Assessment of groundwater resource vulnerability to over-exploitation in a tropical, agricultural basin

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Australian Government
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Globally…

- **70%** of all water extractions are used for irrigation
- **40%** of global population is water scarcity affected
- **1,700,000,0000** people are dependent on unsustainable groundwater use

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SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD

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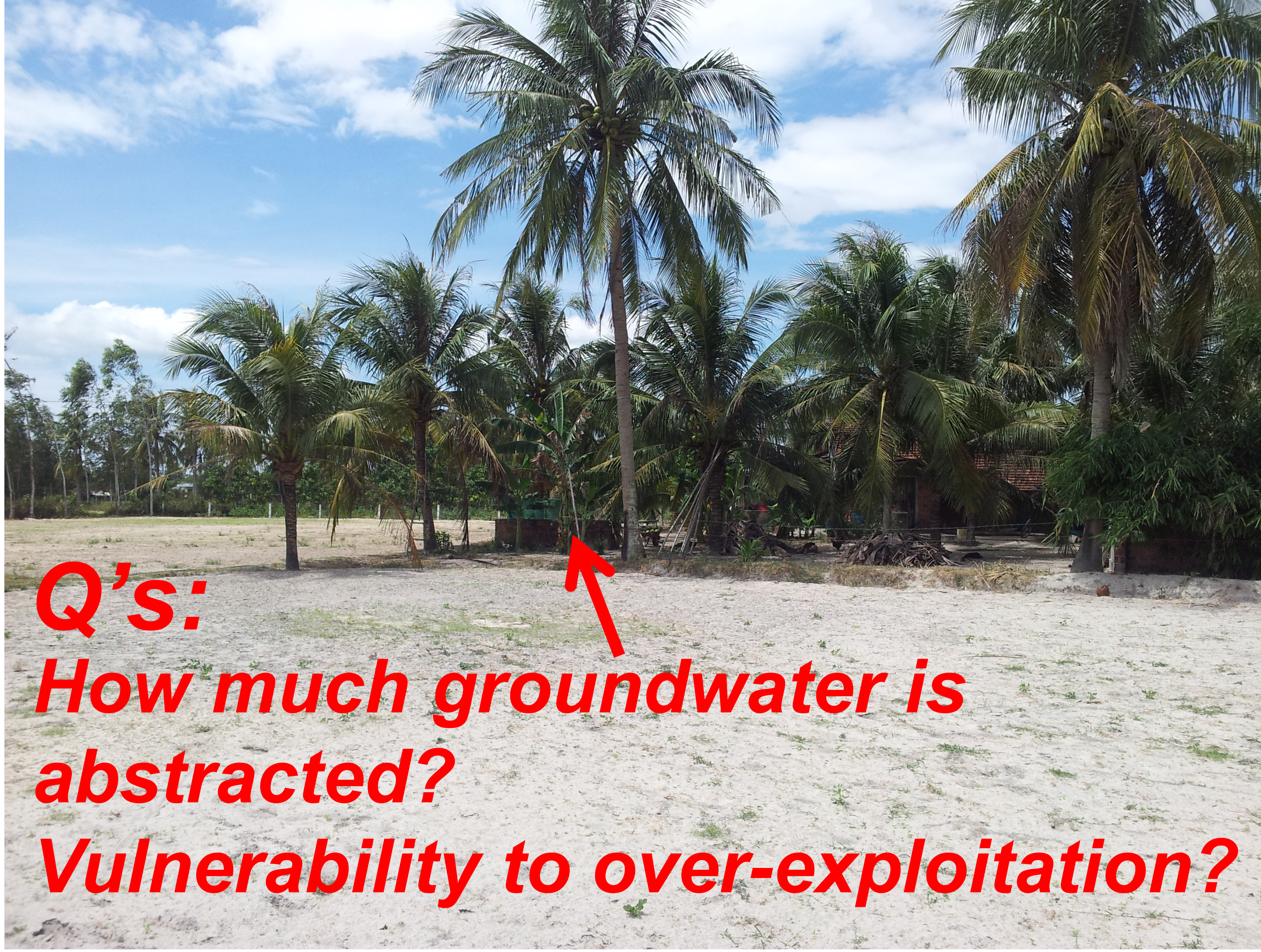
South Central Coastal Vietnam

ACIAR Project aims

"Improve profitability and sustainability of water use in ***groundwater dependent*** smallholder farming systems"

Challenge:

- **Increasing food production**
- **Develop *sustainable* water resources**



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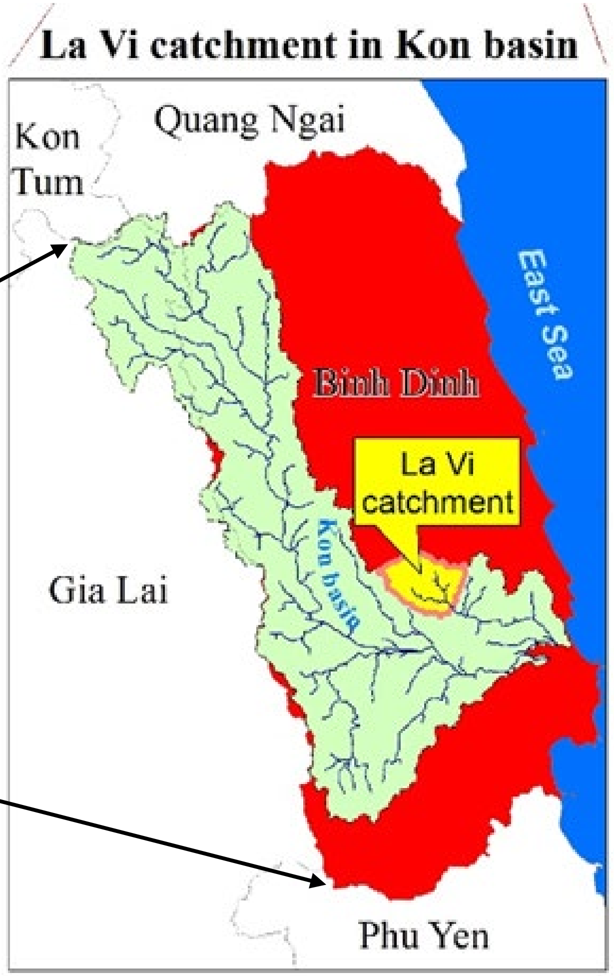
This is a PUB question…

- ***P***rediction of ***U***ngauged (***Groundwater***) ***B***asins
- Globally abstractions cause a ***huge stress*** on groundwater systems
- Challenge for groundwater management is knowing what to manage, i.e. you can only manage what you ***measure***.
- Groundwater abstractions are often ***unrecorded***, esp. in developing areas, hence a large component of the water balance is ***unknown***
- Simple ***multiple methodologies*** commensurate with the possibilities of obtaining data are required.

La Vi Basin, Vietnam



- Area: 100 km^2
- People: 20,000

- Tropical wet

1,300-2,600 mm 1986-2015

- Sandy soil
- Intermit. SW
- GW irrigation dry season

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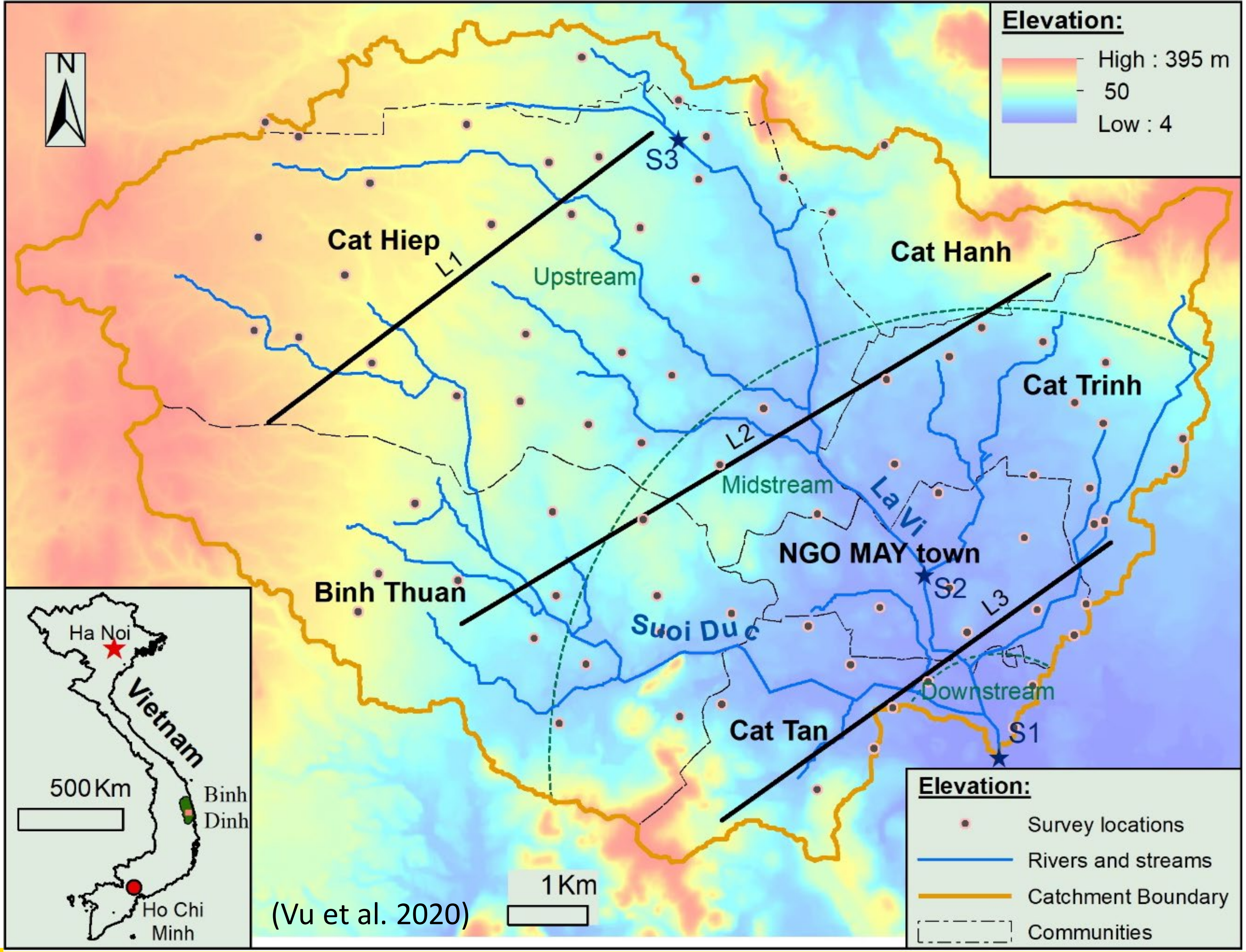
- Improved DEM
- 3 river water level transects (S1-S3)
- 77 farmer surveys
- 3 cross-s. (L1-L3)



(Vu et al. 2020)

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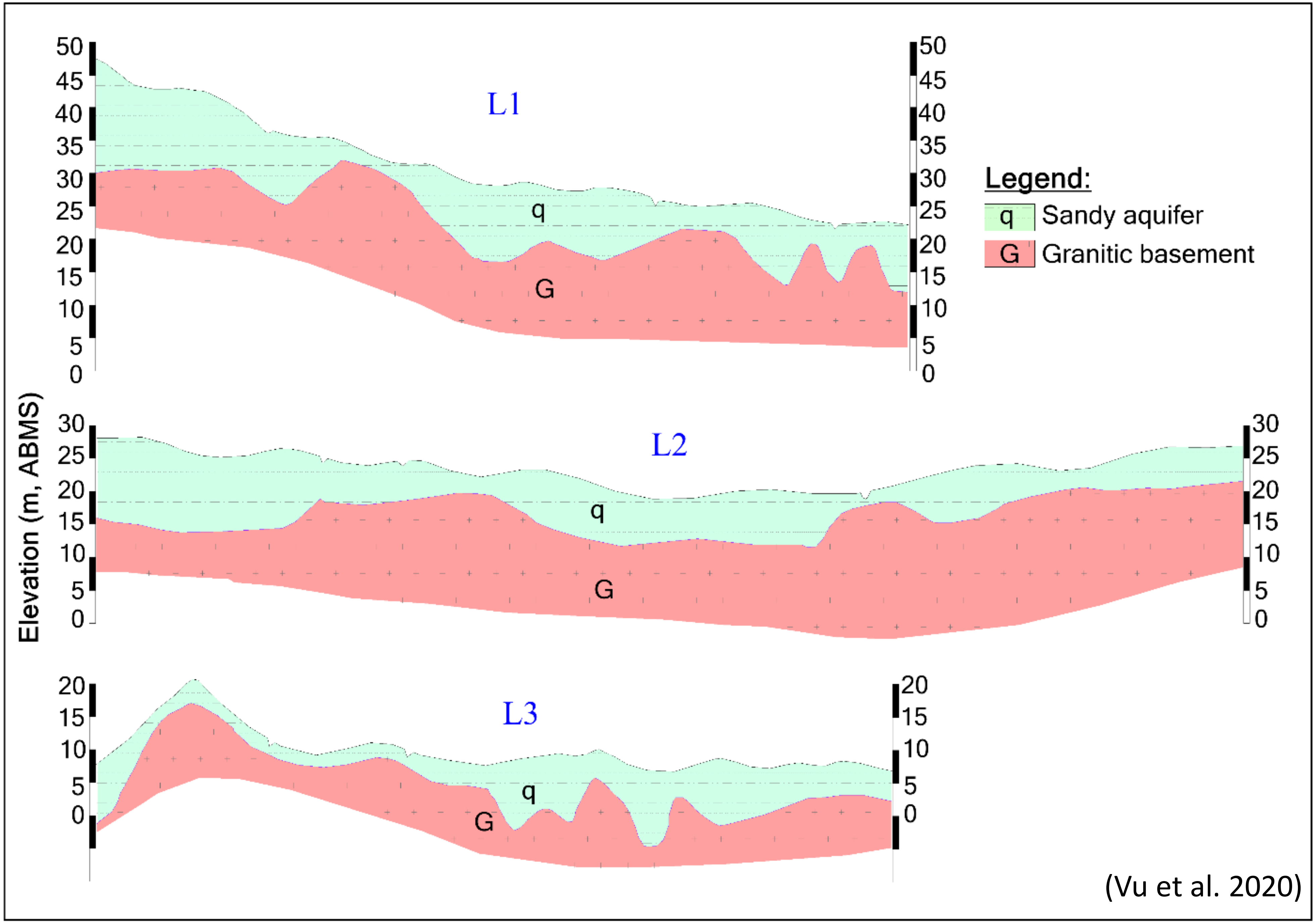
- ERT
- Shallow 5-20 m unconfined aquifer on granite basement



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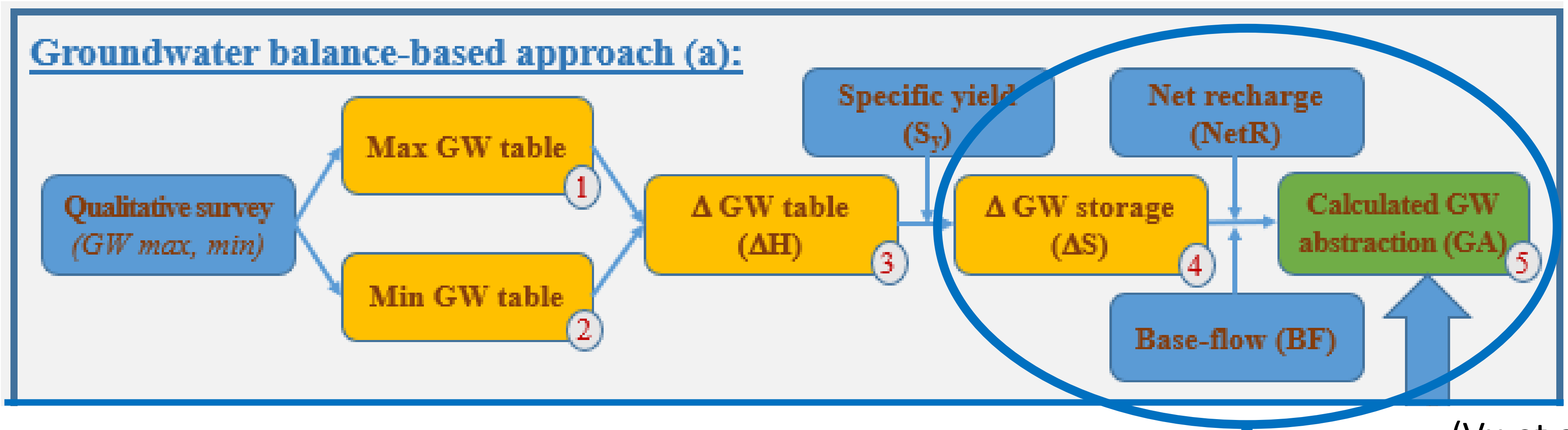
Groundwater abstraction estimation – *1st approach*



(Vu et al. 2020)

Simple catchment average water balance for dry season

Local knowledge

Qualitative field survey

77 farmers between 20-25 October 2015:

- purpose of their wells
- min and max groundwater depths in their wells
- month of occurrence of the corresponding depths
- daily average duration of pumping for each month
- pumping rate was measured during the survey
- area of land irrigated
- applied cropping patterns
- number of persons per farming household
- number of livestock per farm was surveyed

CENTRAL DIVISION FOR WATER RESOURCES PLANNING AND INVESTIGATION

AUSTRALIA-VIETNAM COOPERATION PROGRAM

GROUNWATER EXPLOITATION AND USAGE INVESTIGATION FORM

1. General Information:

Project: *"Integrated soil, water and nutrient management for sustainable agriculture system in South Central Coastal Vietnam"*

Investigation date: _ _/_ _/_ _ _ _

2. Well ID: ; Type: ☐ Well; ☐ Borehole

3. Owner(s): Start date: _ _/_ _ _ _

4. Location and Coordinates:

Village: Commune: District:

Coordinates: X: Y:

5. Usage purposes:

☐ Households *(Description)*:

<Description about No. of users, frequencies of usage and seasonal change in discharge, including the reasons not to use water for particular time>

☐ Irrigation *(Description)*:

<Description about types of crops, frequencies of usage and seasonal change in discharge, including the reasons not to use water for particular time>

☐ Others *(Description)*:

<Description about usage purposes, frequencies of usage and seasonal change in discharge, including the reasons not to use water for particular time>

Yearly usage calendar

Time	Wet? (Y/N)	DTW (m)	Discharge (m^3/d)			
			Dom.	Irr.	Far.	*Sum*
Jan						
Feb						
Mar						
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Sum						

6. Exploitation methods

☐ Pumping: Type of pump: .... Capacity (HP): ....; ☐ Other: ....

7. Salinization and water treatment:

8. Water quality:

Colour: Smell: Tasty:

Further description:

Owner **Authority** **Investigator**

Signature: __________________ Signature: __________________

Name: ____________________ Name: ____________________

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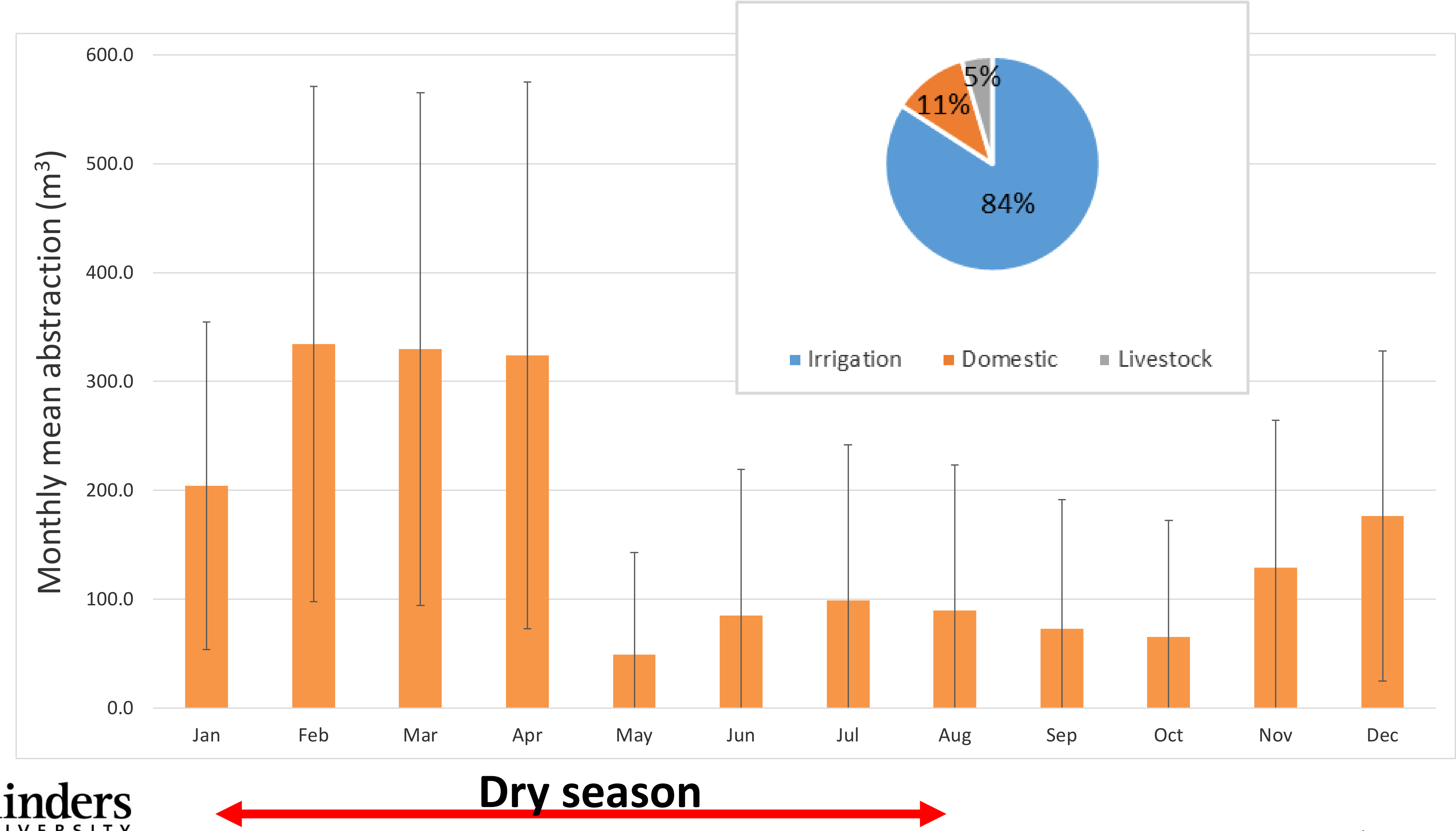
(Vu et al. 2020)

Mean monthly abstraction of interviewed farmers



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(Vu et al. 2020)

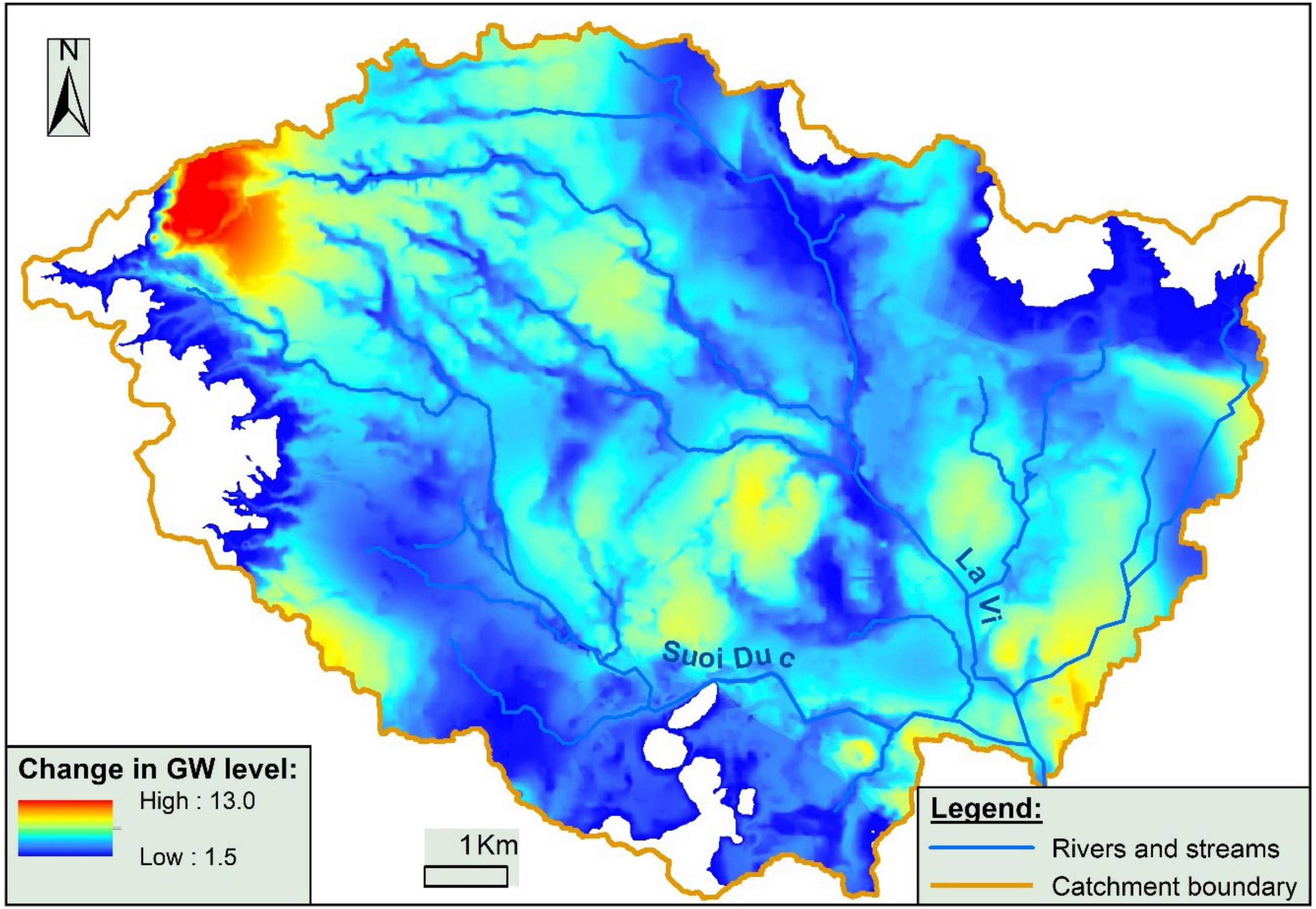
January
max groundwater level

minus

August
min groundwater level

=

Reduction in groundwater level from January to August based on differences in the interpolated maximum and minimum groundwater levels as resulting from the farmer surveys.



(Vu et al. 2020)

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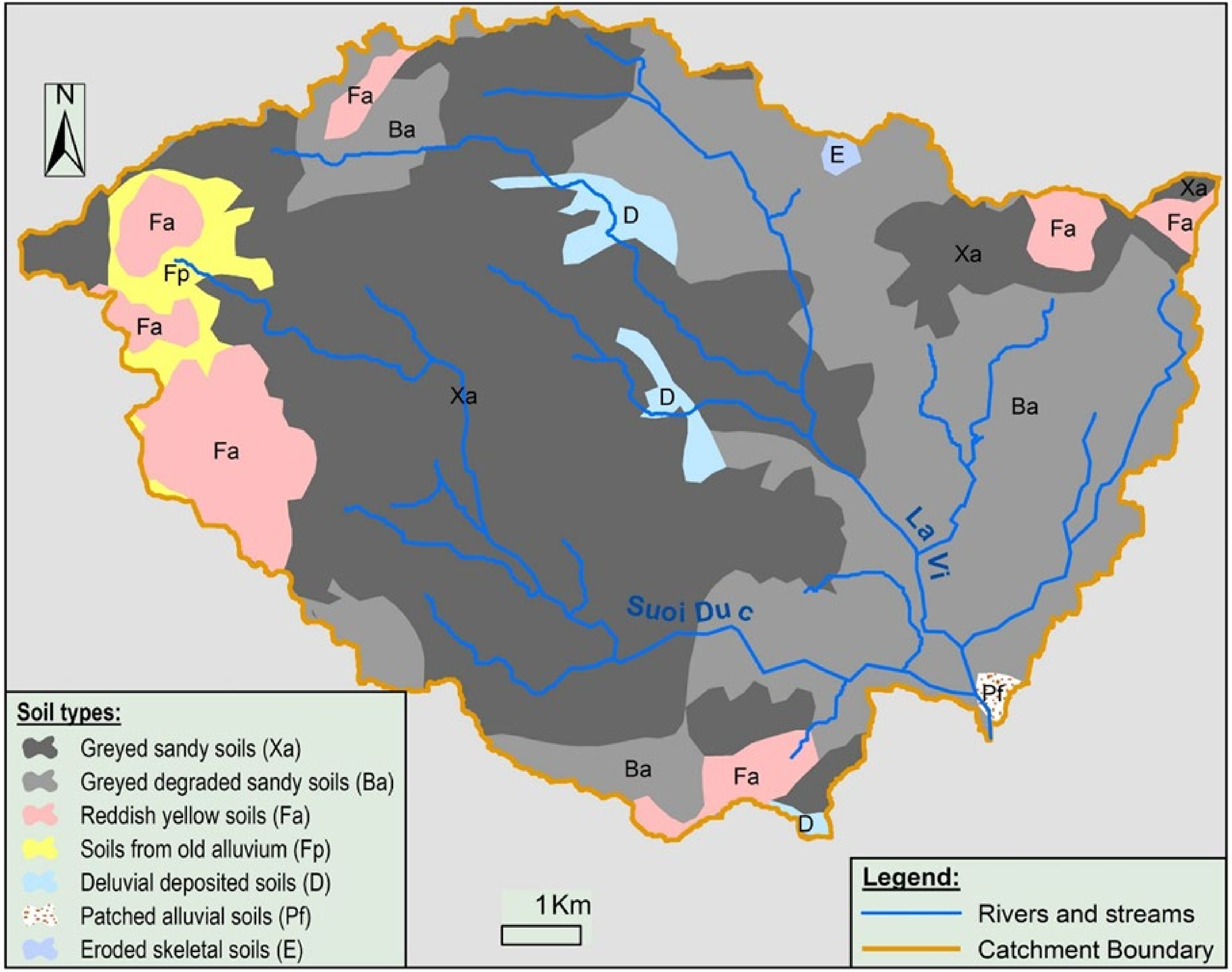
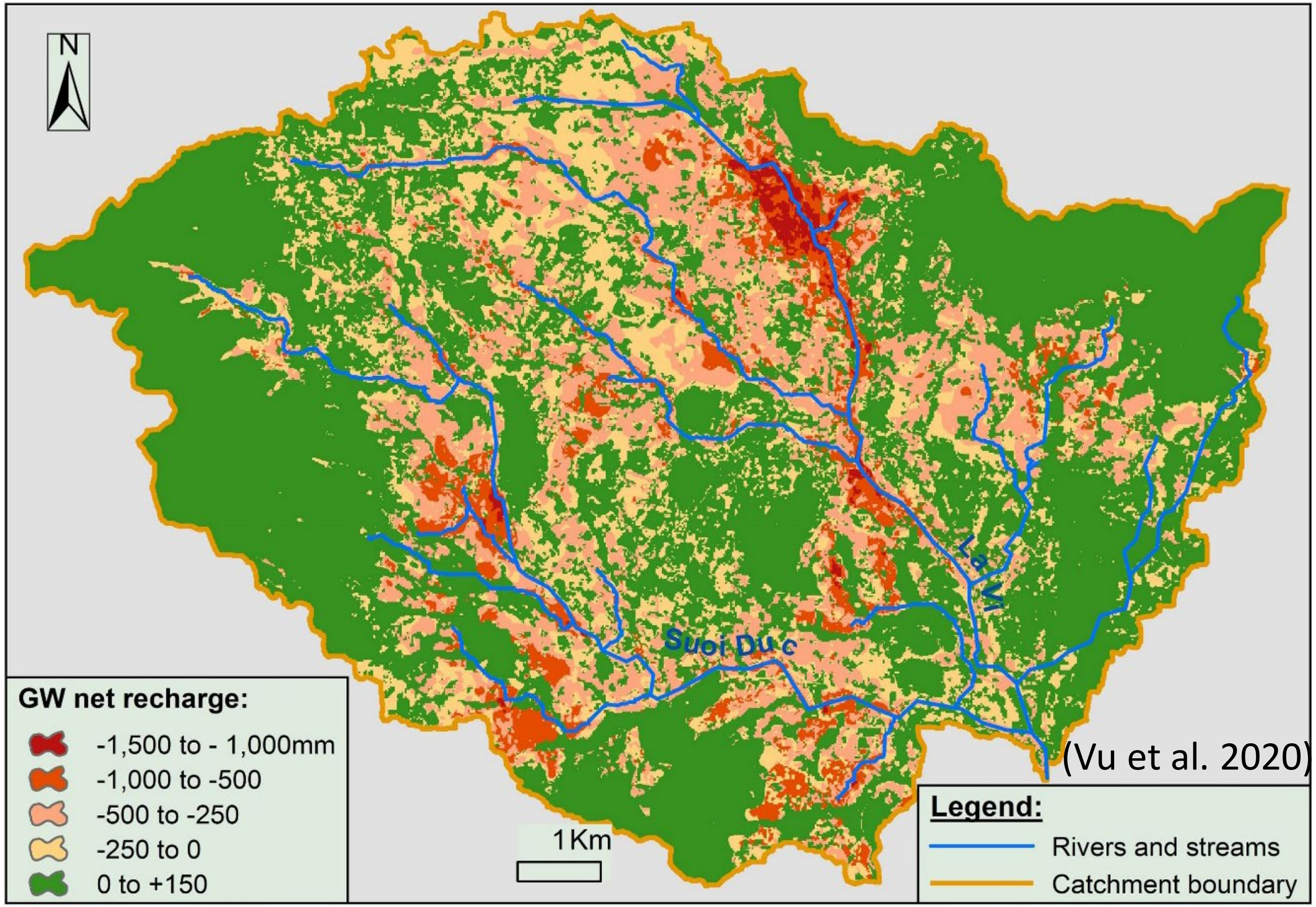
Soil map updated by survey

- Sat K
- FC
- PWP
- pH
- EC



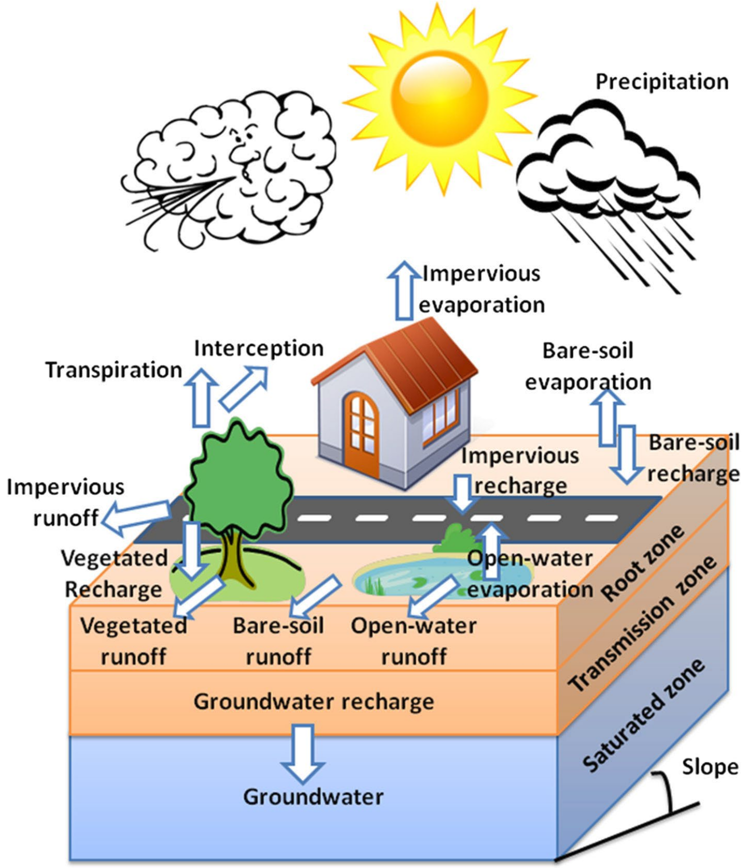
WetSpass-M simulated dry season net recharge

The dry season recharge is mainly negative, i.e. transpiration from groundwater



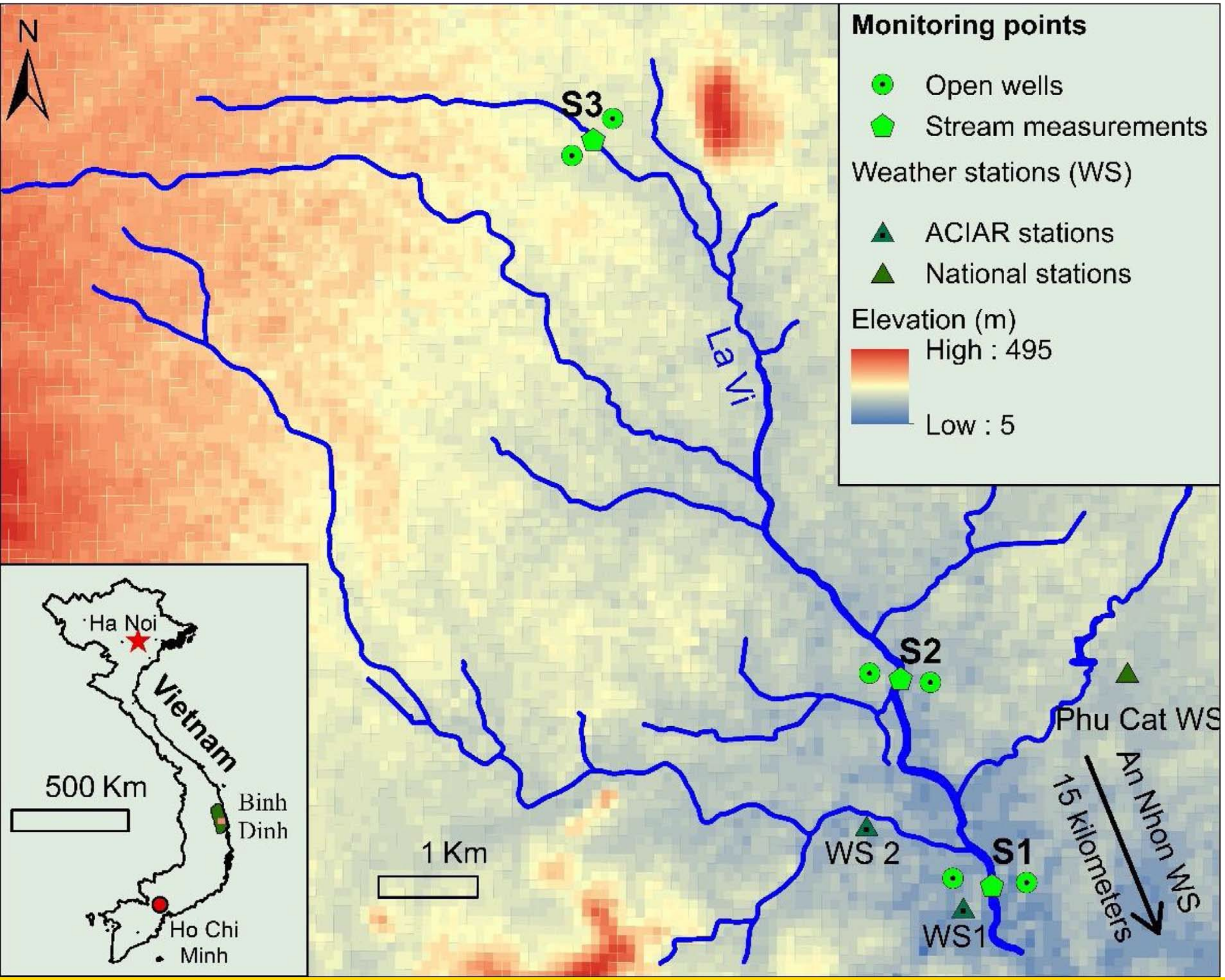
(Vu et al. 2020)

WetSpass-Monthly water balance model



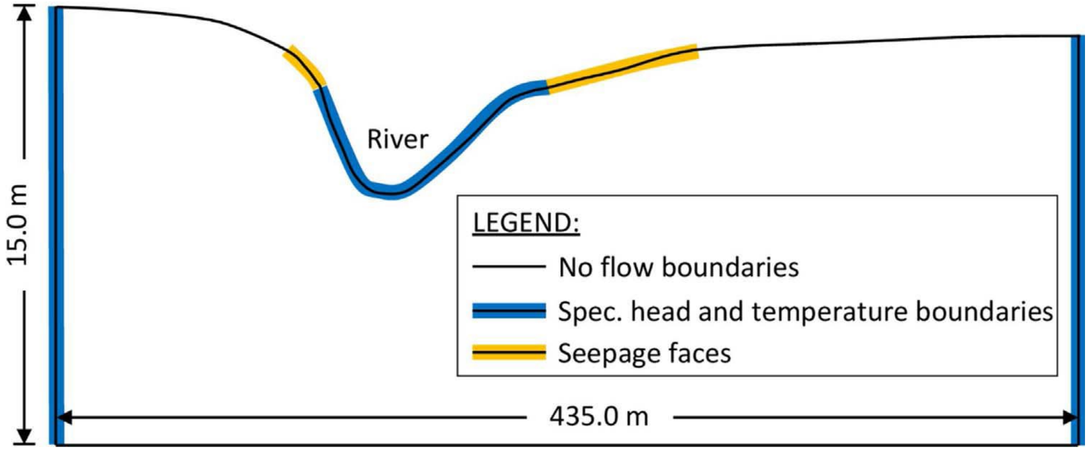
Abdollahi, K., Bashir, I., Verbeiren, B., Harouna, M.R., Van Griensven, A., Huysmans, M. and Batelaan, O., 2017, A distributed monthly water balance model: formulation and application on Black Volta Basin. Environmental Earth Sciences 76(5): 198, http://dx.doi.org/10.1007/s12665-017-6512-1

Dry season baseflow estimation



Extrapolation of baseflow results from:

- **3 water level and temperature cross-sections**
- **VS2DI modelling**



Vu, H.M., Shanafield, M. and Batelaan, O., 2018, Flux dynamics at the groundwater-surface water interface in a tropical catchment. Limnologica 68: 36-45. https://doi.org/10.1016/j.limno.2017.06.003

Dry season (Jan-Aug) water balance

Component	Type	Value Mm^3	Proportion (%)
Change in GW storage	Sources	73	100
Groundwater transpiration	Sinks	10	14
Base-flow		32	44
Rest term = groundwater abstraction		**31**	42

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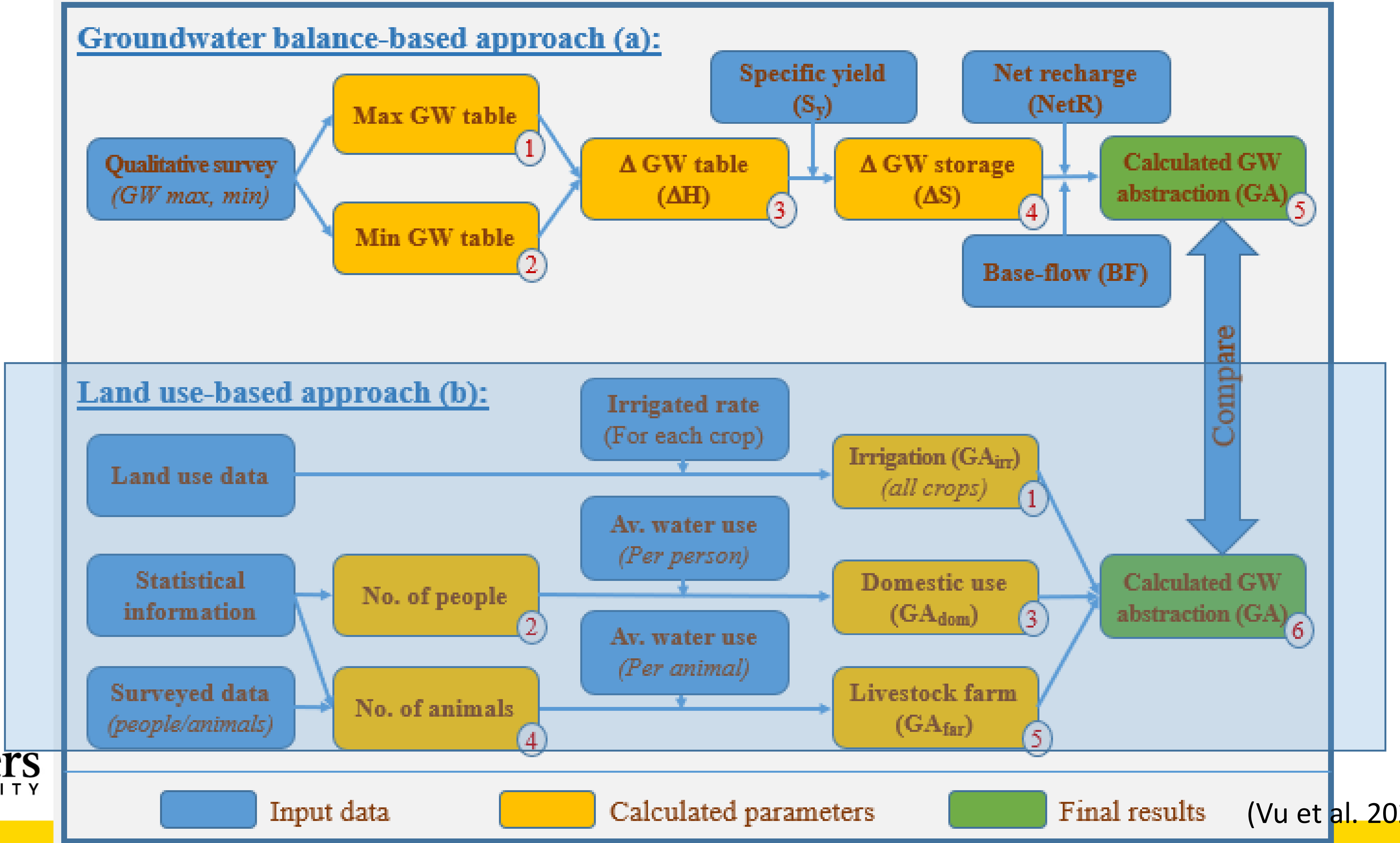
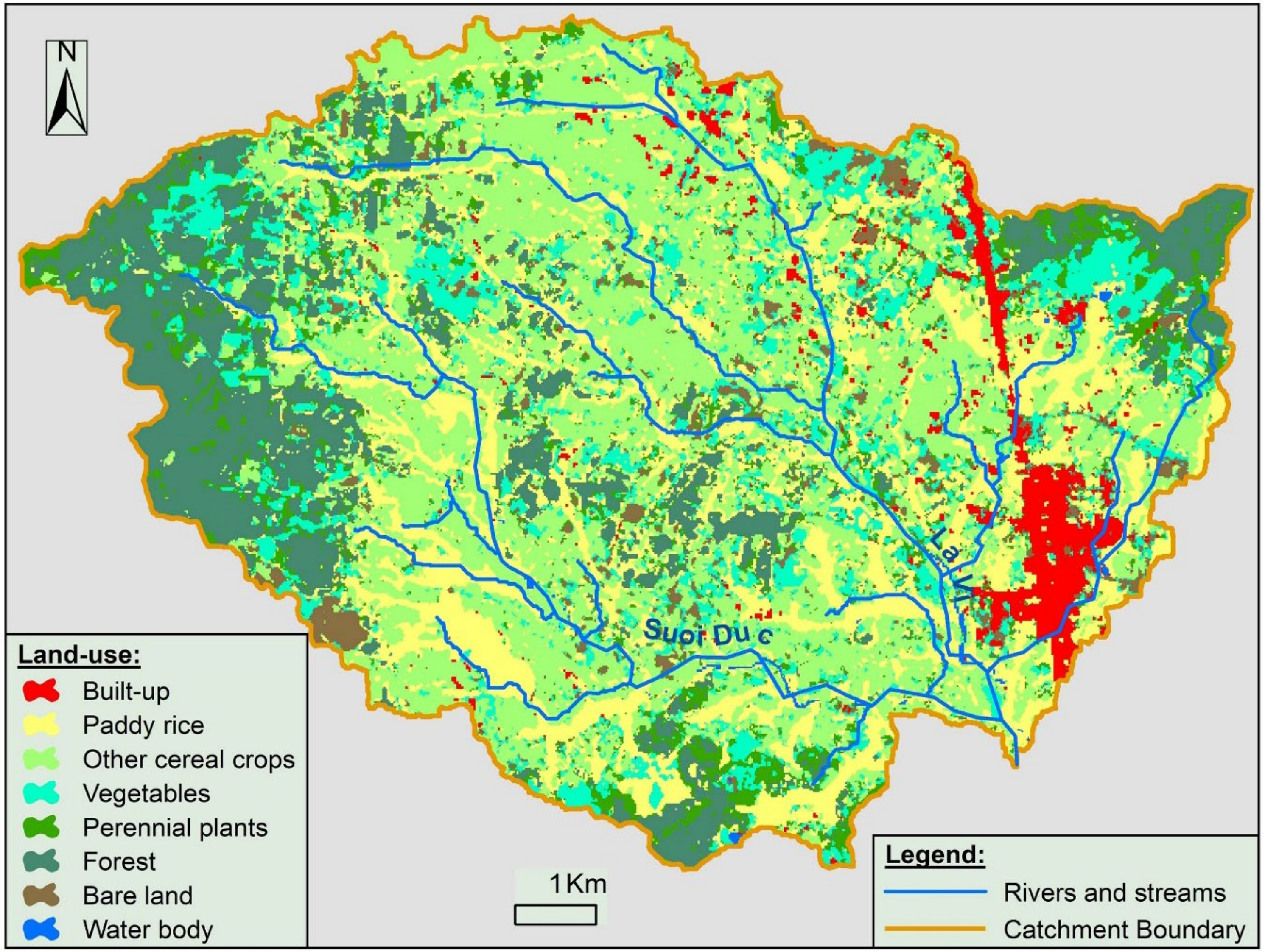
Groundwater abstraction – *2nd approach*



(Vu et al. 2020)

Landcover

2016 Sentinel-2A Supervised classif.



(Vu et al. 2020)

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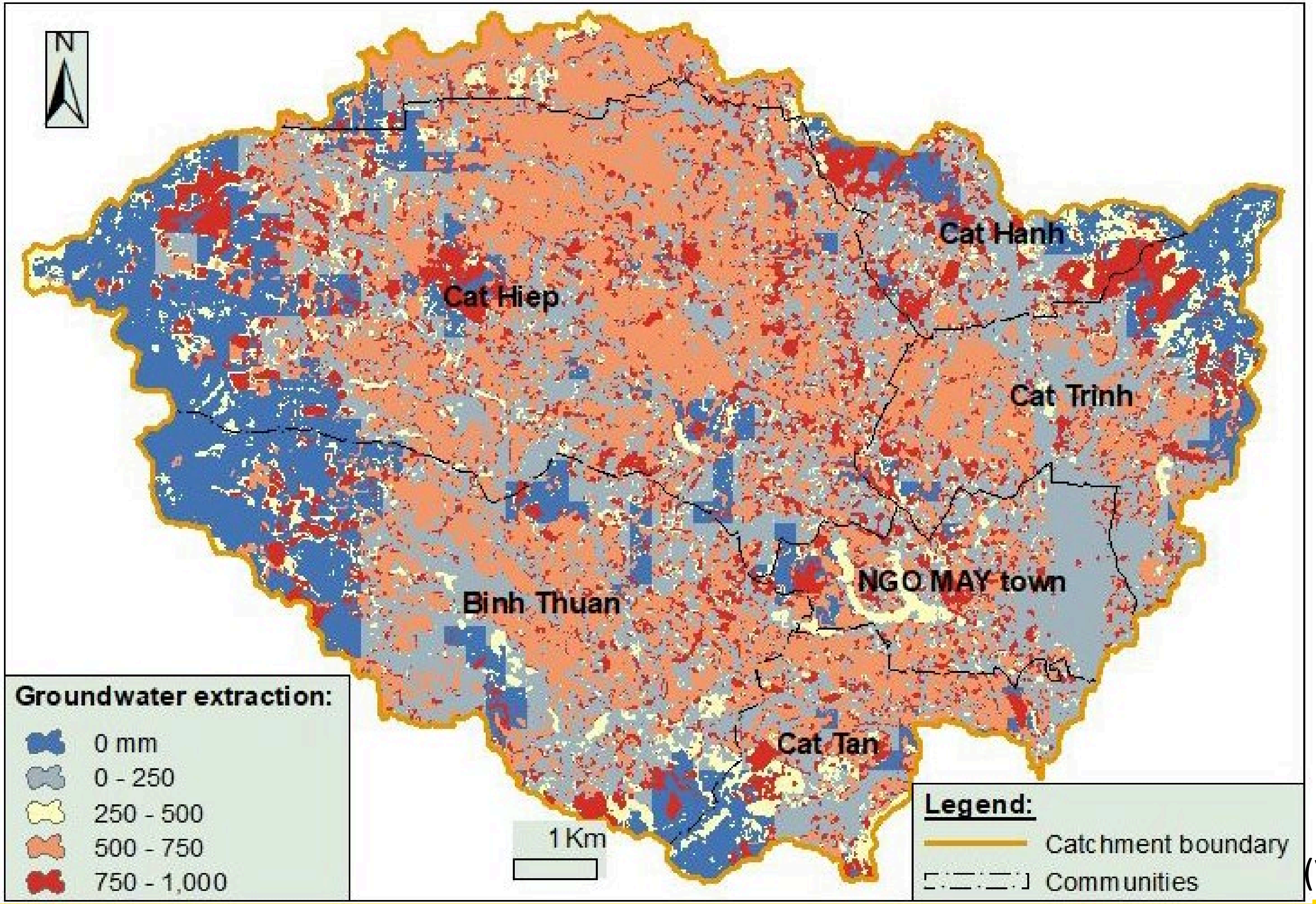
Dry season groundwater abstraction land-use based approach



(Vu et al. 2020)

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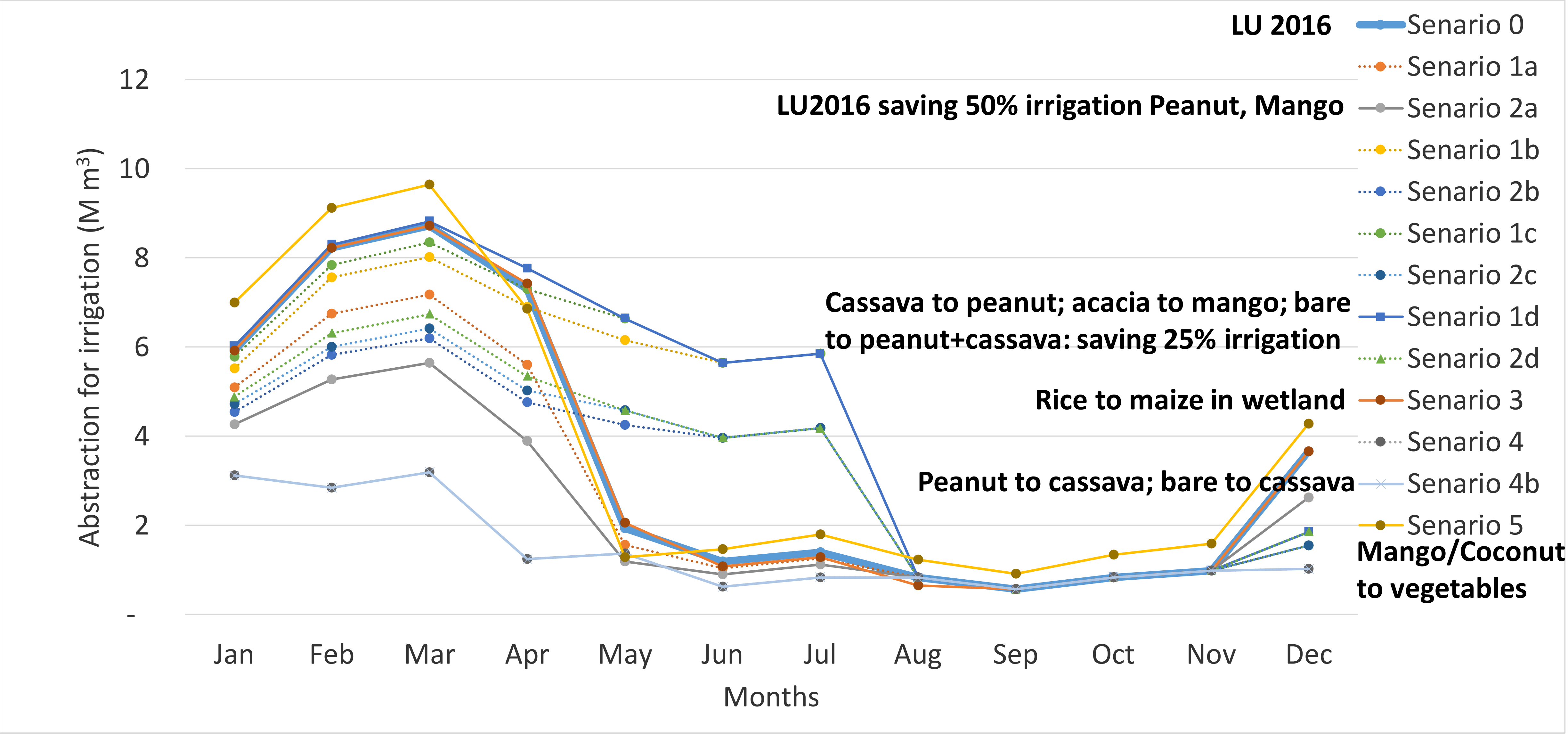
Groundwater abstraction land-use based approach

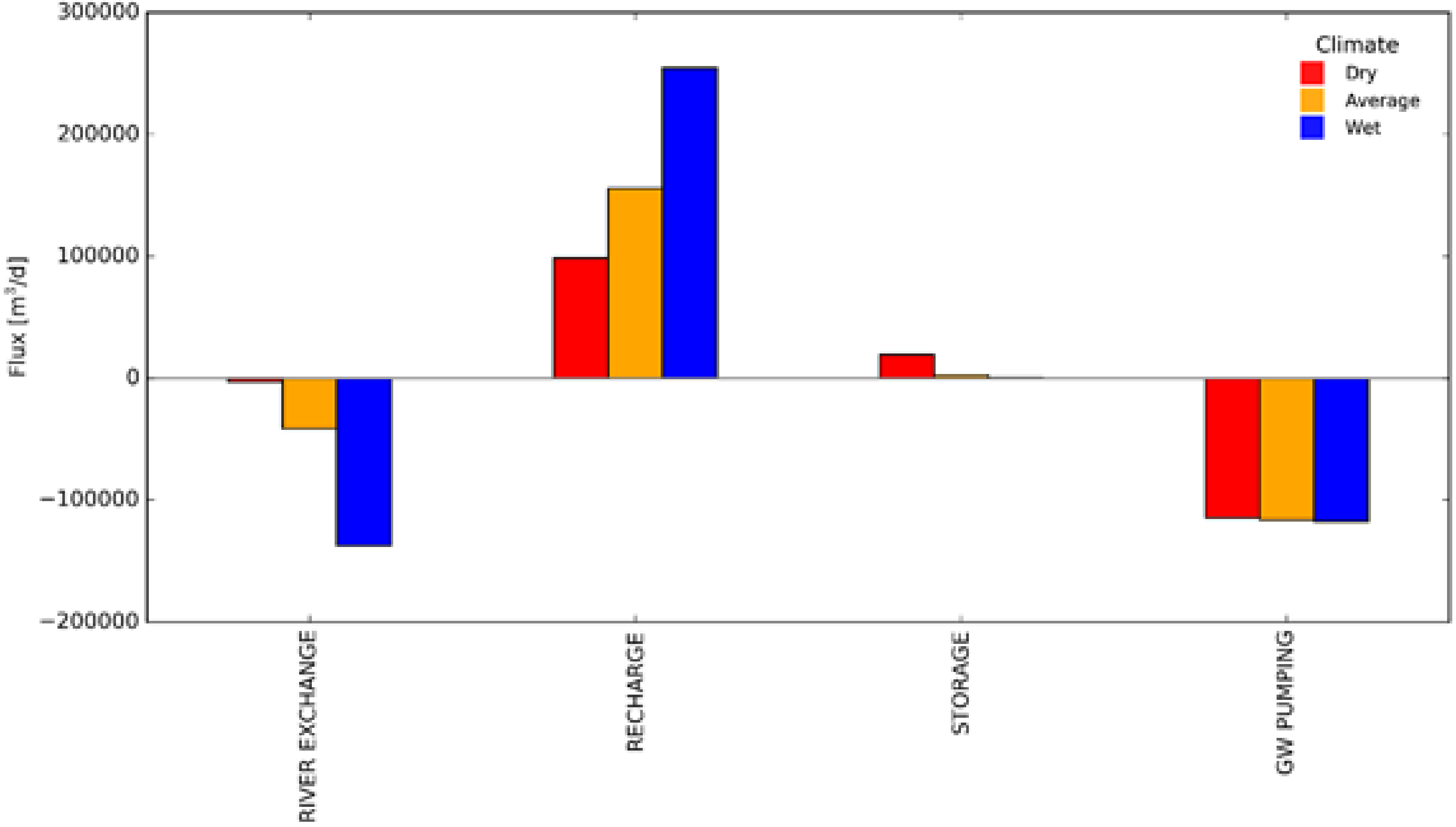
Irrigation rate / Population	As surveyed	Per FAO's guidelines
Converted from house map	**36.2×10^6 m^3**	24.4×10^6 m^3
Downscaled from global population data	36.4×10^6 m^3	24.6×10^6 m^3

Ag. scenarios → groundwater abstraction



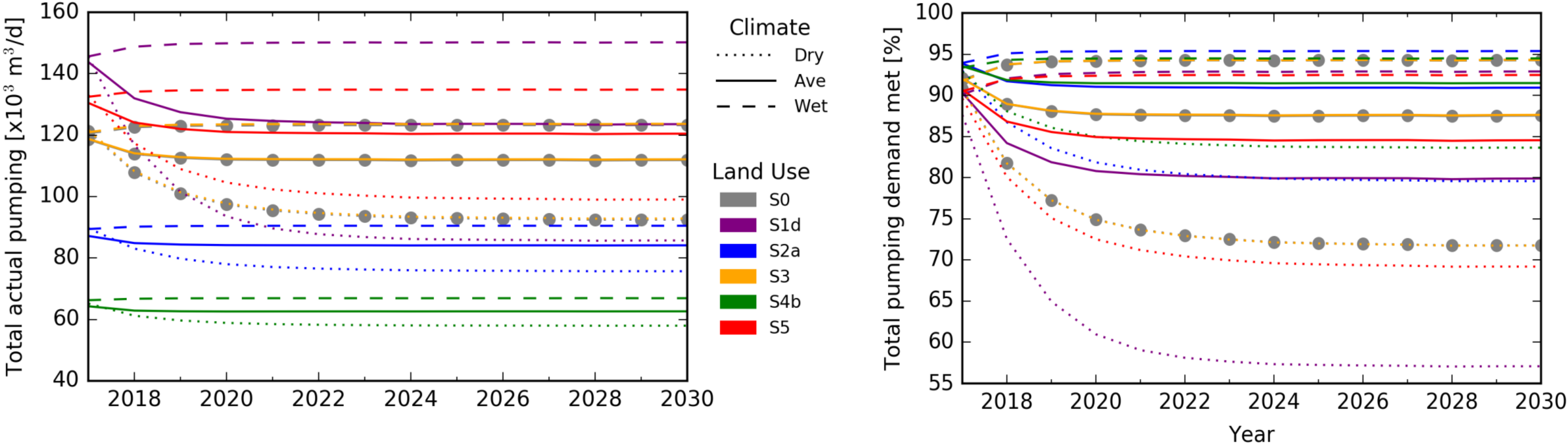
Scenario 0 (base case) → impact of dry, avg, wet year

Notice strong reduction in baseflow and storage under dry conditions



Base case scenario S0 simulated groundwater fluxes for dry, average and wet recharge conditions

WetSpass-M – MODFLOW simulated actual pumping for different scenarios



Total volume of pumping applied (left), and the total percentage of pumping demand met (right) for each scenario.

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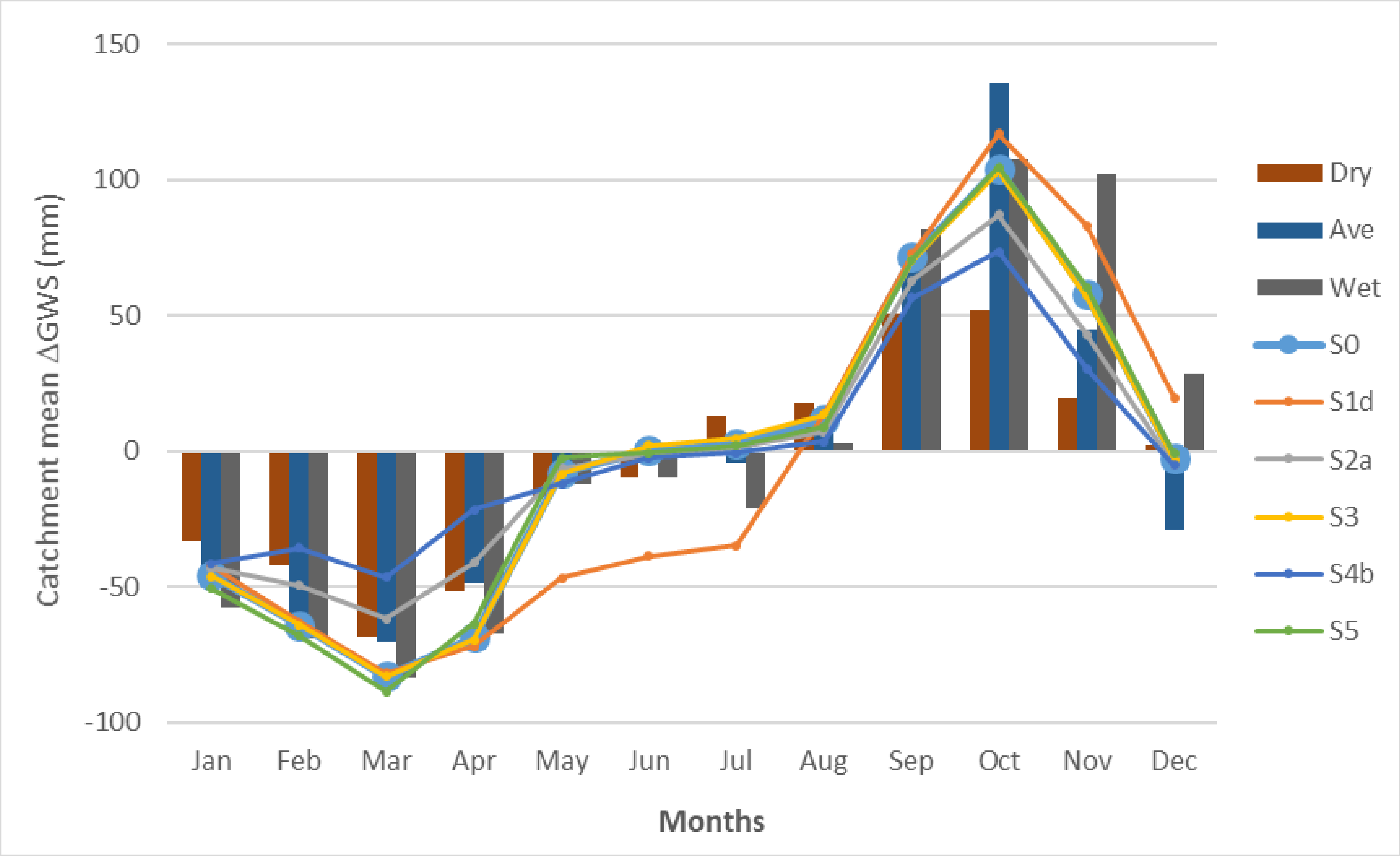
Change in groundwater storage for different scenarios

Temporal variation of the monthly simulated change in groundwater storage for different land use scenarios, averaged over dry, average and wet climatic conditions (line chart) and for dry, average and wet climatic conditions, averaged over all land use scenarios (bar chart).



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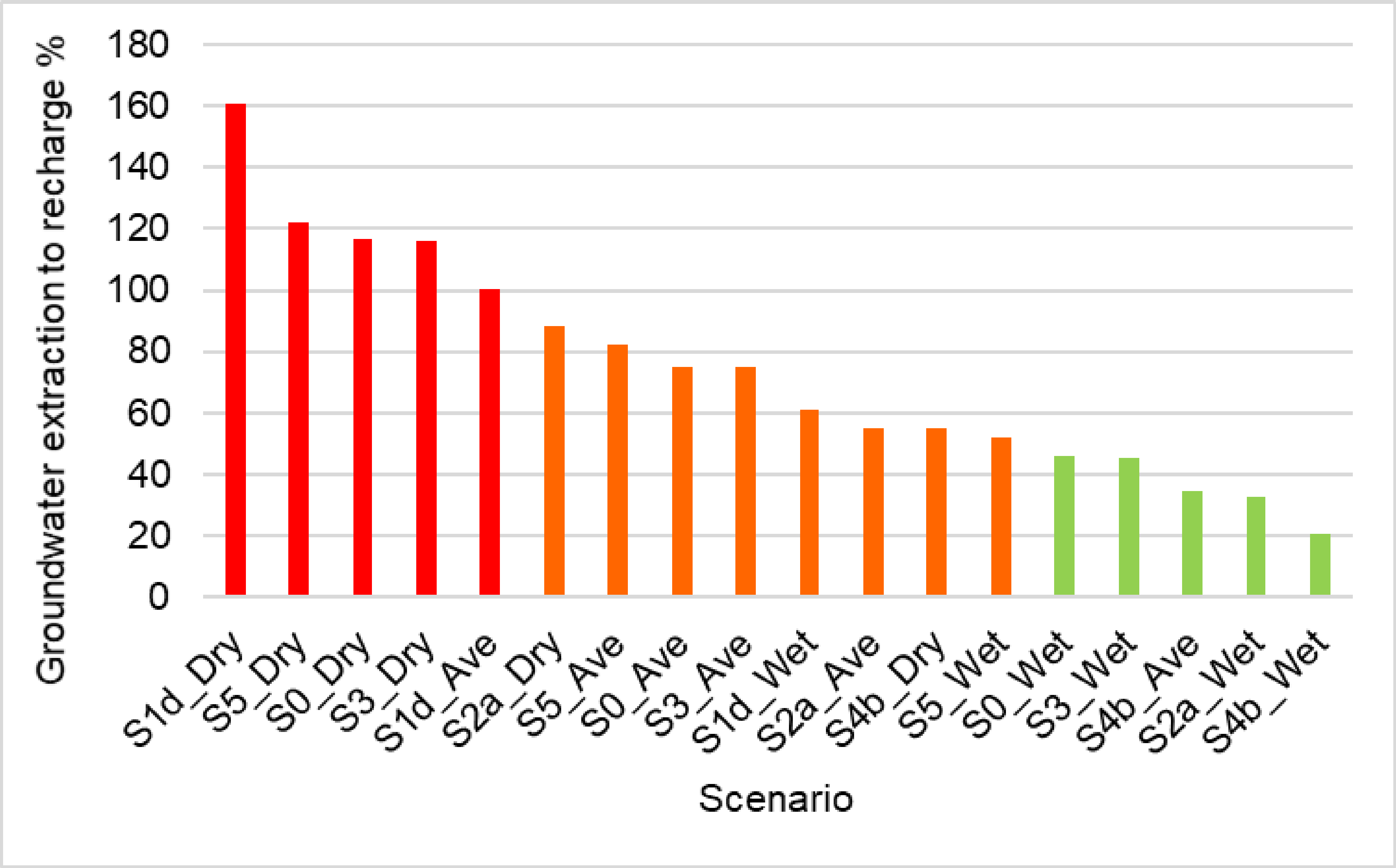
Ratio of groundwater extraction versus groundwater recharge for the different simulated scenarios



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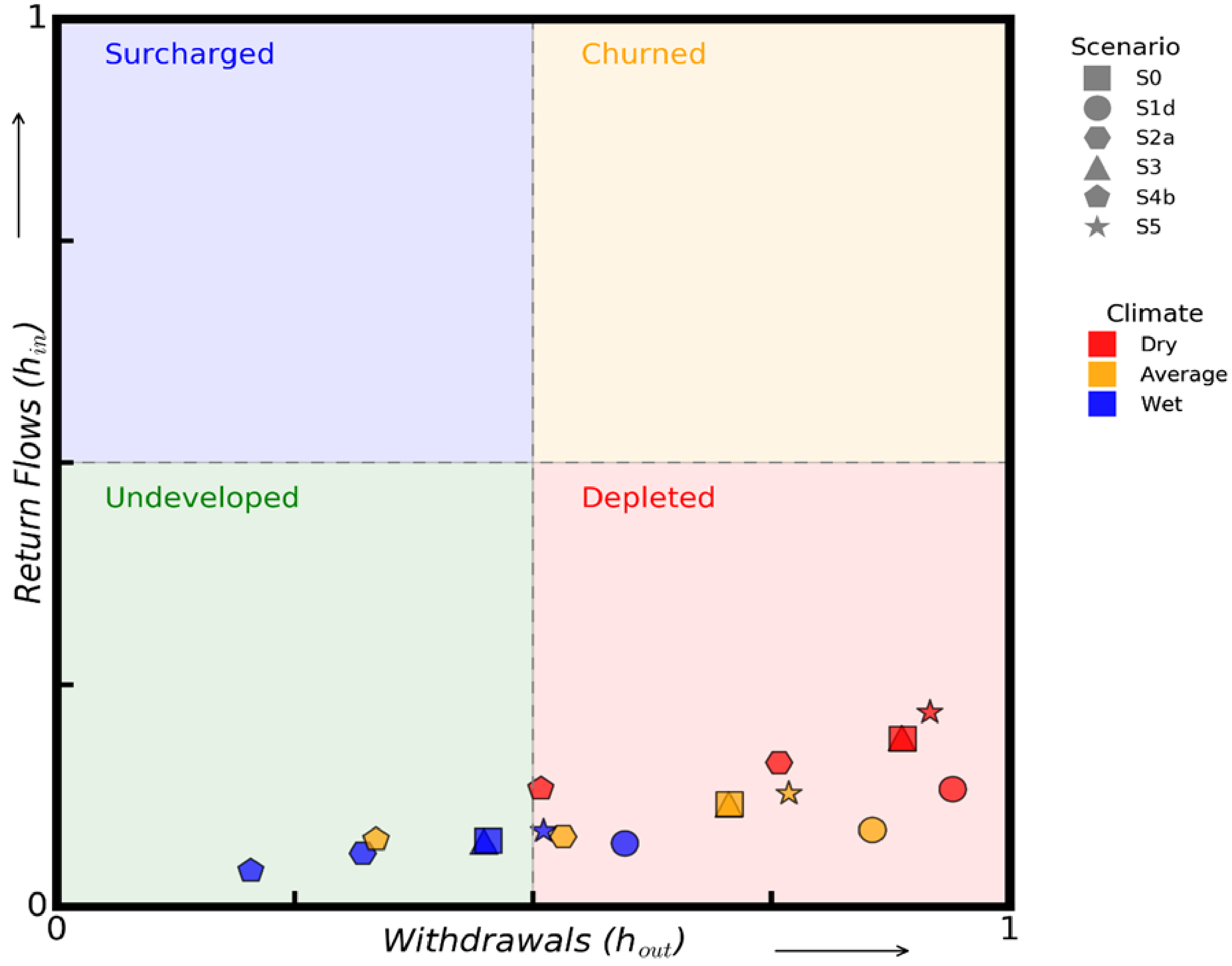
Weiskel et al. (2007) water use regime analysis



Groundwater resources sustainability evaluation of simulated base condition S0 and four different agricultural development scenarios for dry, average and wet climatic conditions.

Groundwater vulnerability

Groundwater vulnerability maps were generated by comparing the change in pumping demand (at each 100 m x 100 m pixel [*i*] being met in year 1 from scenario *A* vs demand being met after 100 years of pumping under demanded groundwater extractions as defined by scenario *A:*

$$Vulnerability[i] = \frac{pump_{actual_A}^{yr=1}}{pump_{forced_A}} \times 100\% - \frac{pump_{actual_A}^{yr=100}}{pump_{forced_A}} \times 100\%$$

With $pump_{actual\_A}$ the actual pumping amount that the groundwater system is able to supply, while $pump_{forced\_A}$ is the amount of groundwater requested to be extracted based on the demand for the irrigation and other groundwater usage as defined by the spatial land use scenario *A*.

A high vulnerability of the groundwater system would indicate that groundwater storage or baseflow is strongly reducing over time and that the demanded groundwater extractions are not sustainable.

Categories of groundwater vulnerability as used to classify the spatial vulnerability analyses

Vulnerability category	Demand met	Interpretation
Extreme	0 – 25%	Mostly unable to meet pumping demand
Very High	25 – 50%	Only a small amount of pumping demand met
High	50-75%	Pumping demand is not securely met
Medium	75-100%	Pumping demand is mostly met
Low	100%	Aquifer supply to pumping demand easily met
Pumping not present	-	Not applicable

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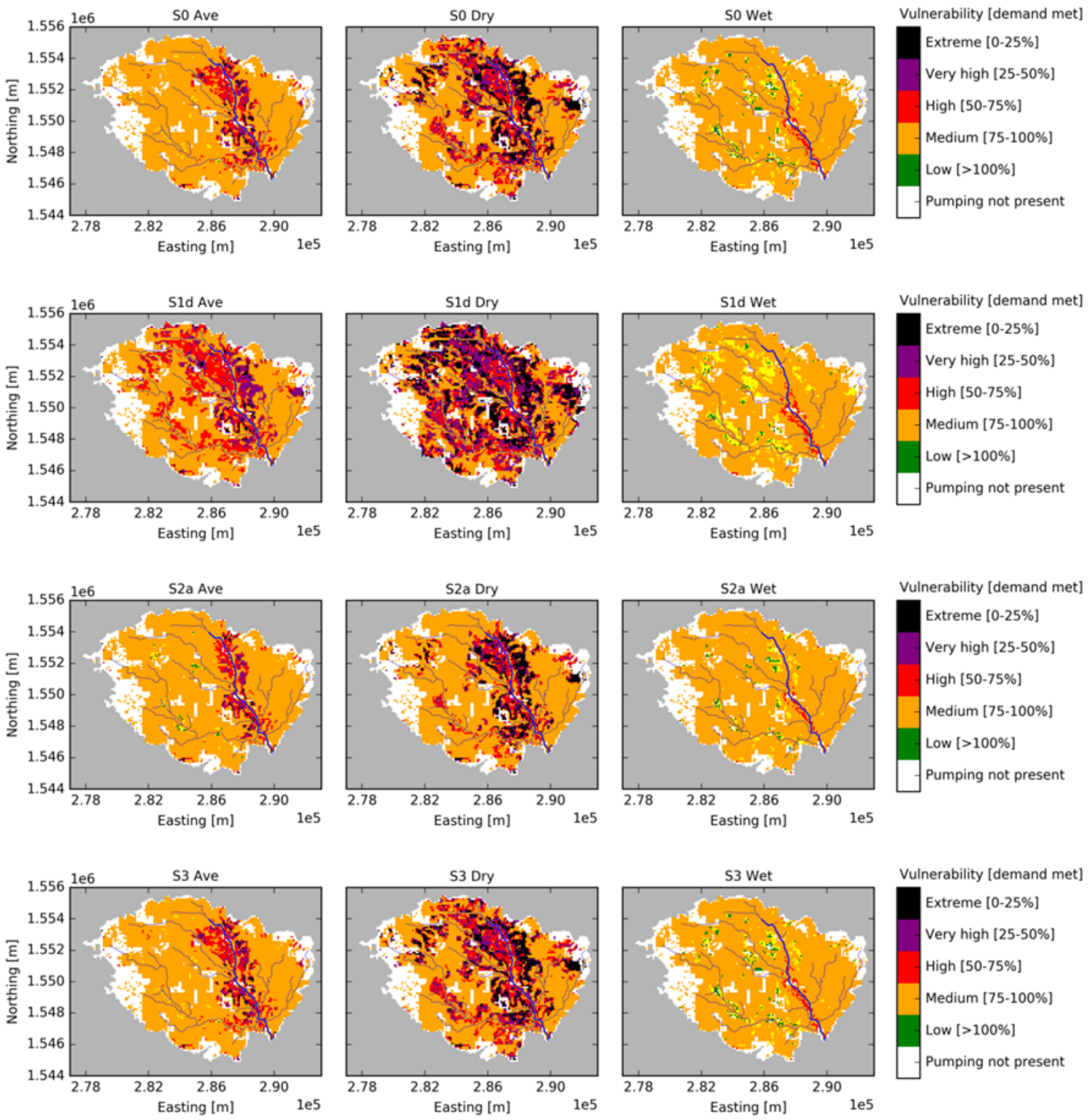
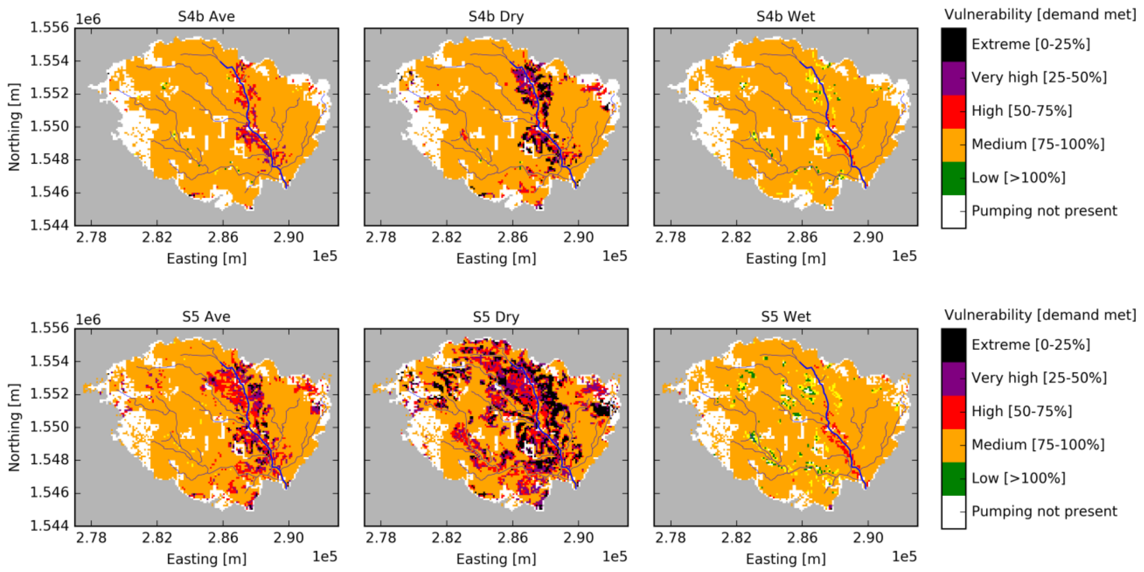
Groundwater vulnerability





Vulnerability during persistent average, dry and wet conditions for land use change scenarios S0, S1d, S2a, S3, S4b and S5.

Conclusions

We developed two comprehensive approaches for estimating groundwater extraction for data limited areas.

A developed coupled water balance (WetSpass-M) model and groundwater flow model (MODFLOW) allows groundwater sustainability evaluation, it shows:

- In wet years groundwater pumping < 46 % of the recharge, which is important for maintaining minimum ecological conditions in river valleys.
- In average precipitation years the groundwater pumping is up to 75 % of recharge.
- In dry years the groundwater pumping > natural recharge, i.e. 116 %, thereby reducing the baseflow to practically zero and effectively reducing groundwater storage by about 7 Mm^3/yr.

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Conclusions

A comparison of the base case and five simulated agricultural development scenarios in terms of the sustainability of the used groundwater resources:

- Recharge does not vary a lot among the scenarios, but much more with level of monsoon rainfall.
- Groundwater pumping varies significantly over the scenarios, five scenarios having an abstraction > recharge to the aquifer system, hence depleting the groundwater system.
- Eight scenarios have an abstraction between 50-100% of the recharge, while five scenarios have an abstraction < 50% of recharge.
- The only sustainable development scenario is one in which rainfed crops like cassava increase in their area coverage. It is the only scenario, which is under wet and average climatic conditions in a ‘safe’ groundwater management space, while being close to this under dry climatic conditions.
- If the cropping patterns stays like base scenario, but irrigating peanut and mango was reduced by 50% the risk of abstraction exceeding recharge is less than in the present case. However, substantial increase in the area of irrigated peanut, even with more water efficient irrigation, would still exacerbate the risk of over-use in dry years.

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Conclusions

"When the well is dry we know the value of water" Benjamin Franklin

Acknowledgements

- Australian Centre for International Agricultural Research for funding the project ‘Integrated water, soil and nutrient management for sustainable farming systems in south central coastal Vietnam and Australia’ SMCN/2012/069.
- John Allwright fellowship for Manh Hai Vu

References

- Abdollahi, K., Bashir, I., Verbeiren, B., Harouna, M.R., Van Griensven, A., Huysmans, M. and Batelaan, O., 2017, A distributed monthly water balance model: formulation and application on Black Volta Basin. Environmental Earth Sciences 76(5): 198, http://dx.doi.org/10.1007/s12665-017-6512-1
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- Vu, H.M., Shanafield, M., Nhat, T.T., Partington, D. and Batelaan, O., 2020, Mapping catchment-scale unmonitored groundwater abstractions: Approaches based on soft data. Journal of Hydrology: Regional Studies (in review)

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Thank you

Questions/Discussion

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