)	-5 – 5	2,465
	Snomeltmax	Maximum melt rate of snow during a year (mm ºC-1 day -1)	0 – 10	5,206
	Snomeltmin	Minimum melt rate of snow during a year (mm ºC-1 day -1)	0 – 10	1,276
	Snomeltlag	Snow pack temperature lag factor	0 – 1	0,973

[7]

Period	R^2	NSE	PBIAS	KGE
Calibration (1992-2004)	0.72	0.51	-12.67	0.55
Validation (2005-2018)	0.75	0.55	-16.49	0.62

Table 4. Calibration and validation statistical values on a daily basis

PBIAS → *Very good*

R^2, NSE, KGE → *Satisfactory*

Simulation of Scenarios A, B and C

4. RESULTS

4.4. Impacts of land-use change and climate variability on hydrological regime

Annual Balance of the Scenarios

Scenarios	P	ET	Runoff	Change ET	Change Runoff
A	1718.3	576.6	1100.2		
B	1722.2	592.1	1079.1	15.5	-21.2
C	1722.2	607.6	1064.1	31.0	-36.1

Table 5. : Simulated average annual runoff and ET under Scenarios A, B and C (mm)

- Precipitation increases minimally
- Rise of temperatures lead to an increase in ET

- The contribution of each of the factors in the increase of ET was 50%
- In the runoff decrease, land-use impact (**41.36%**) was almost as important as climate variability (**58.64%**)

Flood alteration

Scenarios	Q_c	ED	CD	FF	CV(Q_c)	CV(FF)
A	11.21	10.05	13.50	4.31	0.40	0.24
B	15.90	15.30	20.00	4.25	0.44	0.23
C	15.06	14.40	18.80	4.22	0.43	0.23

Table 6. Flood parameters of over A, B and C scenarios (mm)

- Climate variability generated increases of more tan 40% in the variables Qc (Average of the max. daily flow), ED and CD

- The alteration of these variables is slightly mitigated, with decrease values around 5% by reforestation

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4. RESULTS

4.5. Indicators of hydrological alteration

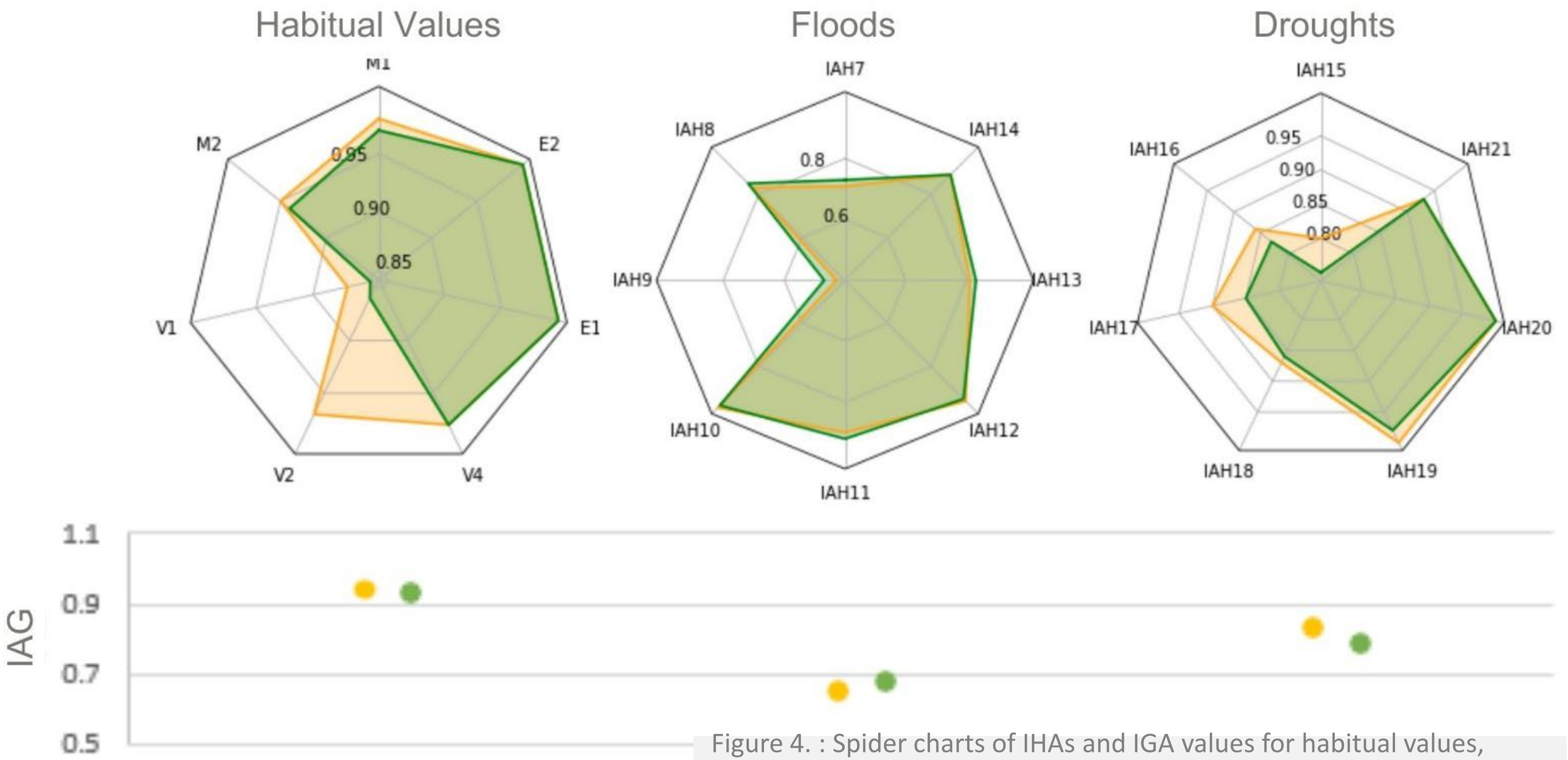
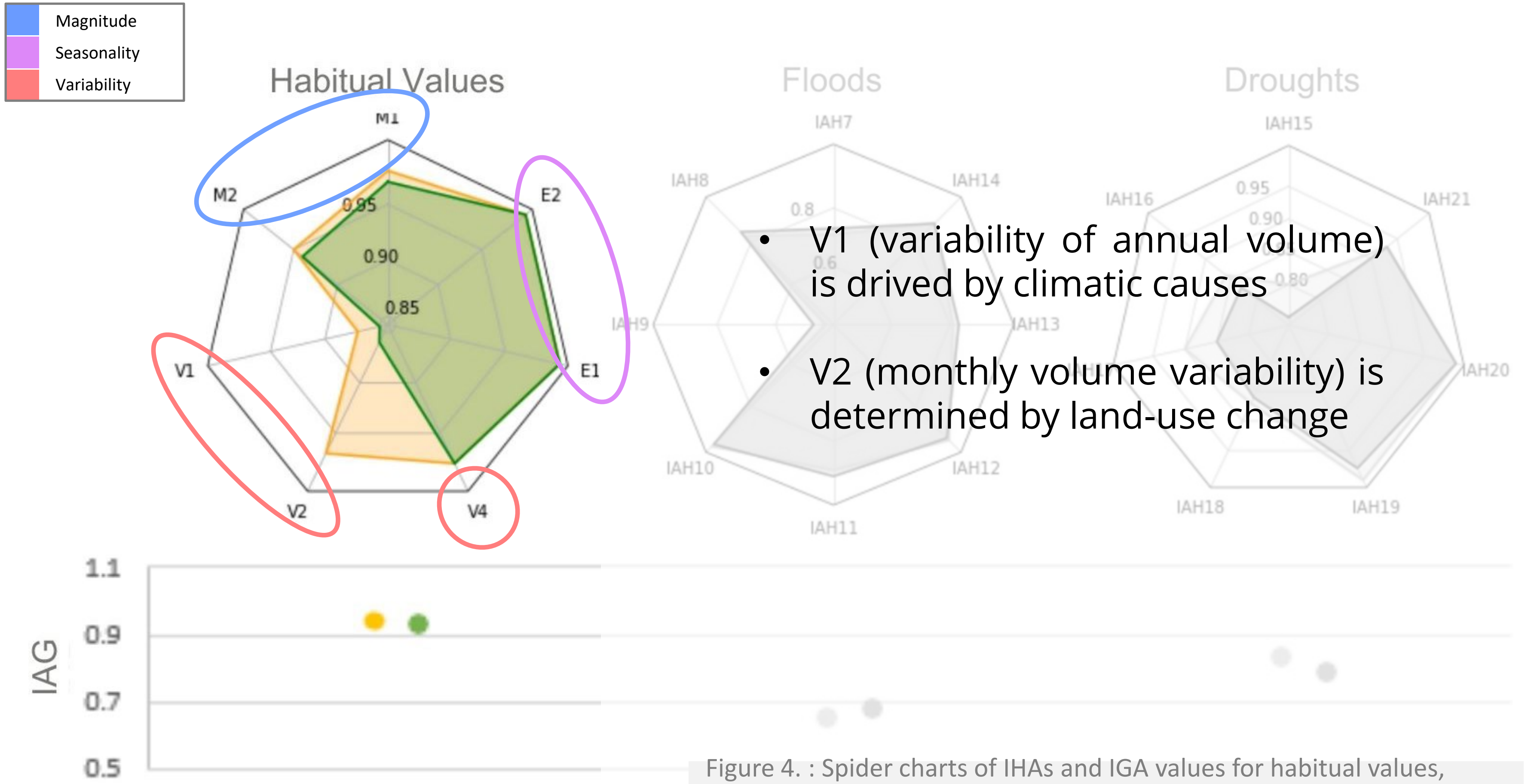


Figure 4. : Spider charts of IHAs and IGA values for habitual values, floods and droughts for Impact A-B and Impact A-C.

4. RESULTS

4.5. Indicators of hydrological alteration



- V1 (variability of annual volume) is drived by climatic causes
- V2 (monthly volume variability) is determined by land-use change

Figure 4. : Spider charts of IHAs and IGA values for habitual values, floods and droughts for Impact A-B and Impact A-C.

4. RESULTS

4.5. Indicators of hydrological alteration

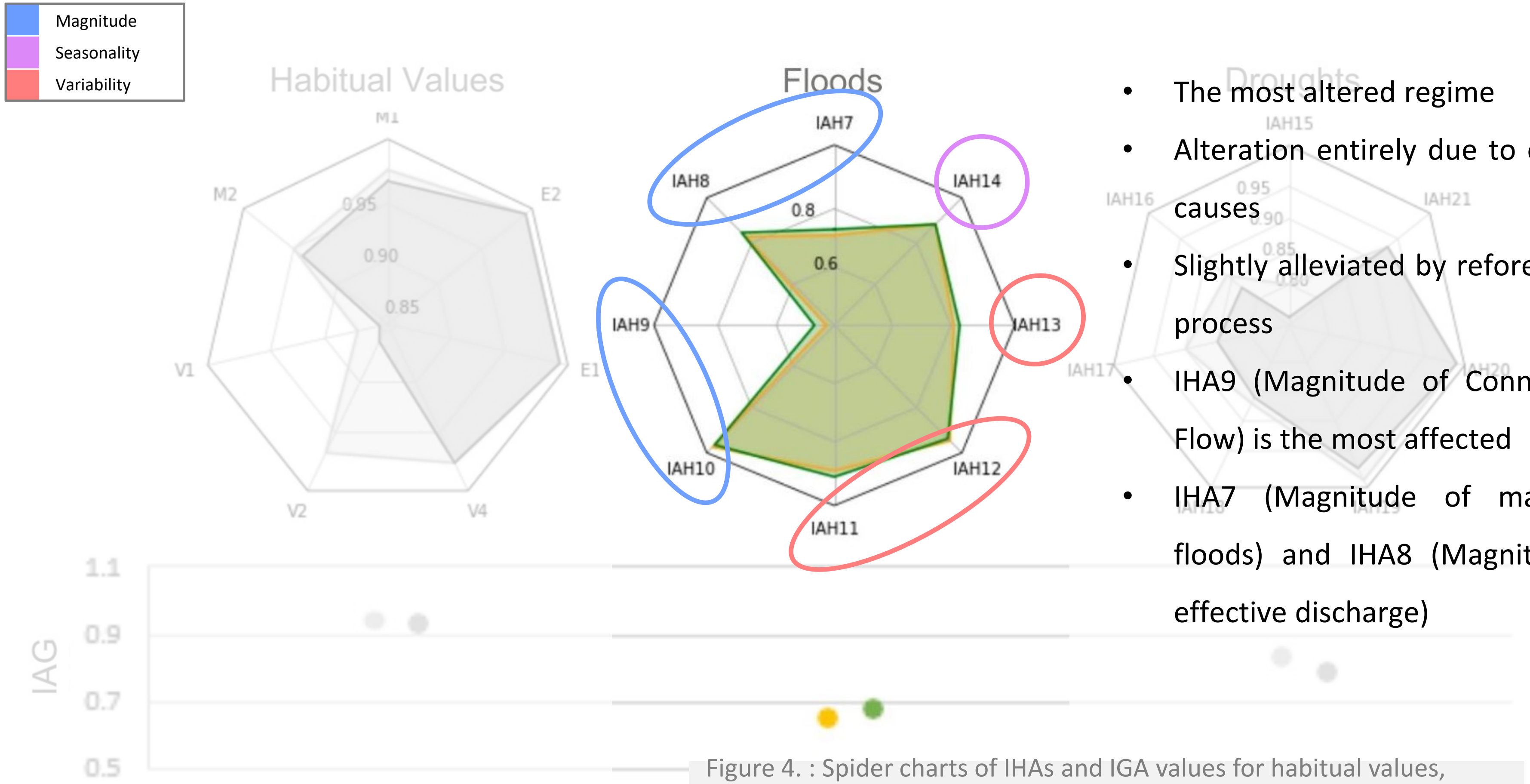


Figure 4. : Spider charts of IHAs and IGA values for habitual values, floods and droughts for Impact A-B and Impact A-C.

- The most altered regime
- Alteration entirely due to climatic causes
- Slightly alleviated by reforestation process
- IHA9 (Magnitude of Connectivity Flow) is the most affected
- IHA7 (Magnitude of máximum floods) and IHA8 (Magnitude of effective discharge)

CONSECUENCES:

- Deficiencies on the transport to the floodplain and riparian river system [8]
- Successional dynamics and aging of riparian habitat [9]

[8] Larsen et al., 2019 ;
[9] Wohl et al., 2015

4. RESULTS

4.5. Indicators of hydrological alteration

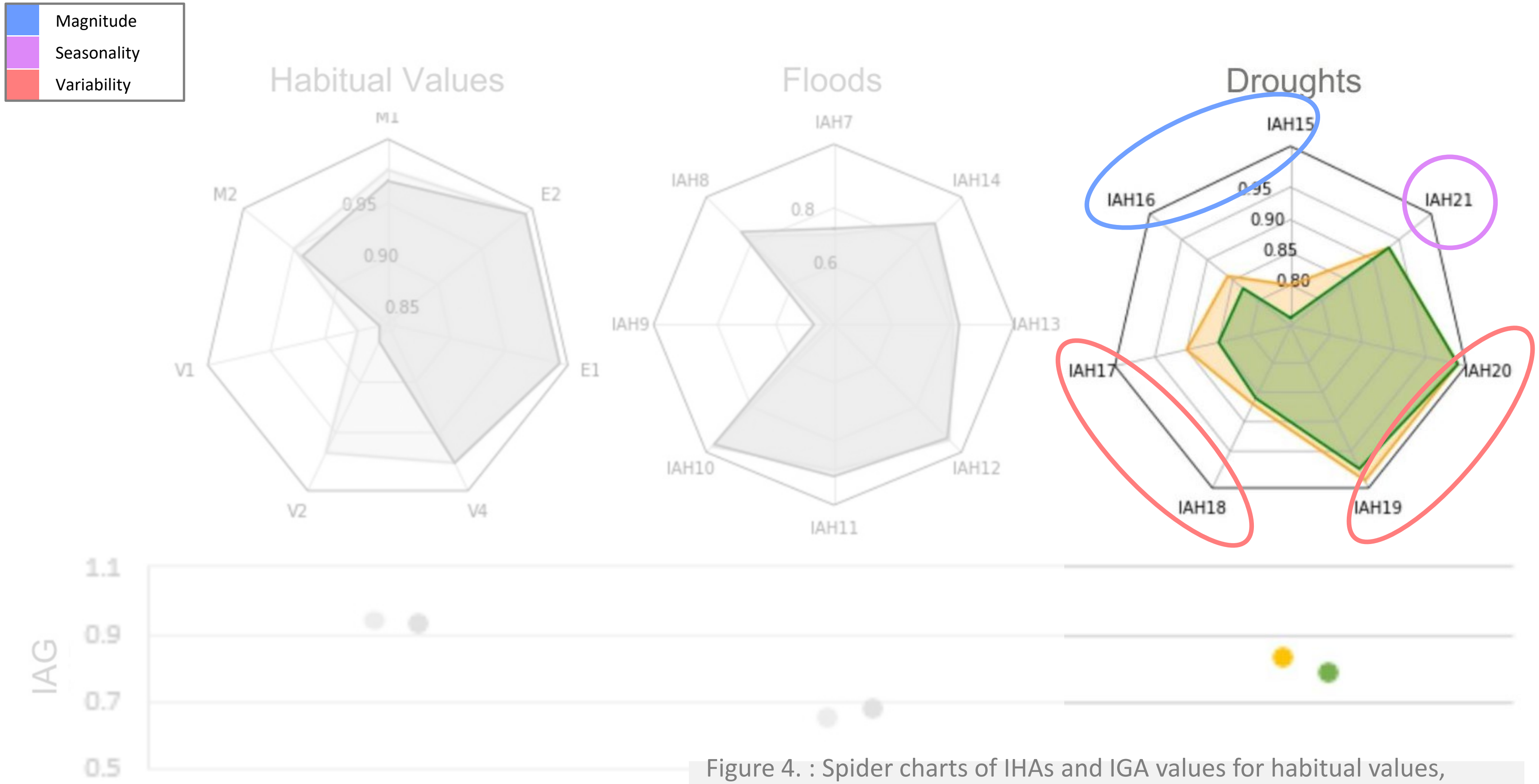


Figure 4. : Spider charts of IHAs and IGA values for habitual values, floods and droughts for Impact A-B and Impact A-C.

- The major alterations occurred in magnitude and frequency
- The combined effect of both factors exhacerbate the alterations on the hydrological regime

4. RESULTS

4.5. Indicators of hydrological alteration

- **H6 (variability of streamflow for each month):**
  - Increases were observed during March, June and October while decreases in variability were detected for winter months
- **H8 / H9 (Maximum/ Minimum relative frequency of the month):**
  - As a consequence of climate variability the probability of the annual maximum occurring in April increases
  - The probability of the minimum in September increases

CONSECUENCES:

- These alterations in the natural seasonal patterns could produce distorsions on the sycrhony with the life cycle of the species

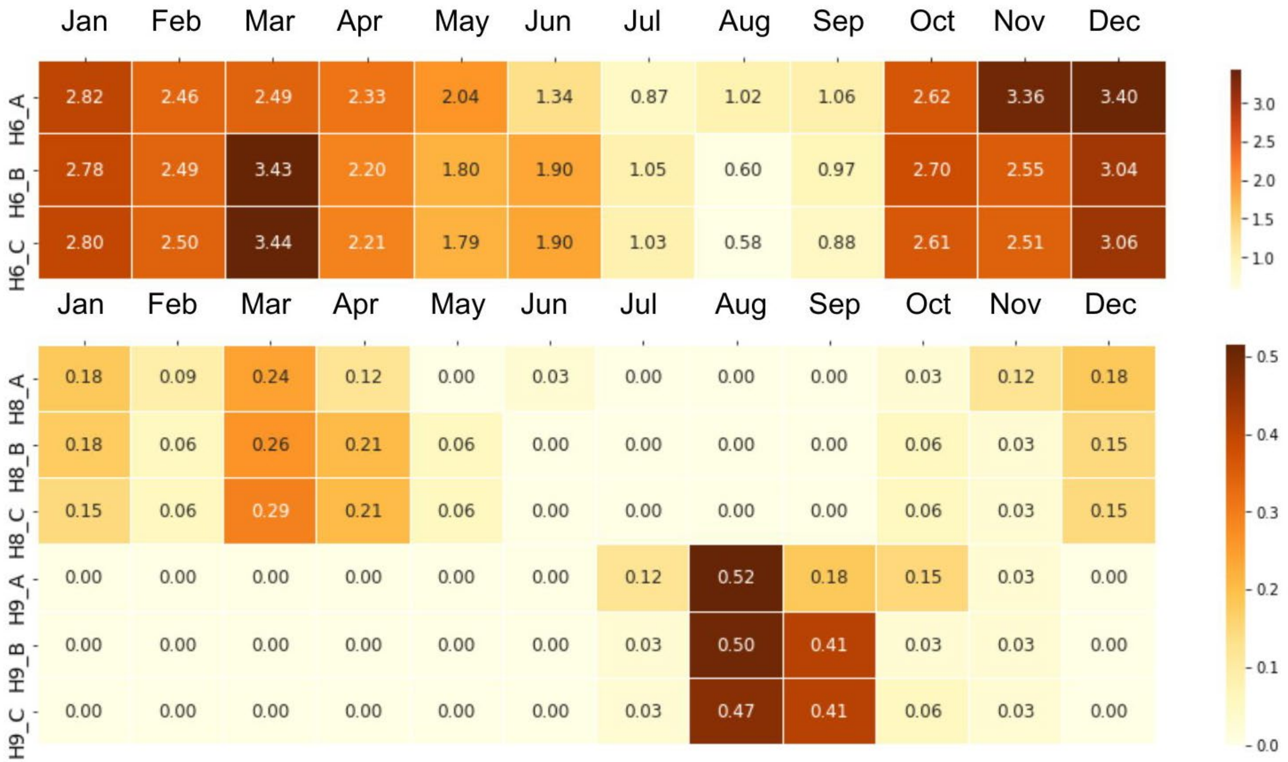


Figure 5. Monthly values for IAHRIS parameters under A, B and C scenario

5. Conclussions

- The favorable results of the model of the Anduña River Basin validate it for the daily simulation of the Scenarios
- The climate trend analysis revealed a significant positive trend for maximum and minimum temperatures and a slight positive trend in precipitation (Lemus-Canovas et al., 2018)
- A radical transformation of the distribution of land-use in the basin was observed, from a land dominated by pastures and shrubs to a basin were forests are predominant
- Climate change and the greenness process have decreased the mean annual streamflow in the Anduña River basin
- The contribution of climate change is of 58.6 %, while the contribution attributed to the greenness process is of 41.1 % ((Juez et al., 2022; Vicente-Serrano et al., 2021; López-Moreno et al., 2008)
- Increase of floods caused by climatic causes (Roy et al., 2001; Stoffel et al., 2016). This increase is attenuated by the reforestation process.
- In the cases of the usual values and extreme minimums (droughts), the reforestation process acted as an aggravating factor in altering the water regime, together with climatic causes.

5. References

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