

Assessing changes in land use and their effects on river flows in tropical catchments of Ecuador

Andy Giler-Ormaza^{1,2}, Rafael Pimentel², and Cristina Aguilar²

·PUCE Sede Manabí, Hydraulic Engineering, Ecuador (andygiler90@hotmail.es)

·Fluvial Dynamics and Hydrology Research Group. Andalusian Institute for Earth System Research, University of Cordoba, Córdoba, Spain

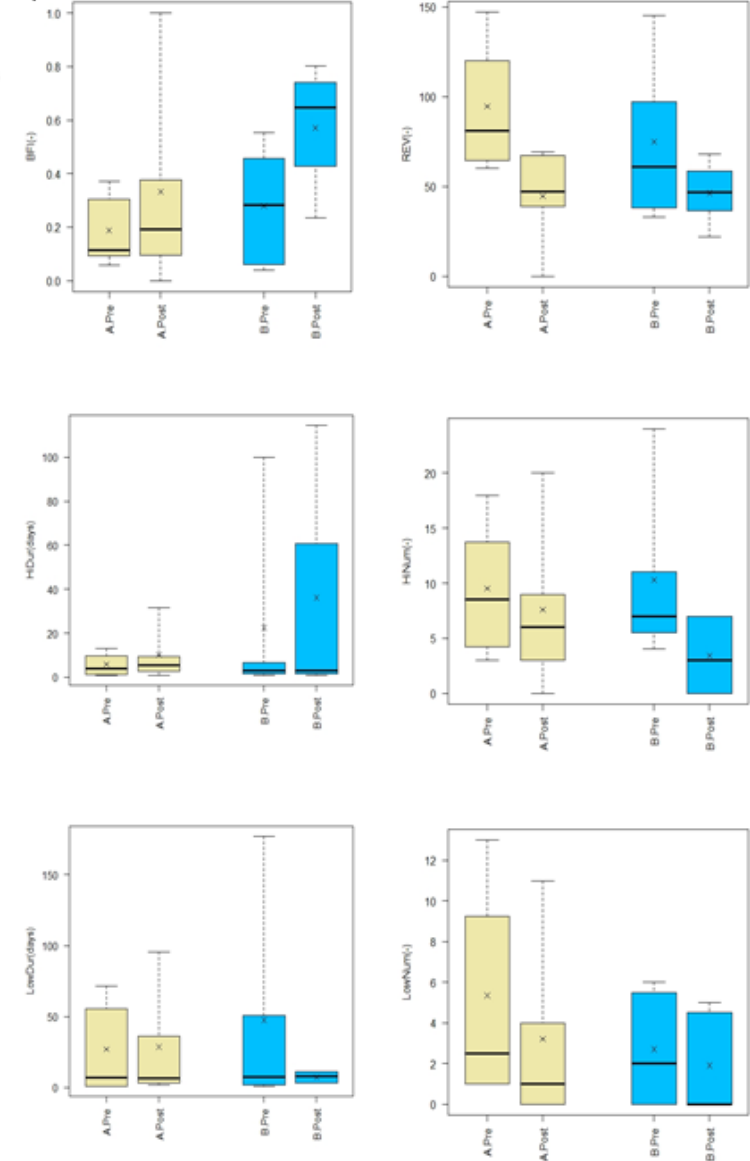
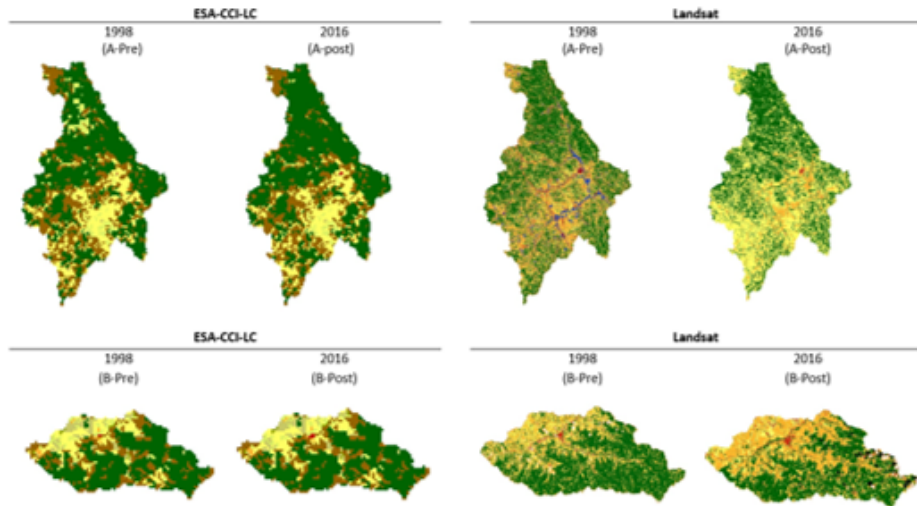
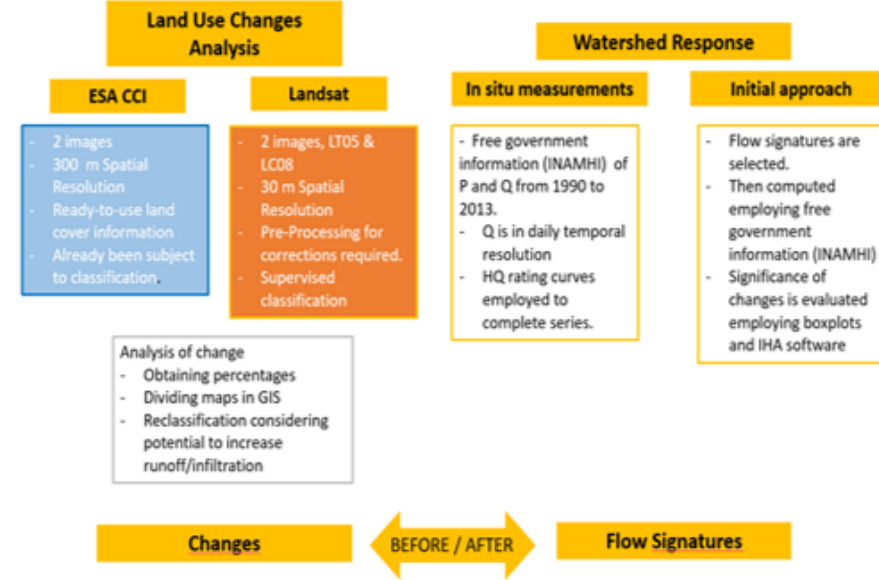
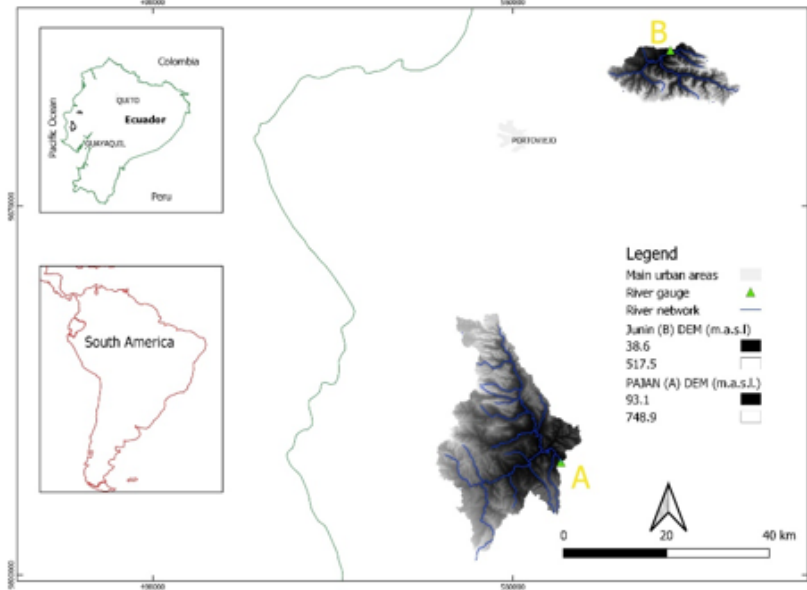
<https://meetingorganizer.copernicus.org/EGU21/EGU21-13190.html>



Image source: Ministerio de Gobierno del Ecuador (2014)



Rio Junin tributary on 27jan2021



Background

- Changes in land use and land cover (LULC) can have direct effects on streamflows at the catchment scale. However, studies of this type are still lacking in some tropical areas of the globe where LULC changes constitute the main anthropic changes at watershed scale; for instance, deforestation, and agricultural modification among others. Therefore, for analysing impacts on streamflow, the first challenge is to achieve a good characterization of LULC.
- Junín and Paján catchments are located on the South American coast in Ecuador. Traditional dominant land use is agriculture for several types of crops including evergreen crops, cash-crops, and for grazing . With population growth and increasing demands for land and food supply, the forest frontier is being pushed further and the grazing activities are increasing.



Image source: El Diario (2009)

Rio Junín on 27jan2021



Overview

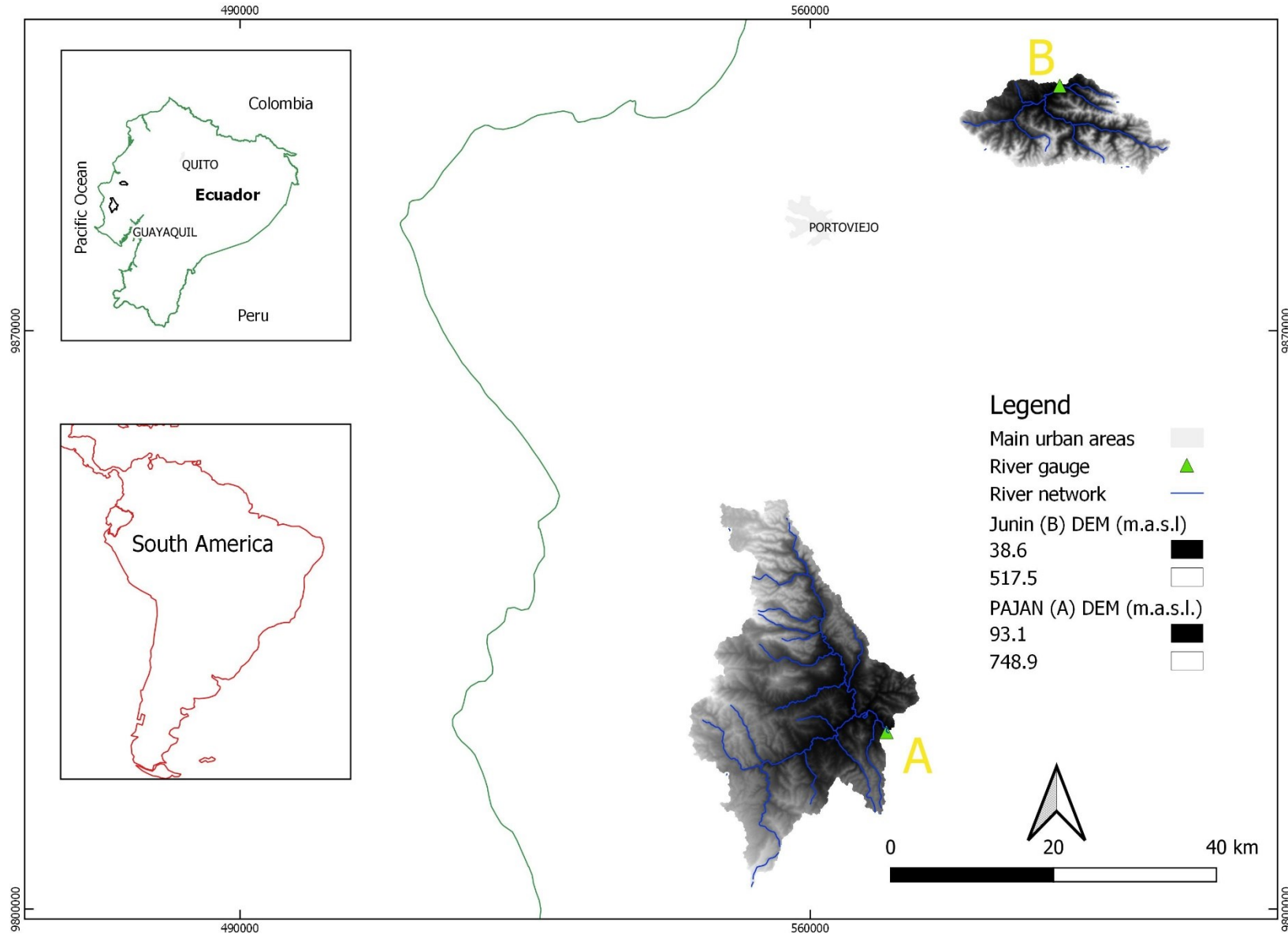
Background

Aims and
Study Site

Methods

First LULCC
results

First impact
results



Aims and Study Site

The objective is to evaluate whether LULC changes have occurred for two small basins (Junín and Paján), and to analyse their possible effects on flows with special emphasis on minimum flows. Both catchments are characterized by savannah (Aw) climate with seasonal rainfall patterns and a long period of minimum to zero precipitation

Overview

Background

Aims and Study Site

Methods

First LULCC results

First impact results

Aims and Study Site

The objective is to evaluate whether LULC changes have occurred for two small basins (Junín and Paján), and to analyse their possible effects on flows with special emphasis on minimum flows. Both catchments are characterized by savannah (Aw) climate with seasonal rainfall patterns and a long period of minimum to zero precipitation

Catchment	Area	Mean Elevation	Slope	Main Land uses*	Mean P Rainy season***	Mean P Dry season**	Mean T
Units	Km²	m a.s.l.		(%)**	mm	mm	Celsius
Paján (A)	640.57	421	0.020	50 (53.7%), 120 (27.2%), 10(14.7%), 30(2.46%)	962.57	42.12	18 to 24
Junín (B)	188.09	278	0.030	50 (49.6%), 120(23.8%), 10 (13.1%), 40(6.78%), 30 (4.75%)	985.47	21.99	18 to 24

*Based on ESA-CCI-LC 2015

**SEE ESA-CCI-LC Legend

- 50 Tree cover broadleaved evergreen closed to open larger than 15%
- 120 Shrubland
- 10 Cropland rainfed
- 40 Mosaic natural vegetation (tree/shrub/herbaceous cover)(larger than 50%)/cropland (less than 50%)
- 30 Mosaic cropland (larger than 50%) / natural vegetation (tree/shrub/herbaceous cover)(less than 50%)

***Taken here from December to May. ENSO years such as 1991, 1997 and 1998 are not considered here

****Taken here from June to November. ENSO years such as 1991, 1997 and 1998 are not considered here

Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

Flow (Q) data available for the study catchments.
Percentages Q data per year per station

INAMHI code- Basin Name (Station ID)/ Years	H359- Pajan* (A) Q (%)	H233- Junin (B) Q (%)
1990	0.0	100.0
1991	100.0	100.0
1992	50.3	100.0
1993	98.4	100.0
1994	100.0	100.0
1995	97.5	100.0
1996	98.9	99.7
1997	98.6	99.7
1998	100.0	83.3
1999	100.0	100.0
2000	99.7	99.7
2001	100.0	100.0
2002	99.7	81.1
2003	98.4	100.0
2004	99.5	78.7
2005	87.7	91.5
2006	100.0	91.5
2007	99.2	0.0
2008	98.9	0.0
2009	100.0	0.0
2010	100.0	0.0
2011	92.9	0.0
2012	99.2	0.0
2013	74.9	0.0

*There was a dam upstream the gauging station.
It was constructed in 1992 and worked for 5 years.
Its reservoir has silted and is now not in operation.
Therefore, this river could now be considered as a
Non-regulated river.

Link: <http://www.eldiario.ec/noticias-manabi-ecuador/353748-riesgo-en-antigua-presa/>

Study site: Flow data available

- Free Q INAMHI data available online.
- Percentages include Q generated with rating curves.
- For Pajan (A), Q available from 1991 to 2013
- For Junín (B), Q available from 1900 to 2006

Overview

Background

Aims and
Study Site

Methods

First LULCC
results

First impact
results

Land Use Changes Analysis

ESA CCI

- 2 images
- 300 m Spatial Resolution
- Annual Temporal Resolution
- Ready-to-use land cover information
- Already been subject to classification

Landsat

- 2 images, Level 1, Terrain Precision, Tier1.
- LT05 & LC08
- 30 m Spatial Resolution
- 8 to 16 days Temporal Resolution
- Pre-Processing for corrections required.
- Supervised classification

Analysis of change

- Obtaining percentages with DataPlotly
- Dividing maps in GIS
- Reclassification considering potential to increase runoff/infiltration
- Reclassification based on hydrologic literature

Watershed Response

In situ measurements

- Evaluation of Data availability of P and Q.
- Free government information (INAMHI) of P and Q from 1990 to 2013.
- Q is in daily temporal resolution
- P and other meteorological variables are in Monthly temporal resolution
- Q and P data available upon request (also INAMHI) can go back to 1972. Still in process.
- Where possible, HQ rating curves employed to complete series.
- IHA software for linear interpolation.

Initial approach

- Flow signatures regarding duration and frequency of extreme events are selected.
- To gain insights, the selected Flow signatures are computed employing free government information (INAMHI) of Q from 1990 to 2013.
- In the meantime more data, are being requested (also INAMHI).
- Significance of changes is evaluated employing boxplots and IHA software

Changes

BEFORE / AFTER

Flow Signatures

Overview

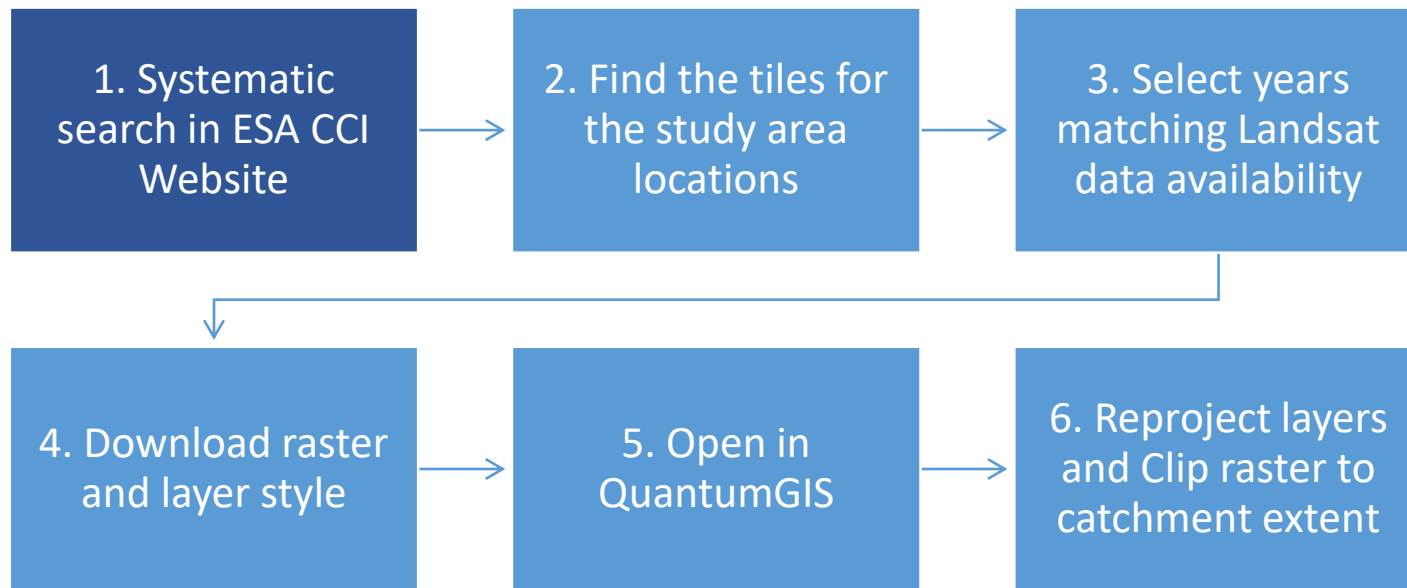
Background

Aims and
Study Site

Methods

First LULCC
results

First impact
results

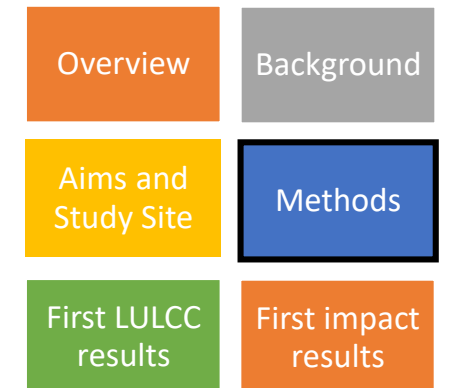


ESA-CCI-LC and DataPlotly workflow

Methods I: ESA CCI

Changes in LULC are studied using two sources of remote sensing information: ESA-CCI-LC (ESA, 2017) at spatial resolution of 300 m and Landsat (USGS, 2018) at spatial resolution of 30 m, together with local authorities reports within the last decades. While ESA-CCI-LC directly provides LULC information, LULC was retrieved from surface reflectance after preprocessing (atmospheric and topographic corrections) from Landsat by using a supervised algorithm.

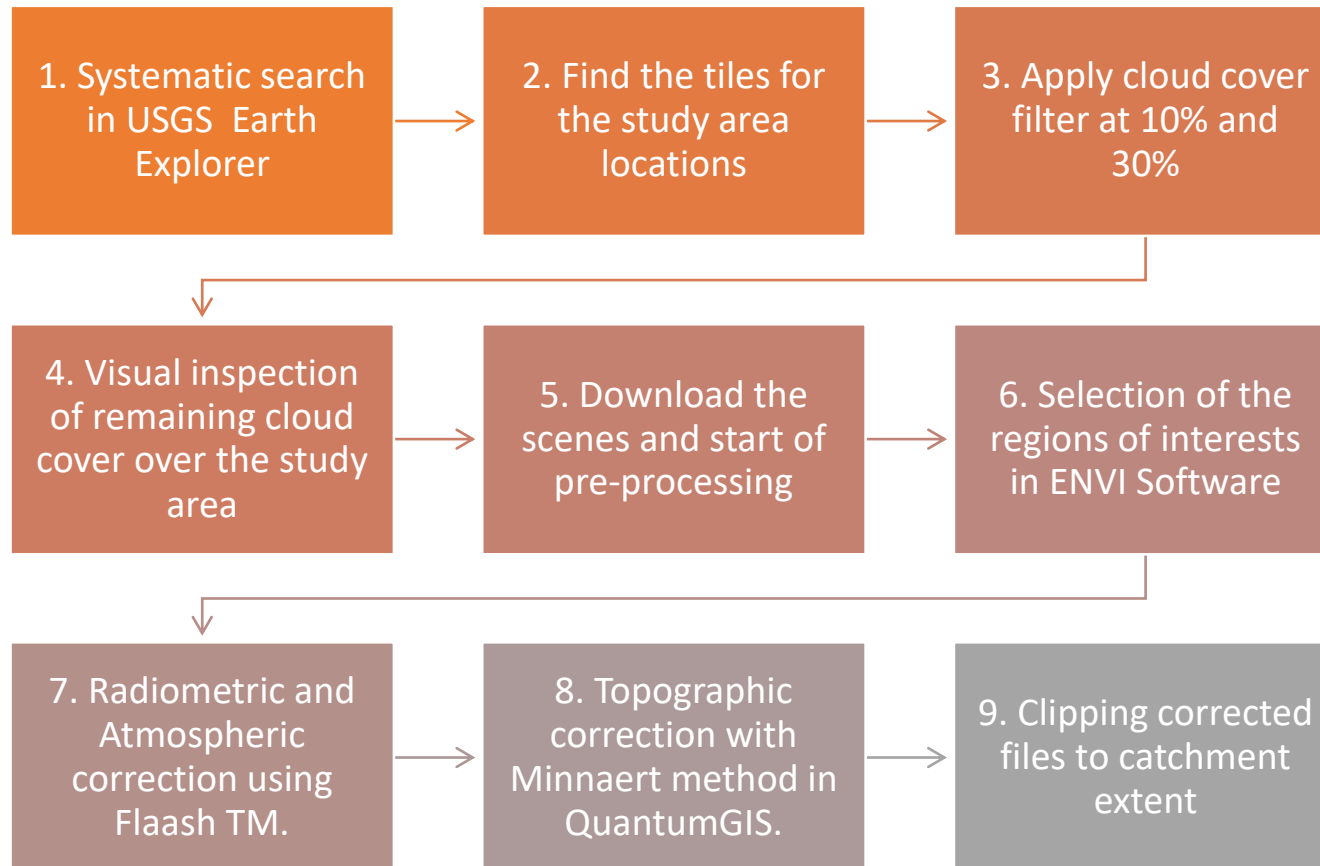
In an **initial approach** the observed changes are compared with variation in streamflow in the outlet of both catchments.



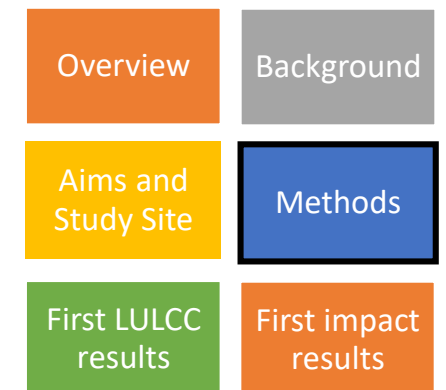
Methods II: Landsat pre-processing

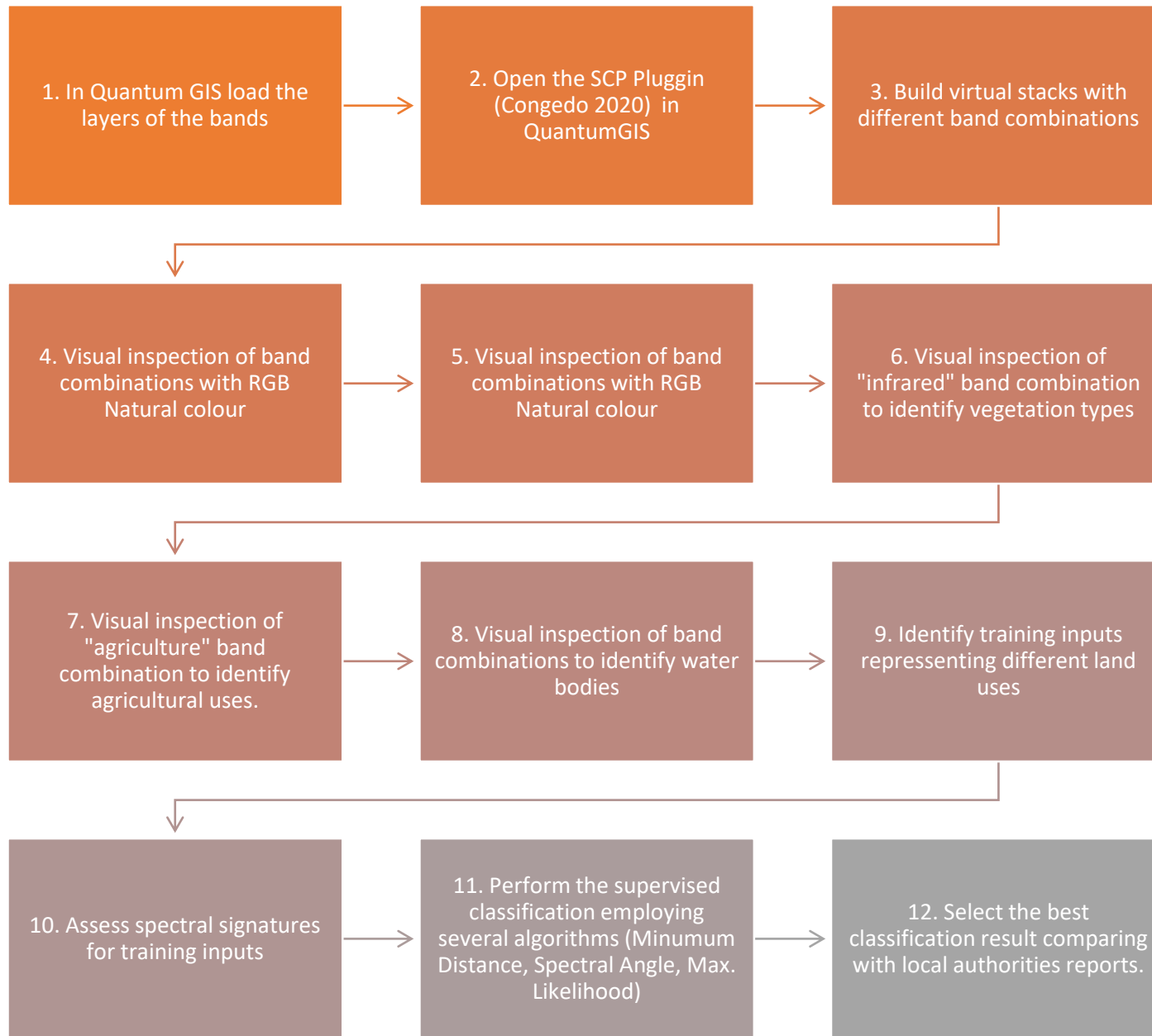
Changes in LULC are studied using two sources of remote sensing information: ESA-CCI-LC (ESA, 2017) at spatial resolution of 300 m and Landsat (USGS, 2018) at spatial resolution of 30 m, together with local authorities reports within the last decades. While ESA-CCI-LC directly provides LULC information, LULC was retrieved from surface reflectance after preprocessing (atmospheric and topographic corrections) from Landsat by using a supervised algorithm.

In an **initial approach** the observed changes are compared with variation in streamflow in the outlet of both catchments.



Landsat downloading and preprocessing workflow



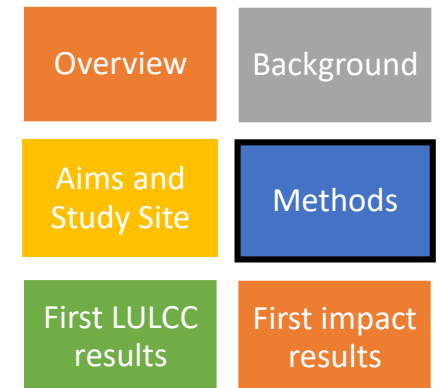


Supervised classification workflow employing Landsat

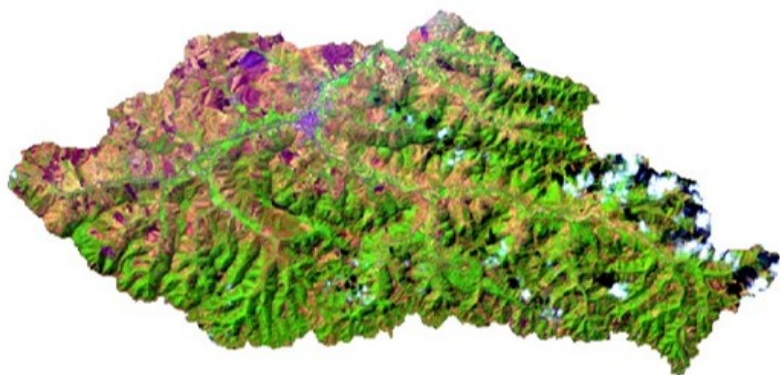
Methods II: Landsat supervised classification

Changes in LULC are studied using two sources of remote sensing information: ESA-CCI-LC (ESA, 2017) at spatial resolution of 300 m and Landsat (USGS, 2018) at spatial resolution of 30 m, together with local authorities reports within the last decades. While ESA-CCI-LC directly provides LULC information, LULC was retrieved from surface reflectance after preprocessing (atmospheric and topographic corrections) from Landsat by using a supervised algorithm.

In an **initial approach** the observed changes are compared with variation in streamflow in the outlet of both catchments.



27 novembre 2016



Methods

Example of Visual inspection of band combinations with Landsat before supervised classification is carried out.

Overview

Background

Aims and
Study Site

Methods

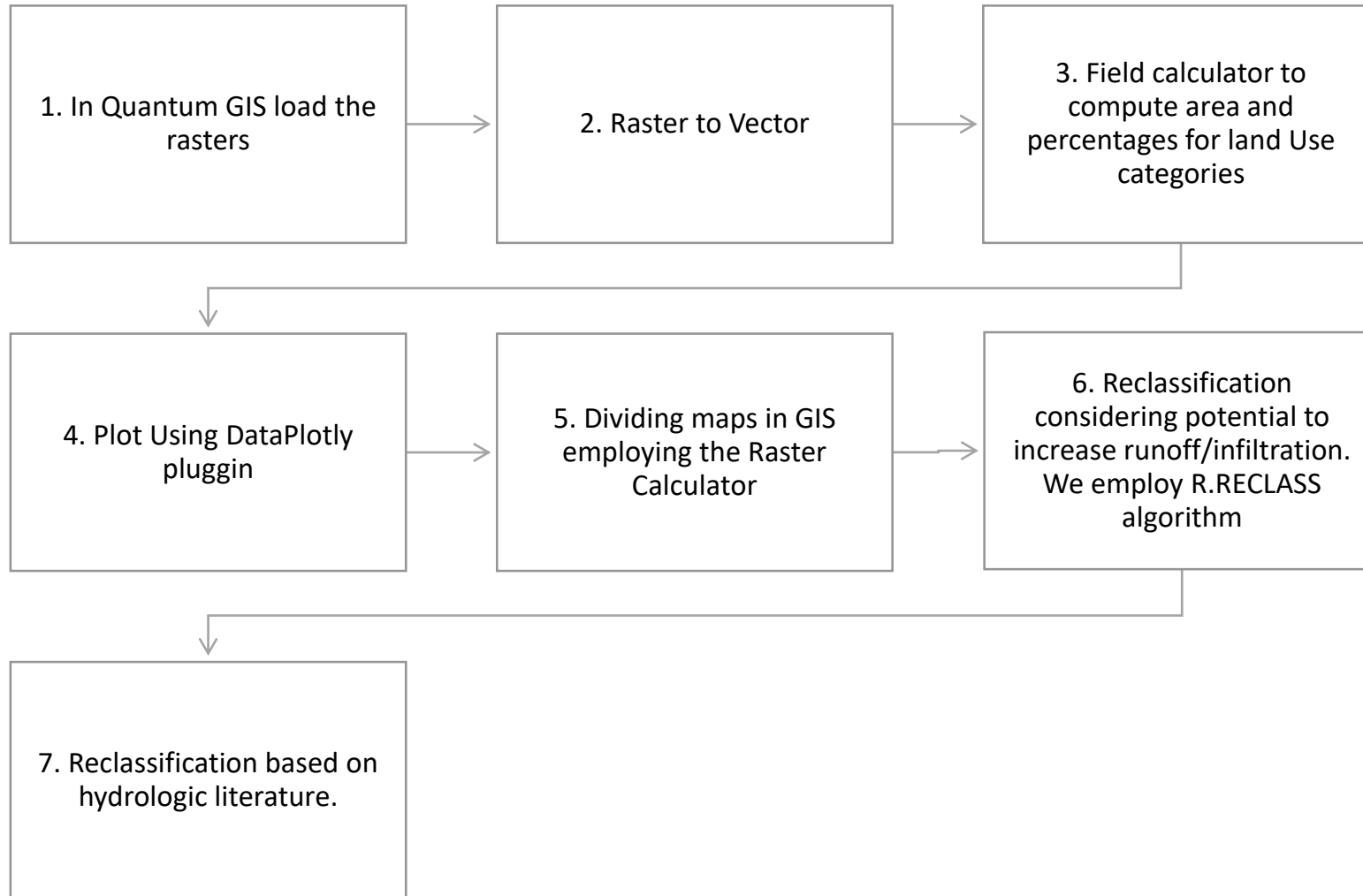
First LULCC
results

First impact
results

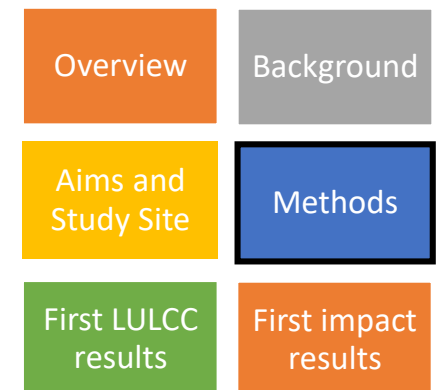
Methods III: Analysis of change

Changes in LULC are studied using two sources of remote sensing information: ESA-CCI-LC (ESA, 2017) at spatial resolution of 300 m and Landsat (USGS, 2018) at spatial resolution of 30 m, together with local authorities reports within the last decades. While ESA-CCI-LC directly provides LULC information, LULC was retrieved from surface reflectance after preprocessing (atmospheric and topographic corrections) from Landsat by using a supervised algorithm.

In an **initial approach** the observed changes are compared with variation in streamflow in the outlet of both catchments.

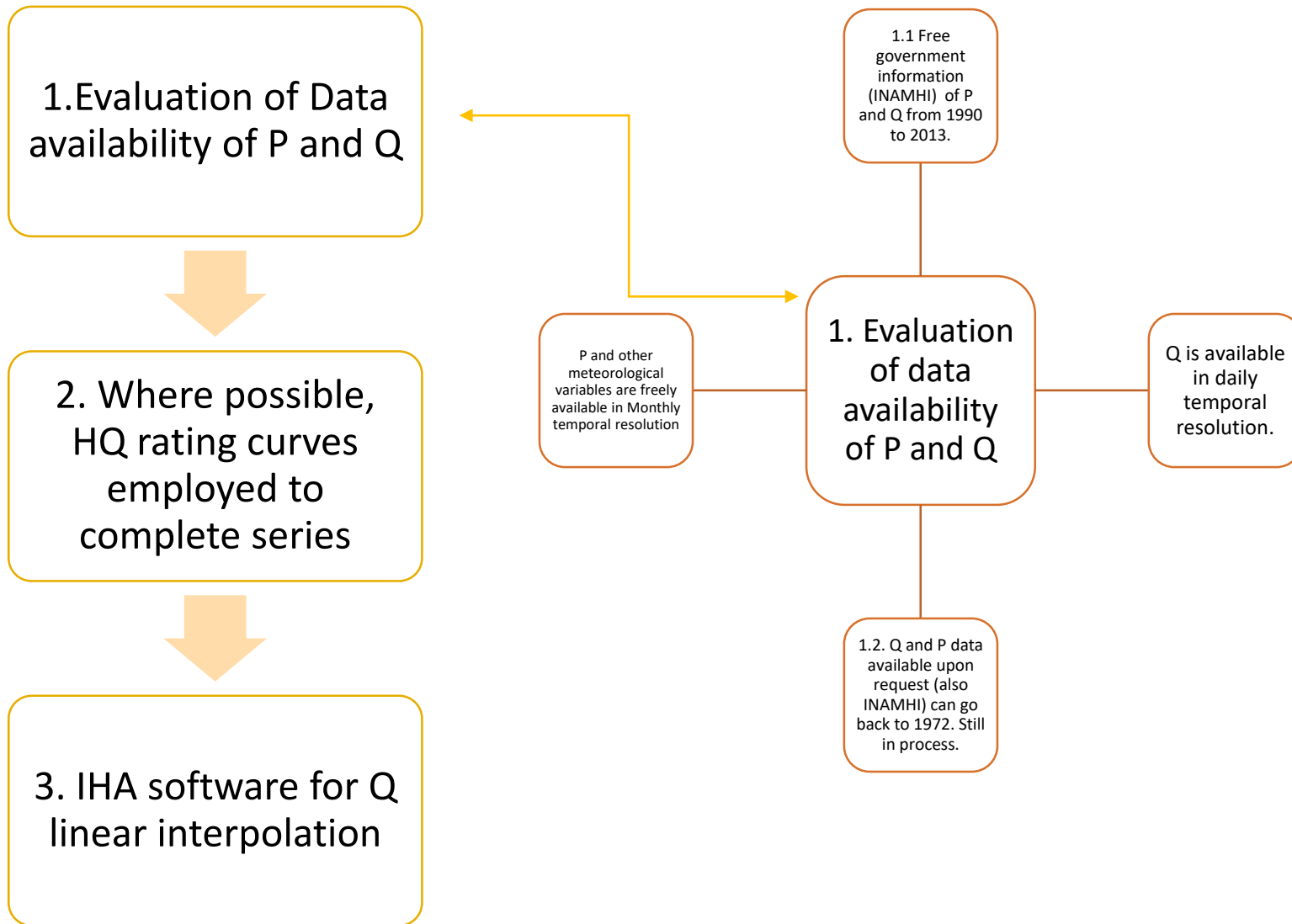


Supervised classification workflow employing Landsat



Methods IV: In-situ measurements and processing.

In a preliminary approach the observed LULC changes are compared with variations in streamflow (Q) in the outlet of both catchments.



Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

1. Flow signatures regarding duration and frequency of extreme events are selected. Based on Kuentz et al (2017), Pimentel and Arheimer (2021), Guzha et al (2015), Zhang et al (2016)



2. Based on Landsat imagery availability with Little cloud cover (only 2 scenes), the Free Q time series is divided in two periods: a) From 1990 to 1998 (before); b) From 1998 to 2013 (after)



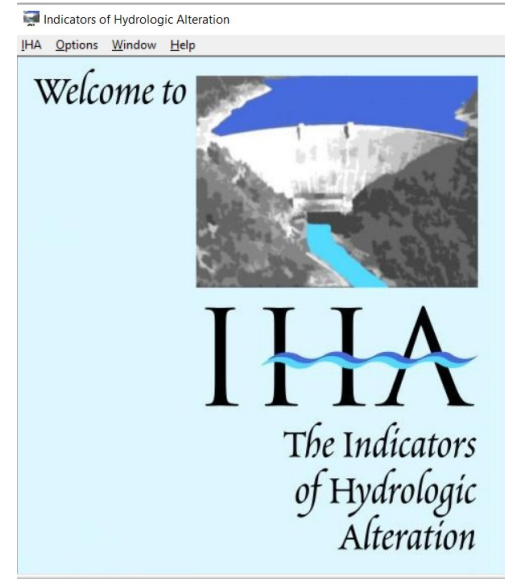
3. To gain insights, the selected Flow signatures are computed employing free government information (INAMHI) of P,Q and H, from 1990 to 2013.



4. Signatures are computed manually in excel, with hydrostats package in R, and with IHA software



5. Significance of changes is evaluated employing IHA software and boxplots



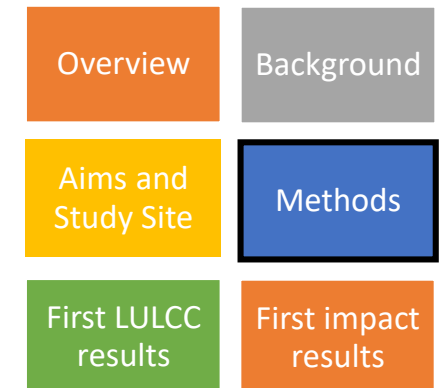
The Nature Conservancy (2011)

Methods V: The Initial approach

In a preliminary approach the observed LULC changes are compared with variation in streamflow in the outlet of both catchments

Flow Signatures are computed and a comparison before/after periods is carried out.

For variation of streamflow to be significant, there must be no interquartile overlapping between boxplots.



Methods V: The Initial approach

There are many Flow Signatures, AKA hydrologic indices, but here we selected a few, adapting Kuentz et al. (2017) and Pimentel and Arheimer (2021).

Component of flow regime		Variable	Units	Description
Magnitude of flow events	Low flow conditions	BFI	-	Baseflow Index: mean of 7-days minimum daily flow within a year divided by mean annual daily flow
Frequency events of flow	Low flow conditions	LowNum	-	Annual number of low flow spells (threshold equal to of flow conditions 25% of mean daily flow)
	High flow conditions	HiNum	-	Annual number of high flow conditions occurrences (threshold 75th percentile)
Duration of the flow events	Low flow conditions	LowDur	Days	Duration of daily flows below the annual 25th percentile of daily flows
	High flow conditions	HiDur	Days	Duration of daily flows above the annual 75th percentile of daily flows
Rate of change in flow events		Rev	-	annual number of reversals (change in the sign in the day-to-day change time series)

Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

First LULCC Results

- Regarding Landsat scenes, cloud cover was extensive in the study catchments.
- The catchments in this study can be evaluated using Landsat satellite paths 10 and 11; and rows 60 and 61
- We found a total of 3237 scenes from which only 15 scenes had less than 10% cloud cover
- Out of the 15 images, only 2 allowed for the visualization of the full extent of our catchments.
- Because our catchments are also headwaters of important local rivers, and the divide matches the highest elevations of a coastal cordillera, clouds tend to be concentrated most of the time in those places.
- In summary, out of the many potential Landsat tiles, only 2 could be employed along the study period.

Years available	1972 to 2013	1982-2013	1999-2020	2013-2020
Landsat sensor/ Cloud cover filter	LS 1-5 MSS	LS 4-5 TM	LS 7ETM+	LS 8 OLI/TIRS
No filter	122	800	1610	705
30% Cloud filter	17	40	77	24
10% Cloud filter	4	3	5	3

Number of Landsat scenes results with no cloud filter, with 30% filter and with 10% filter

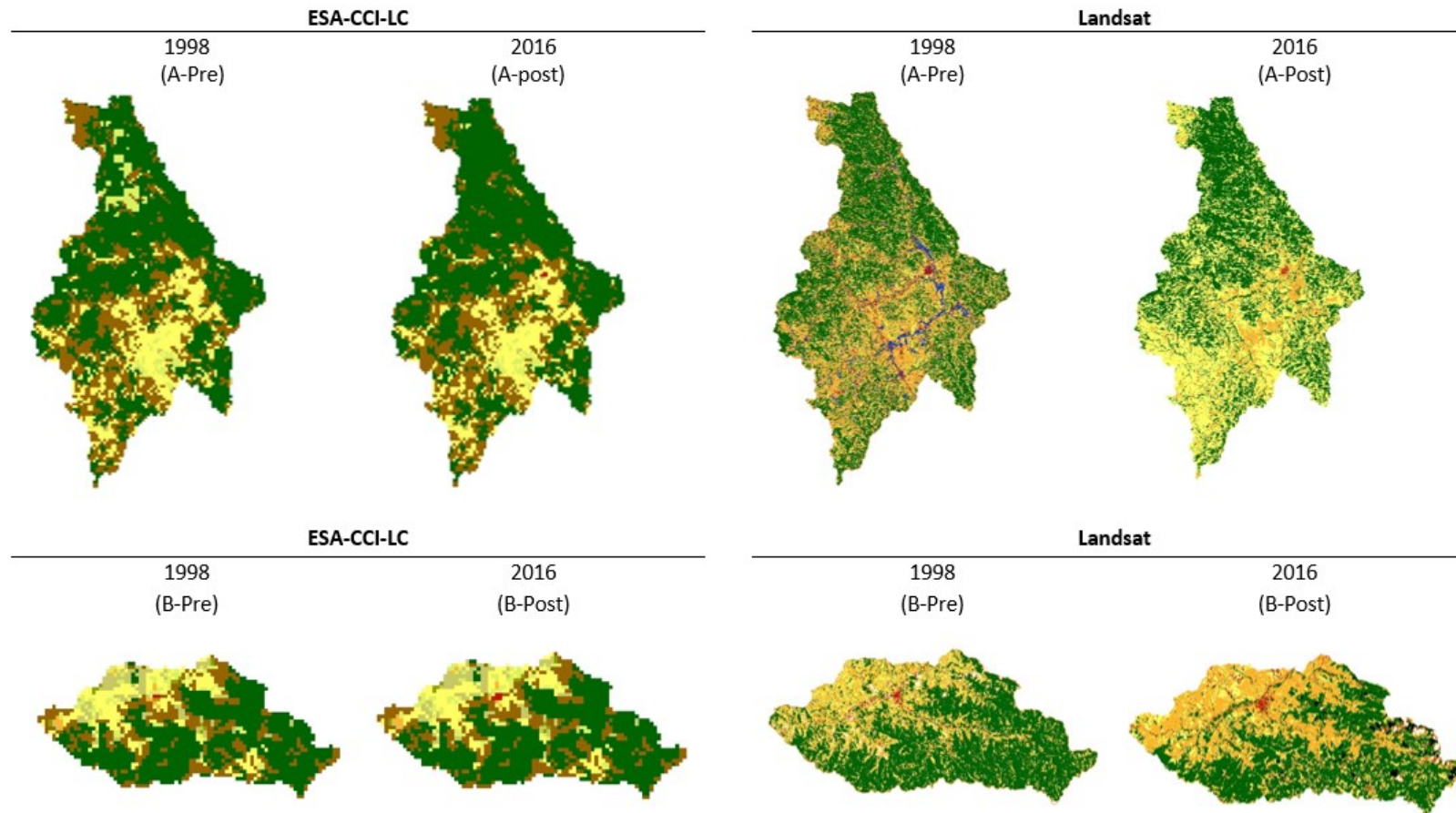
Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

- Cropland rainfed
- Mosaic cropland (>50%) / natural vegetation (tree shrub herbaceous cover) (<50%)
- Mosaic natural vegetation (tree shrub herbaceous cover) (>50%) / cropland (<50%)
- Tree cover broadleaved evergreen closed to open (>15%)
- Shrubland
- Grassland
- Urban areas
- Bare areas
- Water bodies

First LULCC Results

Results show that for one of the catchments, B, ESA-CCI-LC does not reflect changes, while the analysis with Landsat TM shows a decrease of 11.7% of evergreen in favor of agricultural activities.

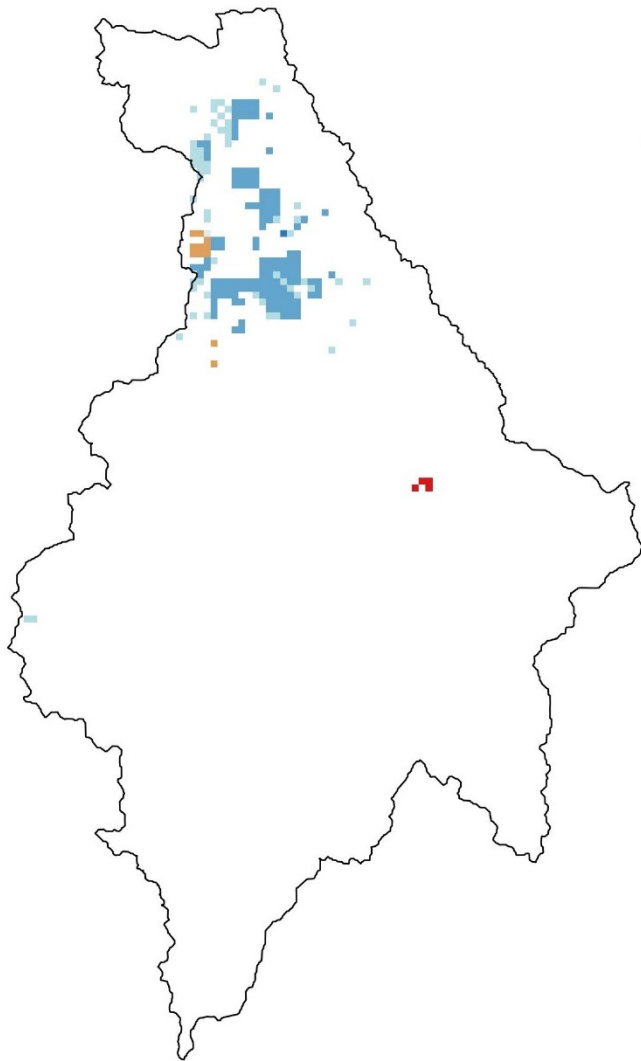
For the other basin, A, the first source indicates a 2.8% increase in evergreen forest, while the second source indicates the opposite, a decrease of 7.4%.



Comparison of results employing both sources: ESA-CCI-LC (Left) and Landsat (Right). Legend adopted from ESA Land Cover CCI PRODUCT USER GUIDE VERSION 2.0

Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

Legend



- 0.0526 cropland rainfed to urban
- 0.2 cropland rainfed to forest
- 0.22 cropland herbaceous to forest
- 0.42 forest to shrubland
- 0.6 mosaic half cropland to forest
- 0.684 grassland to urban
- 1 No change
- 2.4 shrubland to forest
- 4 shrubland to mosaic half cropland
- 12 shrubland to rainfed cropland

Instructions to reclassify

instructionsRclass5thOp: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
0.58 thru 0.62 = 1
0.2 thru 0.2 = 1
0.22 thru 0.22 = 1
0.4 thru 0.4 = 1
2.4 thru 2.4 = 1
0.42 thru 0.42 = 2
12 thru 12 = 2
6 thru 6 = 2
4 thru 4 = 2
0.684211 thru 0.684211 = 2
0.0526316 thru 0.0526316 = 2
1 thru 1 = 0
```

Changes from 1998 to 2016. Pajan catchment (A)

First LULCC Results

- Here the results from dividing the ESA-CCI-LC maps employing the Raster Calculator.
- Only Pajan showed changes, Junín did not show any.
- Afterwards, the values in the legend were reclassified

Overview

Background

Aims and
Study Site

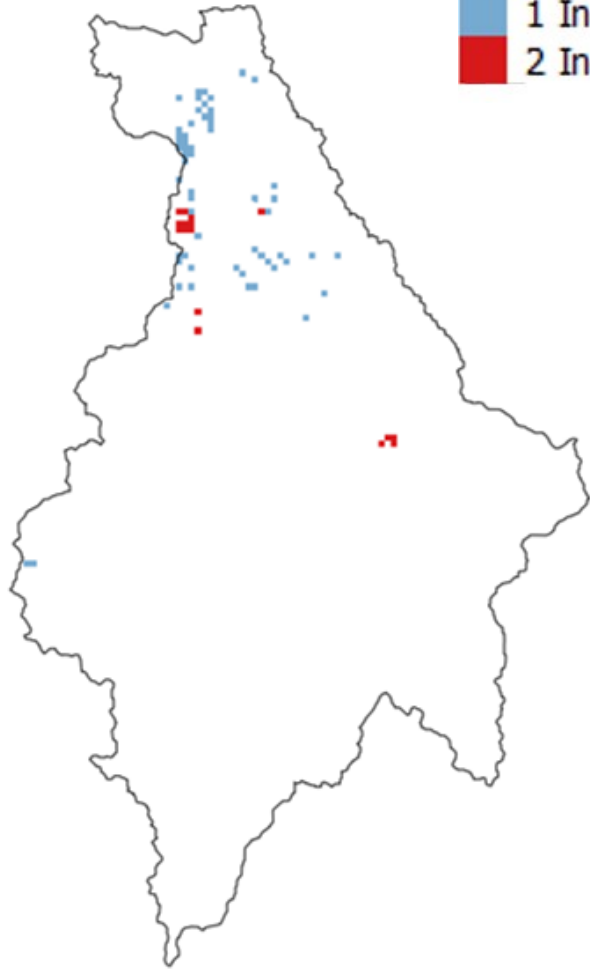
Methods

First LULCC
results

First impact
results

Legend

- 0 No change
- 1 Increased infiltration
- 2 Increased runoff



Instructions to reclassify

instructionsRclass5thOp: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
0.58 thru 0.62 = 1
0.2 thru 0.2 = 1
0.22 thru 0.22 = 1
0.4 thru 0.4 = 1
2.4 thru 2.4 = 1
0.42 thru 0.42 = 2
12 thru 12 = 2
6 thru 6 = 2
4 thru 4 = 2
0.684211 thru 0.684211 = 2
0.0526316 thru 0.0526316 = 2
1 thru 1 = 0
```

First LULCC Results

- Some of the LULC changes detected with ESA-CCI-LC are expected to increase runoff, while other changes, to increase infiltration
- Reclassification considering potential to increase runoff/infiltration, based on hydrologic literature.
- R.RECLASS Algorithm or its execution (or both) here have a flaw. It is not working to the expected output.

Overview

Background

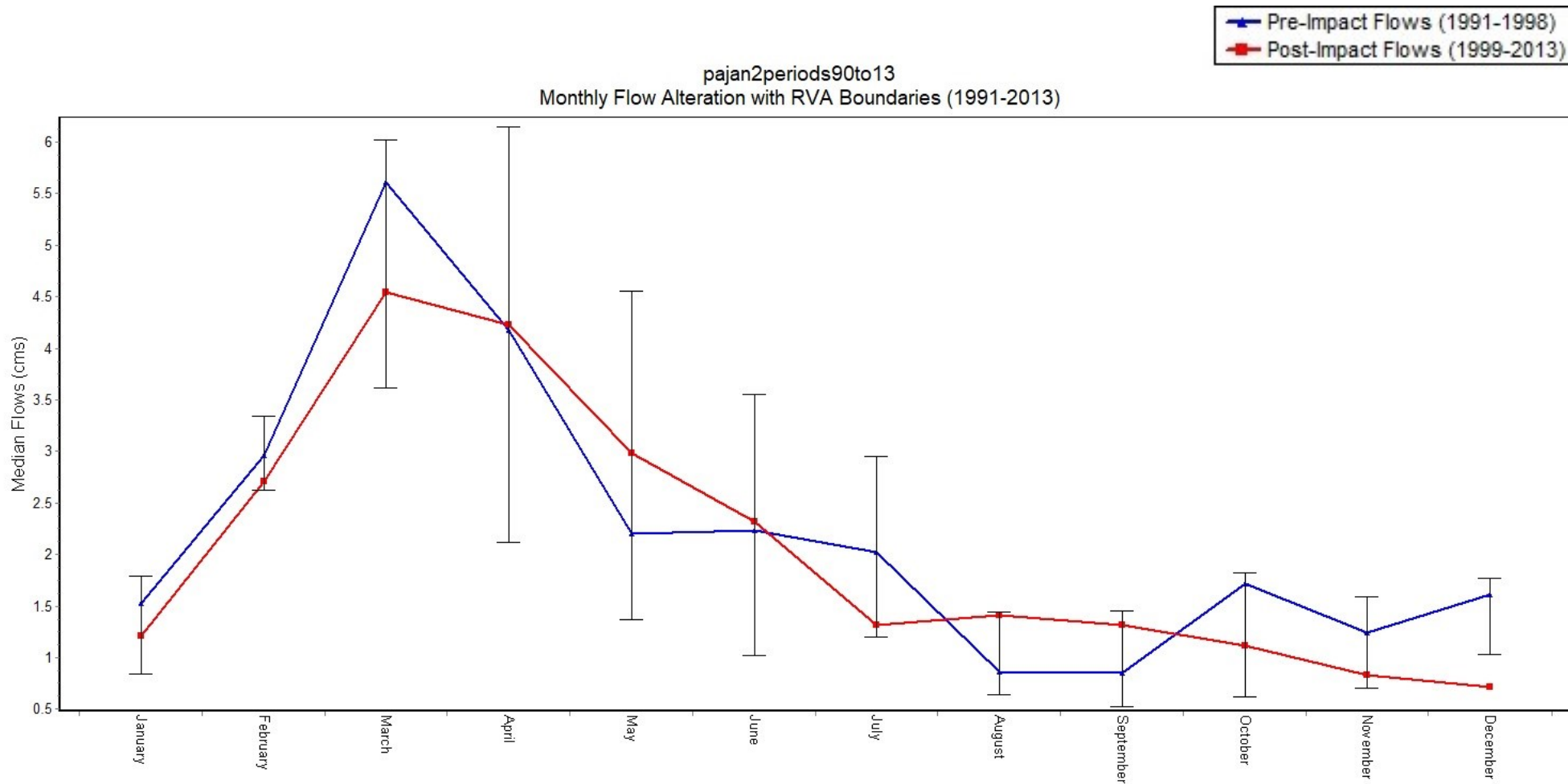
Aims and
Study Site

Methods

First LULCC
results

First impact
results

First impact Results: 1 monthly patterns



Overview

Background

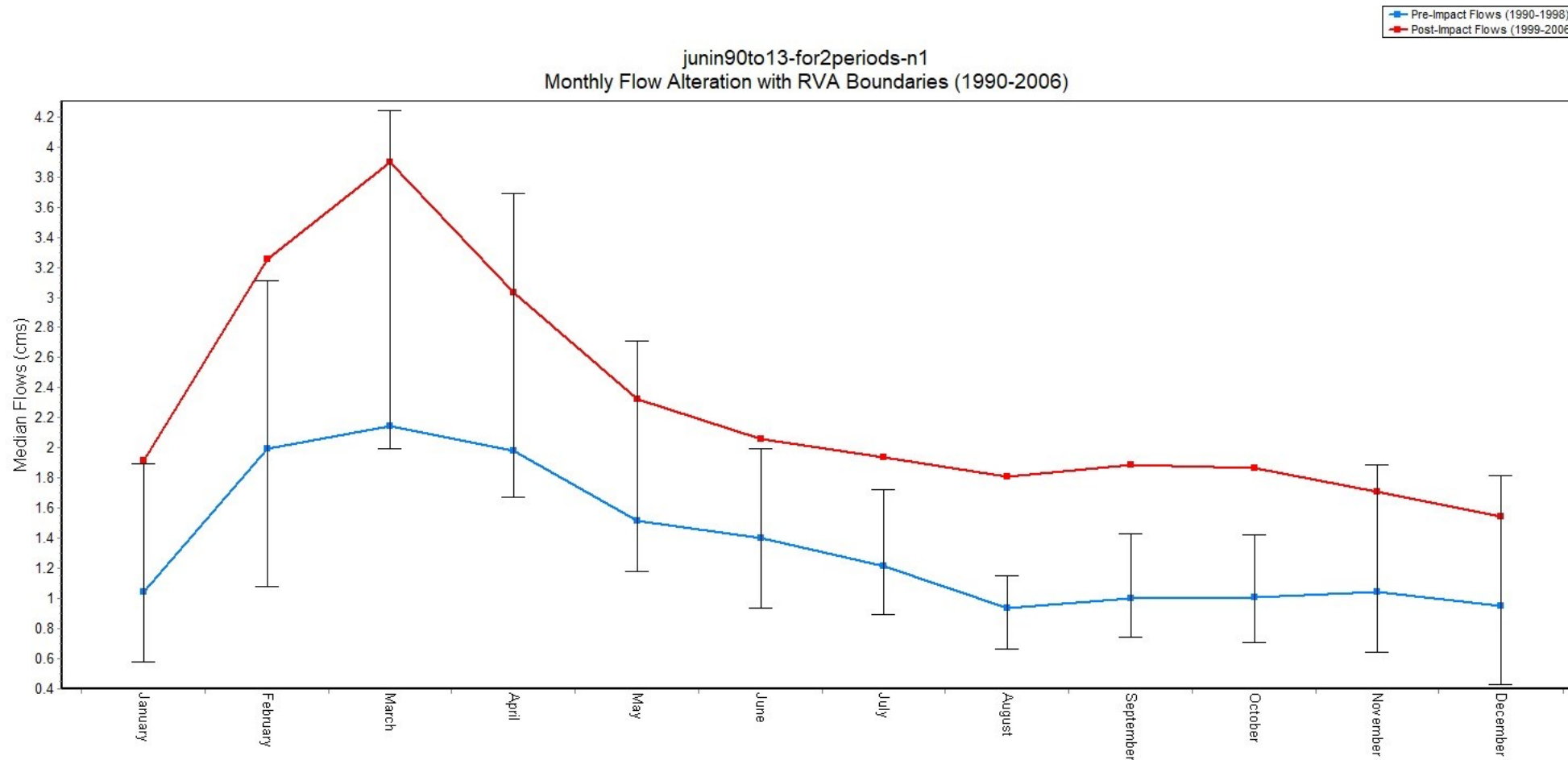
Aims and
Study Site

Methods

First LULCC
results

First impact
results

First impact Results: 1 monthly patterns



Overview

Background

Aims and
Study Site

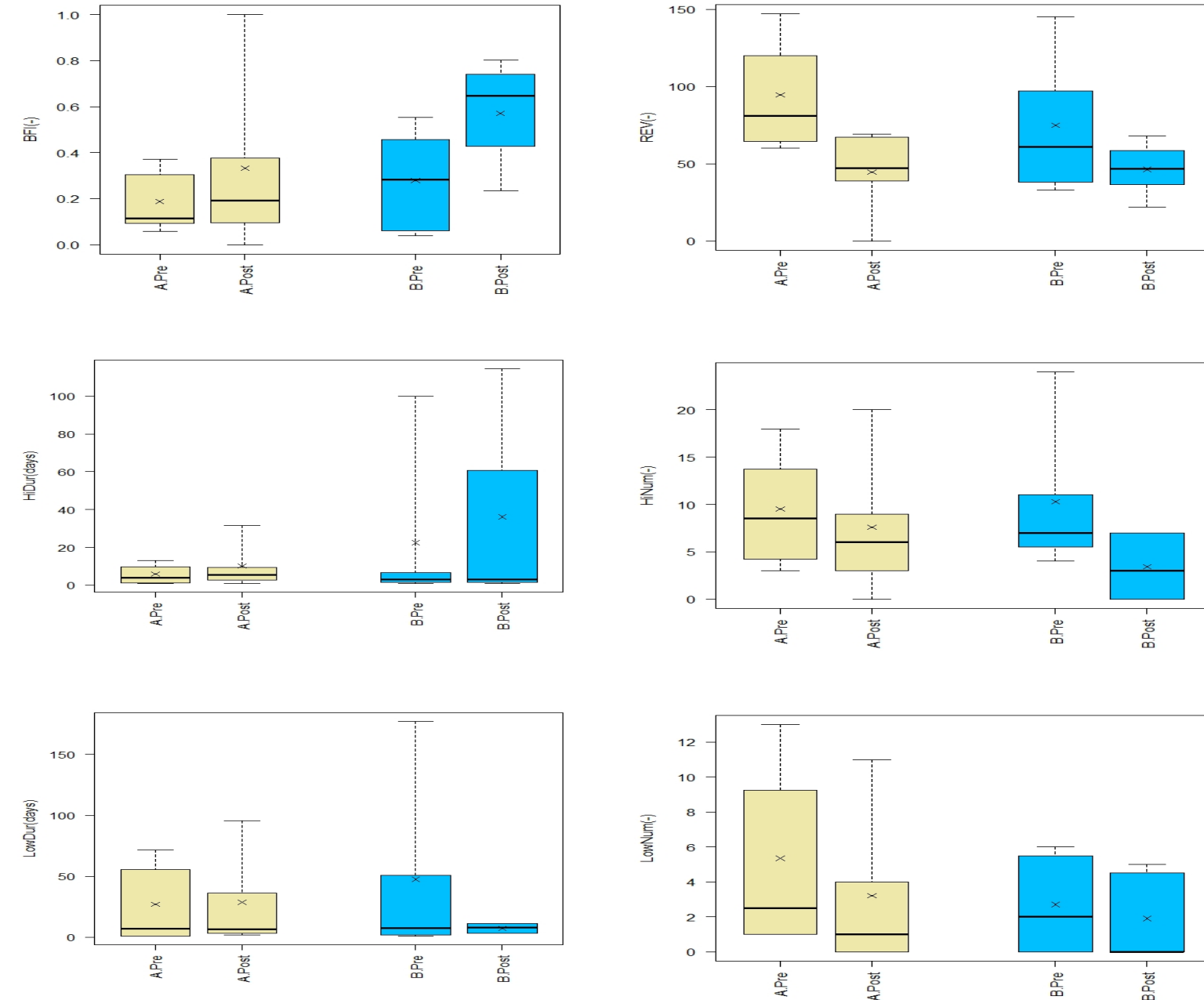
Methods

First LULCC
results

First impact
results

First impact Results: II boxplots

- To gain insights we computed the flow signatures with the freely available 1990 to 2013 Q data.
- Annual results were plotted with boxplots.
- The box shows 50% of the data (interquartile range), whiskers refer to percentiles 10th and 90th, the solid line represents the median value and x the mean value.
- For catchment A, in total 23 samples, 8 and 15 in the pre- and post-LULC change periods respectively.
- For catchment B, in total 17 samples, 9 and 8 in the pre- and post-LULC change periods respectively.



Distribution of annual values of the 6 descriptors for the pre- and post-LULC change periods in each of the two selected catchments.

Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

First impact results

- Signature values were within the same variation range. Thus, in general, no major changes are observed for the selected signatures.
- Perhaps it is interesting to note that 3 signatures, Rev, HiNum, LowDur have shown some degree of change. They have all decreased for both A and B catchments.
- The lower number of reversals in both catchments might indicate less regulation the flows. For Pajan (A) catchment, this makes sense because there was a dam upstream the gauge station in the pre-impact period.
- On the other hand, the BFI might be increasing for Junín (B) catchment. This is counterintuitive because, in none of the sources (ESA, Landsat, nor government reports) land use has moved towards soil and water conservation.
- The BFI increase in catchment B might be attributable to either:
 - i) the long-term effect of the strong 1998 ENSO event which might have replenished aquifers*;
 - ii) Measuring errors. The rating curve might have changed. To rule out this possibility we are requesting the curve equations through time.

*We shall then, investigate the aquifers and geology in the area.

Overview	Background
Aims and Study Site	Methods
First LULCC results	First impact results

Conclusions

- The two sources (ESA-CCI-LC and Landsat) show different results. Furthermore, in some places the results are in opposite directions, i.e., places where ESA-CCI-LC indicates afforestation while Landsat deforestation.
- ESA-CCI-LC indicates that LULC changes have occurred in Pajan (A) catchment. While the supervised classification employing Landsat indicates LULC changes have occurred in both catchments.
- The contradictions in these sources highlight the importance of taking into account local knowledge as well as the appropriate selection of spatial resolution in the analysis.
- No changes in signatures are to be directly attributed to the LULC change.
- Regarding the effects of the LULC changes in streamflow the **initial approach** was not sufficient to capture any direct effect and therefore, a deeper analysis based on specific features of the streamflow signal are planned as the next step.
- Natural climate variability must be checked in detail to be able to rule it out of any possible effect of LULC changes on flow signatures

Overview

Background

Aims and
Study Site

Methods

First LULCC
results

First impact
results

We will look for more sources of LULC and more Landsat scenes. Despite search filters at higher than 30% are not likely to provide any good scene, a small possibility remains.

Landsat LULC pre and post change shall be divided to show more clearly the affected places.

We will reclassify with other algorithms (if possible)

Next steps: I LULC Change

- We expect to find more Landsat scenes for our study sites.
- Also, to be able to present the LULC changes in a better way.

Overview

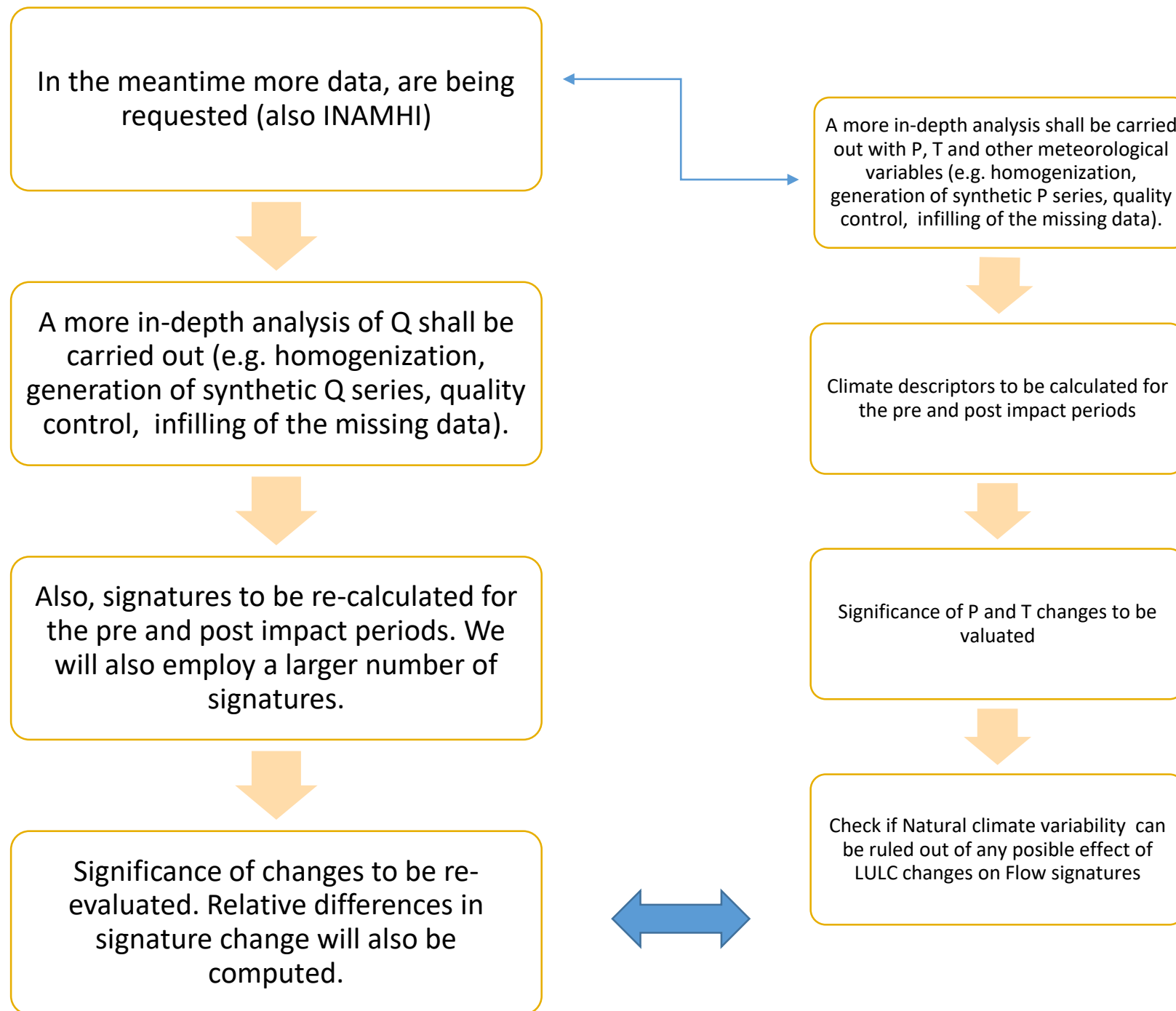
Background

Aims and
Study Site

Methods

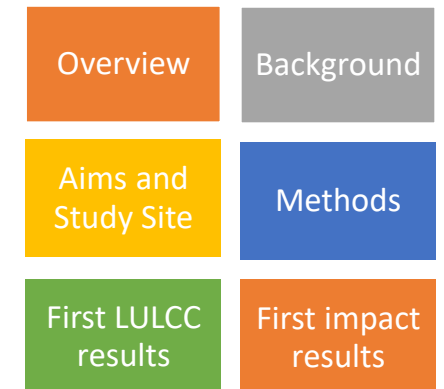
First LULCC
results

First impact
results



Next steps: II Flow analysis

- We expect to have more years of data.
- Also, improving the quality of data will be a priority.
- Try some rainfall-runoff modelling (i.e., Herrero & Aguilar 2009).



Some References

- Congedo, L. (2016). Semi-Automatic Classification Plugin - User Manual. 208. <https://doi.org/10.5281/zenodo.4587408>
- El-Diario. (2009, November 14). 70% del ganado en Manabí está en riesgo. p. Online. Retrieved from shorturl.at/drxE6
- ESA. (2017). Land Cover CCI Product User Guide Version 2. Tech. Rep. Retrieved from maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf
- Grass-GIS. (2021). r.reclass - GRASS GIS manual. Retrieved April 22, 2021, from <https://grass.osgeo.org/grass79/manuals/r.reclass.html>
- Guzha, A. C., Nobrega, R. L. B., Kovacs, K., Rebola-Lichtenberg, J., Amorim, R. S. S., & Gerold, G. (2015). Characterizing rainfall-runoff signatures from micro-catchments with contrasting land cover characteristics in southern Amazonia. *Hydrological Processes*, 29(4), 508–521. <https://doi.org/10.1002/hyp.10161>
- Herrero, J., & Aguilar, C. (2009). WiMMed , a distributed physically-based watershed model (I): Description and validation. (December 2015). <https://doi.org/10.1201/b10999-58>
- Kuentz, A., Arheimer, B., Hundecha, Y., & Wagener, T. (2017). Understanding hydrologic variability across Europe through catchment classification. *Hydrology and Earth System Sciences*, 21(6), 2863–2879. <https://doi.org/10.5194/hess-21-2863-2017>
- Ministerio-De-Gobierno-Ecuador. (2014). Control para frenar tala de árboles y tráfico de madera en Manabí. Retrieved March 25, 2021, from <https://www.ministeriodegobierno.gob.ec/control-para-frenar-tala-de-arboles-y-trafico-de-madera-en-manabi/>
- Olden, J. D., & Poff, N. L. (2003). Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. *River Research and Applications*, 19(2), 101–121. <https://doi.org/10.1002/rra.700>
- Pimentel, R., & Arheimer, B. (2021). Hydrological impacts of a wildfire in a Boreal region: The Västmanland fire 2014 (Sweden). *Science of the Total Environment*, 756. <https://doi.org/10.1016/j.scitotenv.2020.143519>
- The Nature Conservancy. (2011). Indicadores de alteración hidrológica. 89. Retrieved from https://www.conservationgateway.org/Documents/IHAV7-1_manual_Spanish_0.pdf
- USGS. (2018). Landsat and USGS products. Retrieved from https://www.usgs.gov/centers/eros/data-citation?qt-science_support_page_related_con=0#
- Zhang, Z., Huang, Y., & Huang, J. (2016). Hydrologic alteration associated with dam construction in a medium-sized coastal watershed of southeast China. *Water (Switzerland)*, 8(8). <https://doi.org/10.3390/w8080317>

Thank you!