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The resilience of shallow groundwater resources in Dangila *woreda*, northwest Ethiopia, to climate variability, increasing abstraction and land use change

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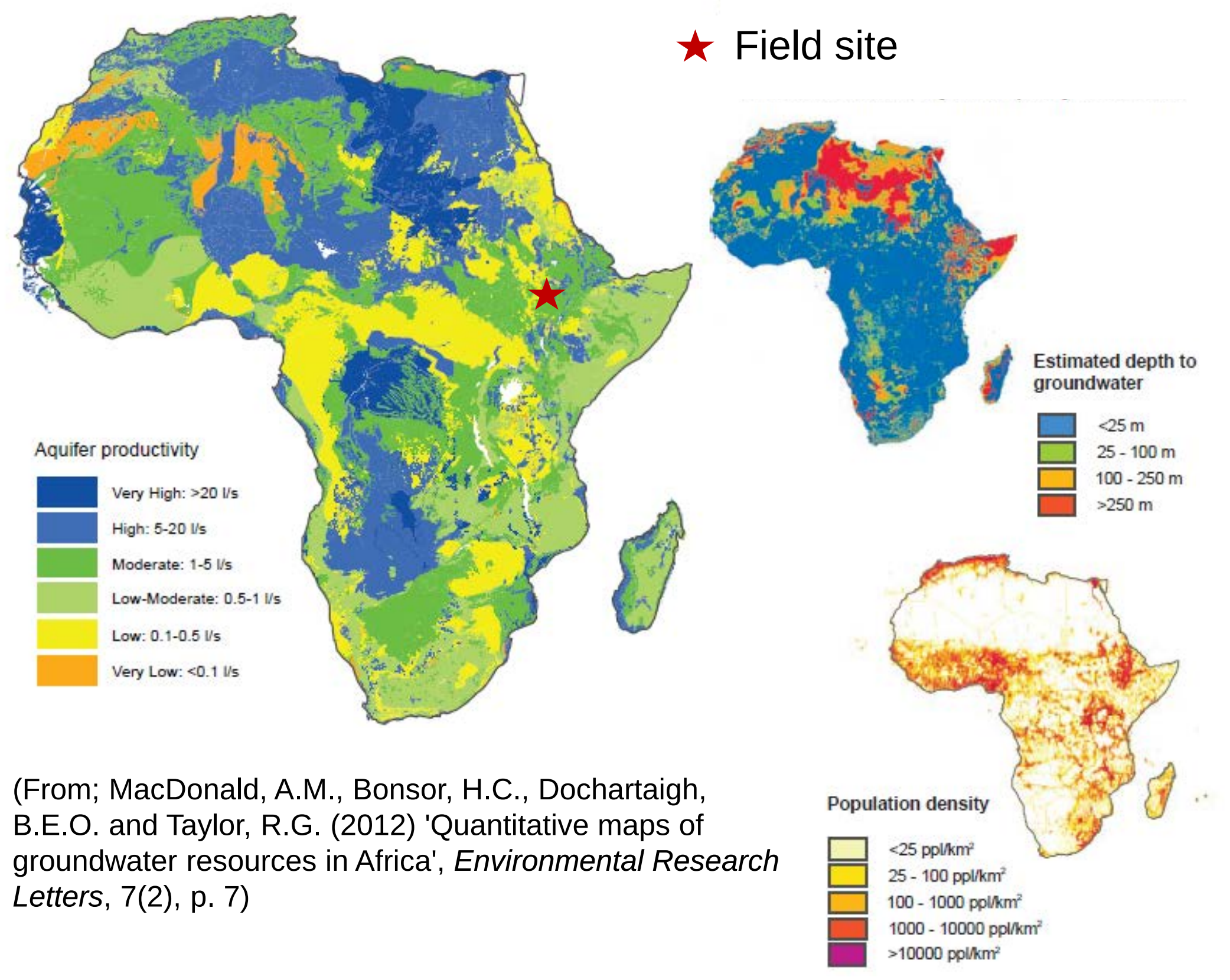
Background

Productive use of groundwater resources for irrigation in sub-Saharan Africa currently remains low but is expected to increase significantly in the near future, potentially providing a widespread poverty reduction. Their accessibility means shallow groundwater resources are most likely to be used by poorer communities, but they are also the most vulnerable to over-exploitation and climatic variability. Recent studies based on climate modelling and remote sensing data have demonstrated the abundance of groundwater resources at a broad scale, however, there is a scarcity of data to support its local management to reduce vulnerability.



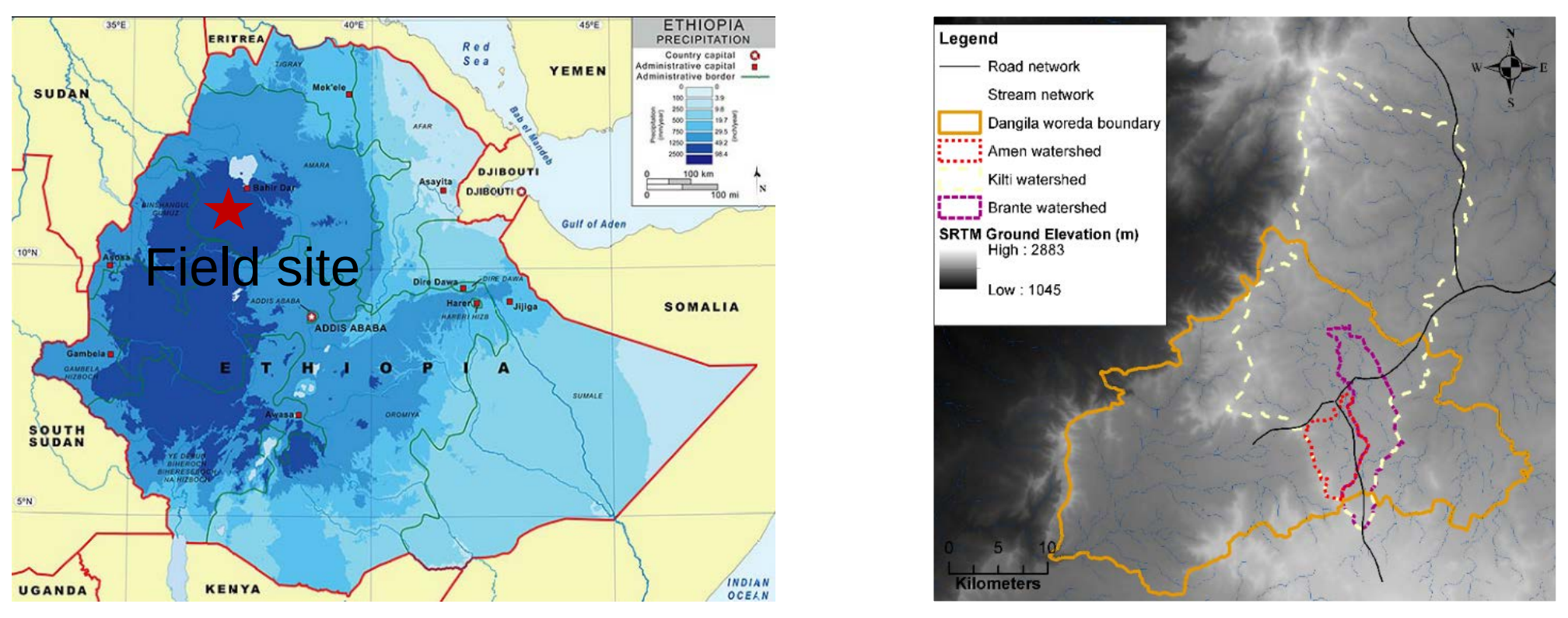
(From; MacDonald, A.M., Bonsor, H.C., Dochartaigh, B.E.O. and Taylor, R.G. (2012) 'Quantitative maps of groundwater resources in Africa', *Environmental Research Letters*, 7(2), p. 7)

Continental-scale hydrogeological assessment of Africa

Aim and research questions

The aim of the research is to determine the potential for shallow groundwater resources around Dangila *woreda* (district) to be used for small-scale irrigation by rural communities, supplementing the existing rainfed agriculture.

- Which areas show the greatest potential for sustainable intensification of agriculture through irrigation?
- How will climate variability, land use change and increased abstraction impact the shallow groundwater resource and surface water?

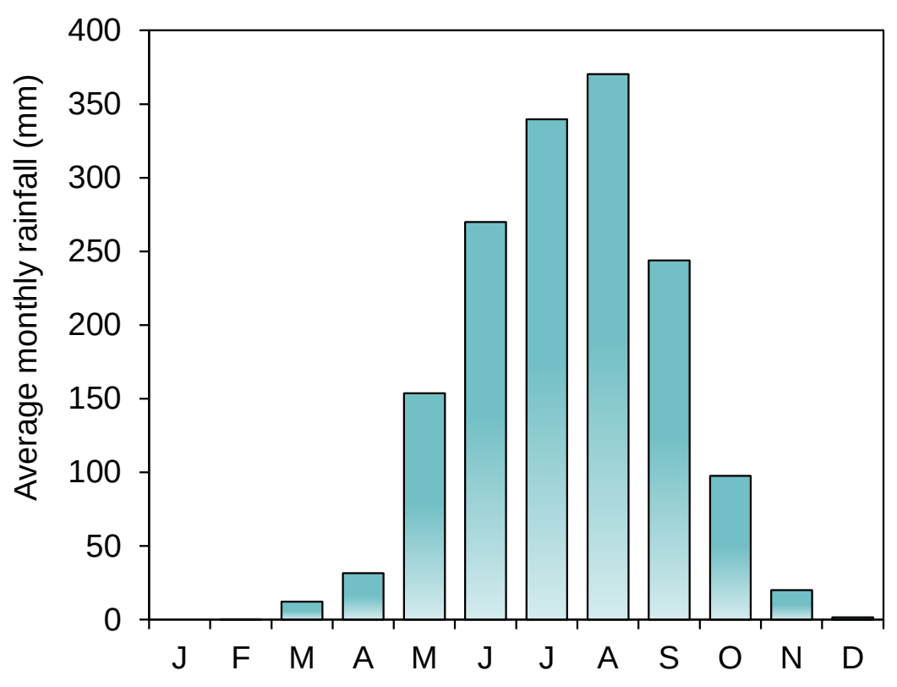


Precipitation map of Ethiopia and map of the modelled catchments

Typical scenery at the field site, showing the seasonally inundated floodplain pasture with crops and dwellings on slopes.

Field site

Area: ~900 km^2
Average elevation: ~2100 m
Average annual rainfall: ~1600 mm
Population: 160,000 of which 132,000 are rural
Primary source of livelihood: Crop–livestock mixed subsistence farming, rainfed agriculture predominates
Geology: Red clayey loam soils above weathered regolith above Cenozoic basalt and trachyte at 3-15 m



Field visits

Prolonged (3-5 week) field visits were conducted for hydrogeological investigations. Two visits coincided with the end of the dry seasons (period of greatest water scarcity) in 2015 and 2017, and another took place at the end of the 2015 wet season.

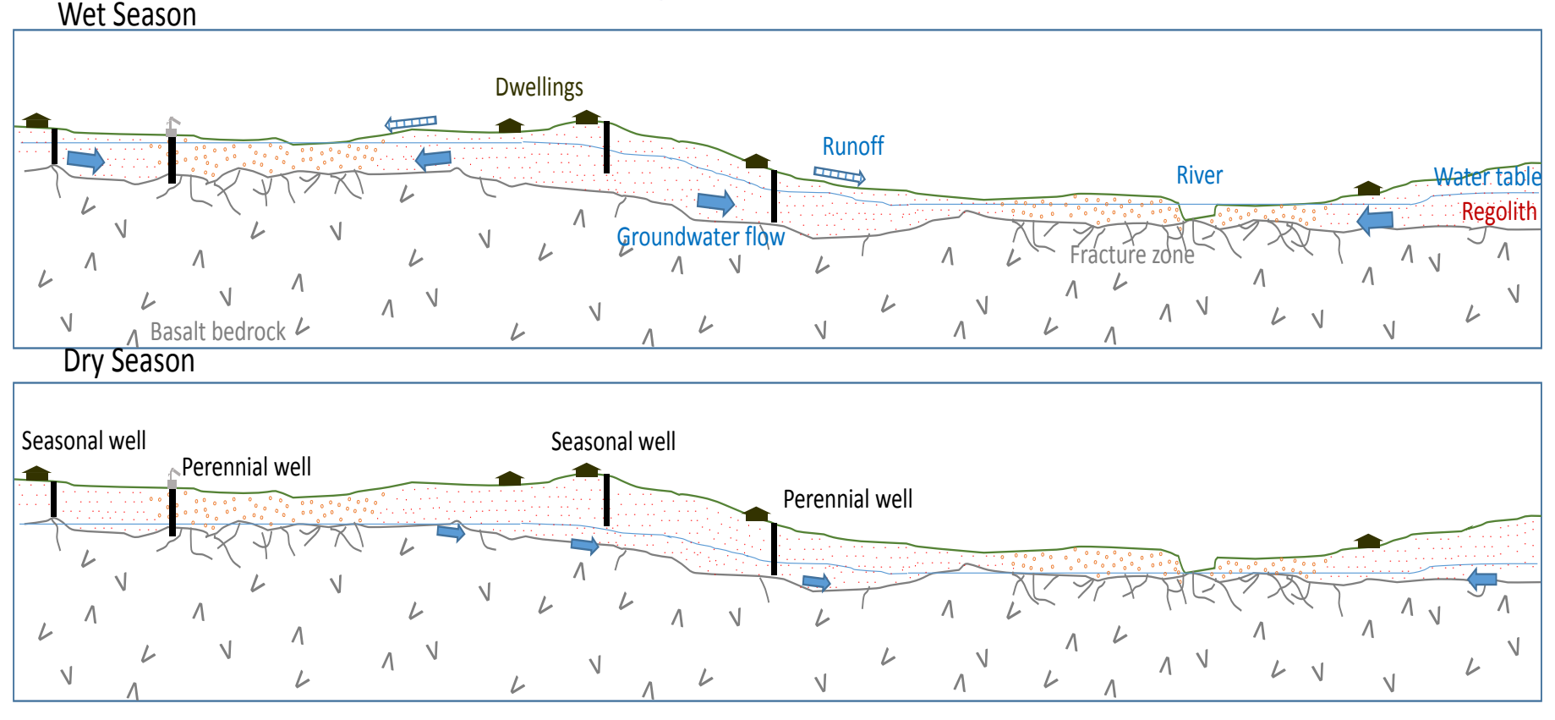
Physical measurements and sampling for major ion and stable isotope analysis from a developed spring (left) and a rope and washer pump

Pumping/recovery test on a hand-dug well (left) and geological survey in the Gizani river in addition to surveying seasonal and perennial reaches

Measuring radon-222 concentration (left), flow-gauging in the Kilti river (centre) and a workshop with the Dangesheta local community

Conceptual model

Season and topography govern shallow groundwater levels and are more of a control on hydrogeology than geological variation, which is subtle in the regolith which hosts the shallow aquifer. In-situ and laboratory analysis of groundwater chemistry (major ion, stable isotope and radon-222) suggest the shallow regolith aquifer is not connected to the deep aquifer and that groundwater flow directions do not necessarily match surface water flow directions.

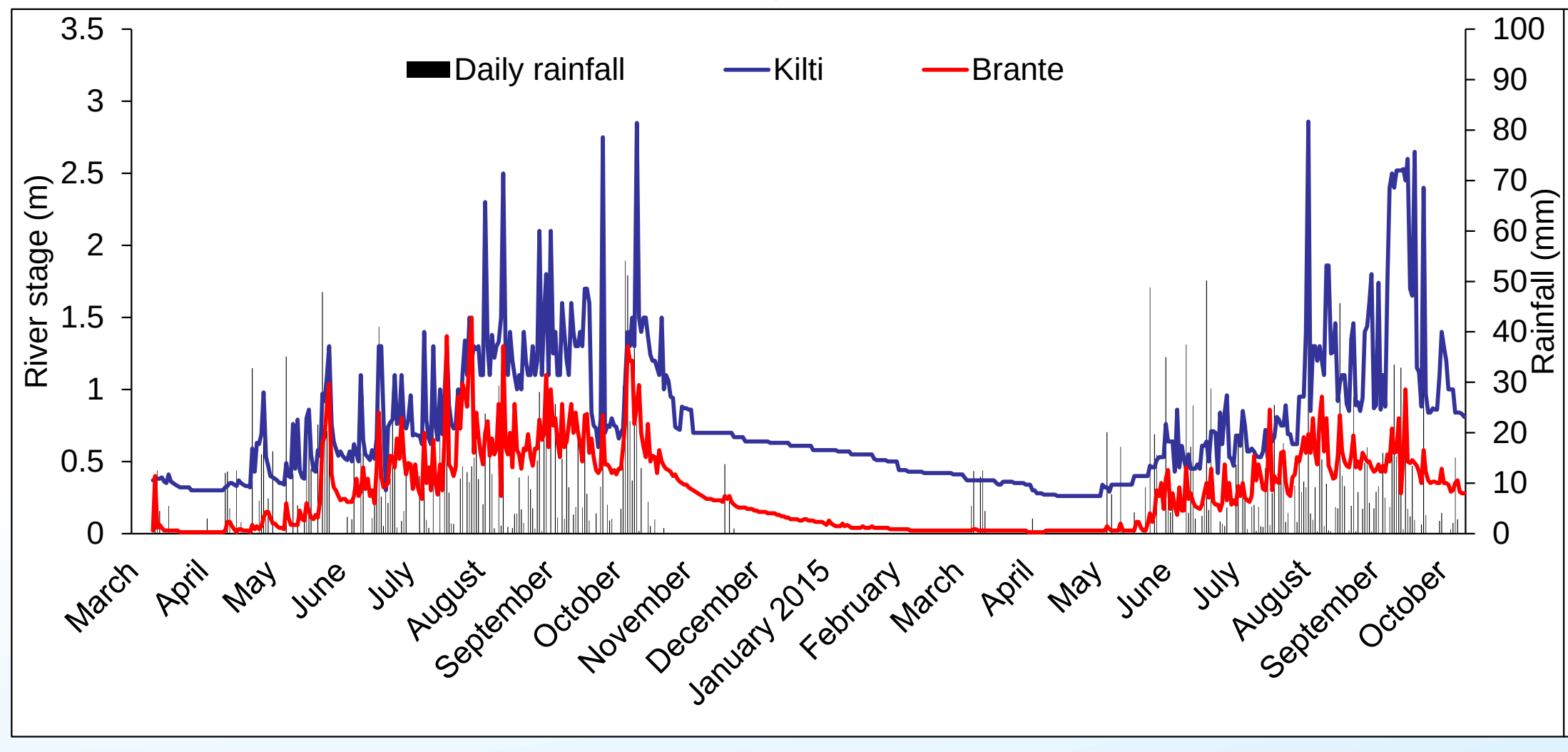


Conceptual cross sections during wet and dry seasons

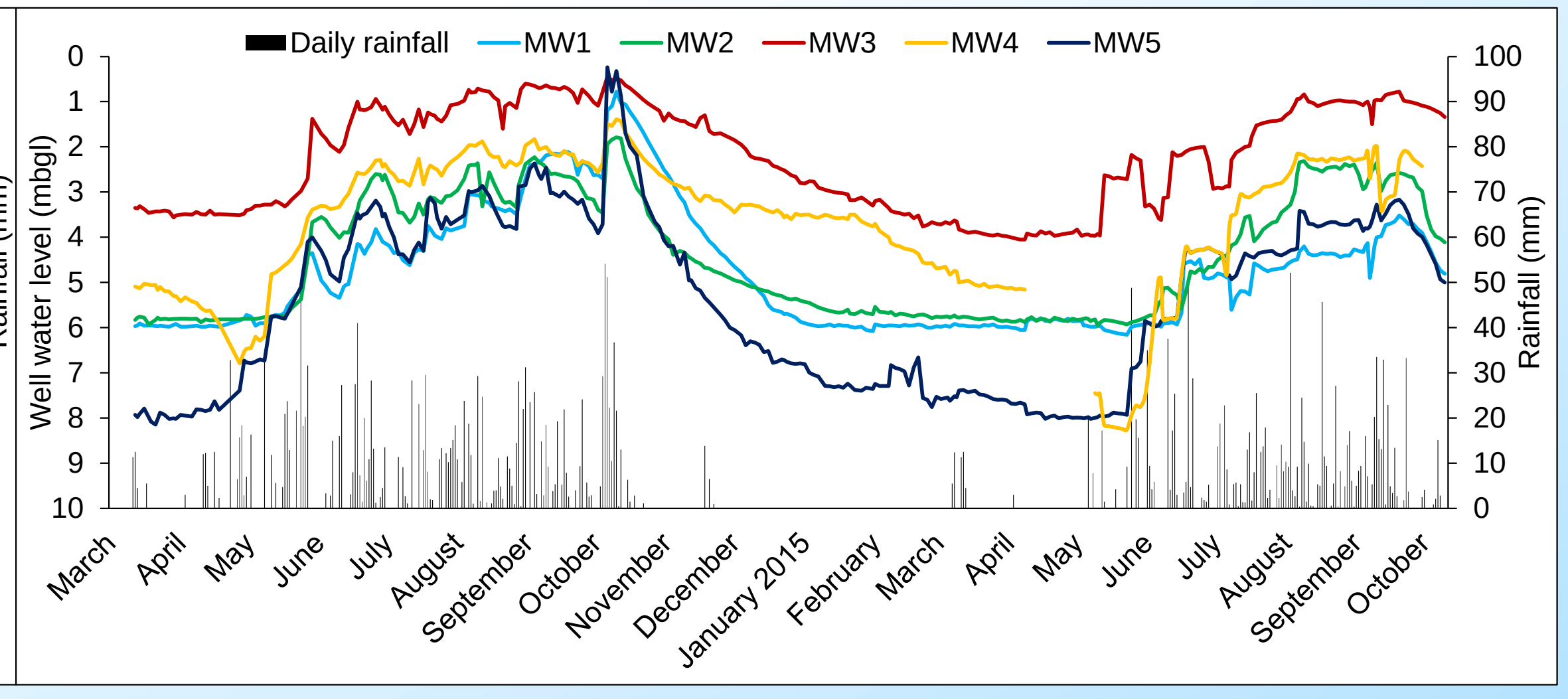
Community-based monitoring

Due to the sparse formal meteorological and hydrological monitoring networks in the region and the lack of groundwater observational data, a community-based monitoring programme was initiated. After initial community workshops, locations were selected for groundwater monitoring, river gauge boards and a rain gauge. Local observers were trained to collect daily data.

Reconstruction of the Kilti river gauge board (left) following damage during wet season floods, the rain gauge (centre) and measuring depth to groundwater in a monitoring well



Community monitored rainfall and river stage

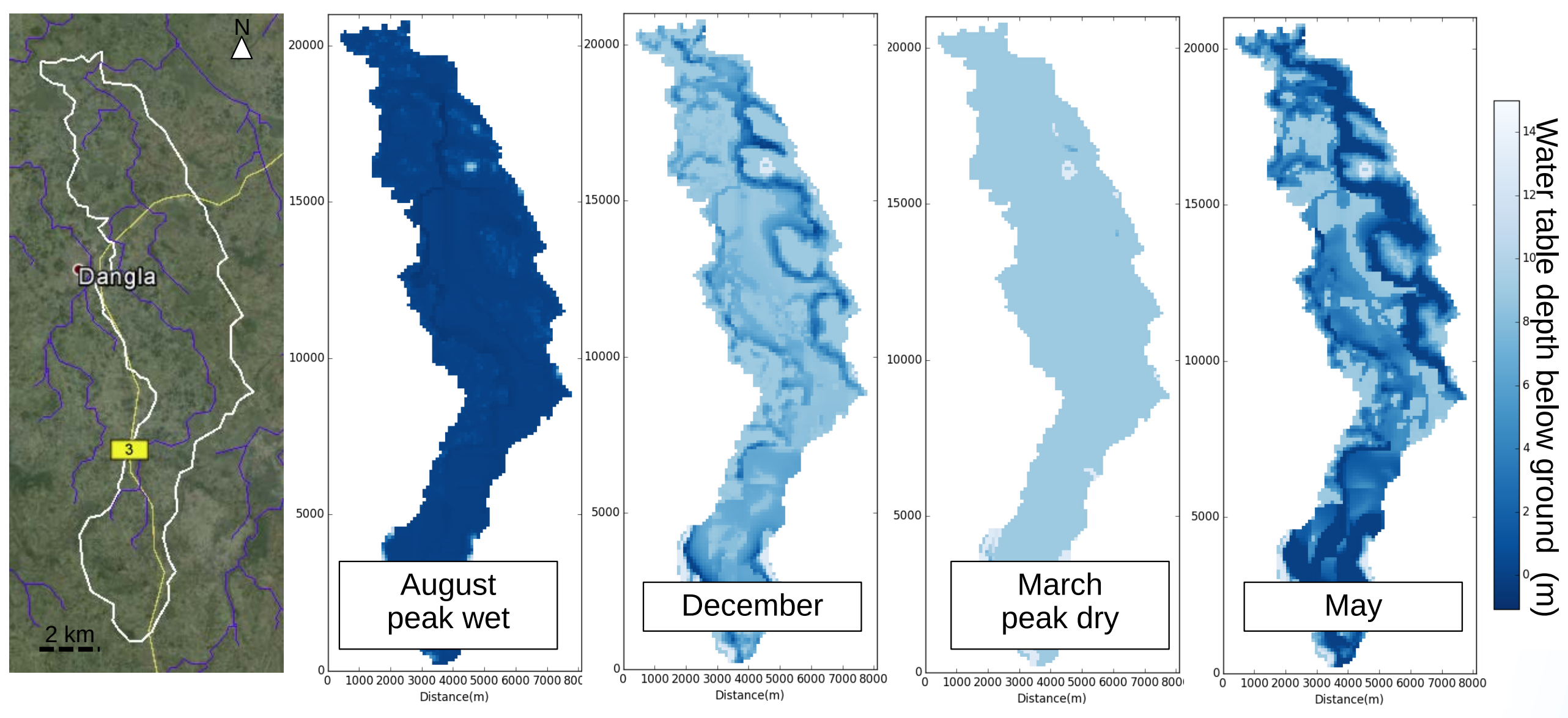


Community monitored rainfall and groundwater level

The community data has been statistically validated against formal sources confirming its quality and value. This aspect of the research was recently published in the Journal of Hydrology: Walker, D., Forsythe, N., Parkin, G., Gowing, J. (2016). "Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme." Journal of Hydrology **538**: 713-725.

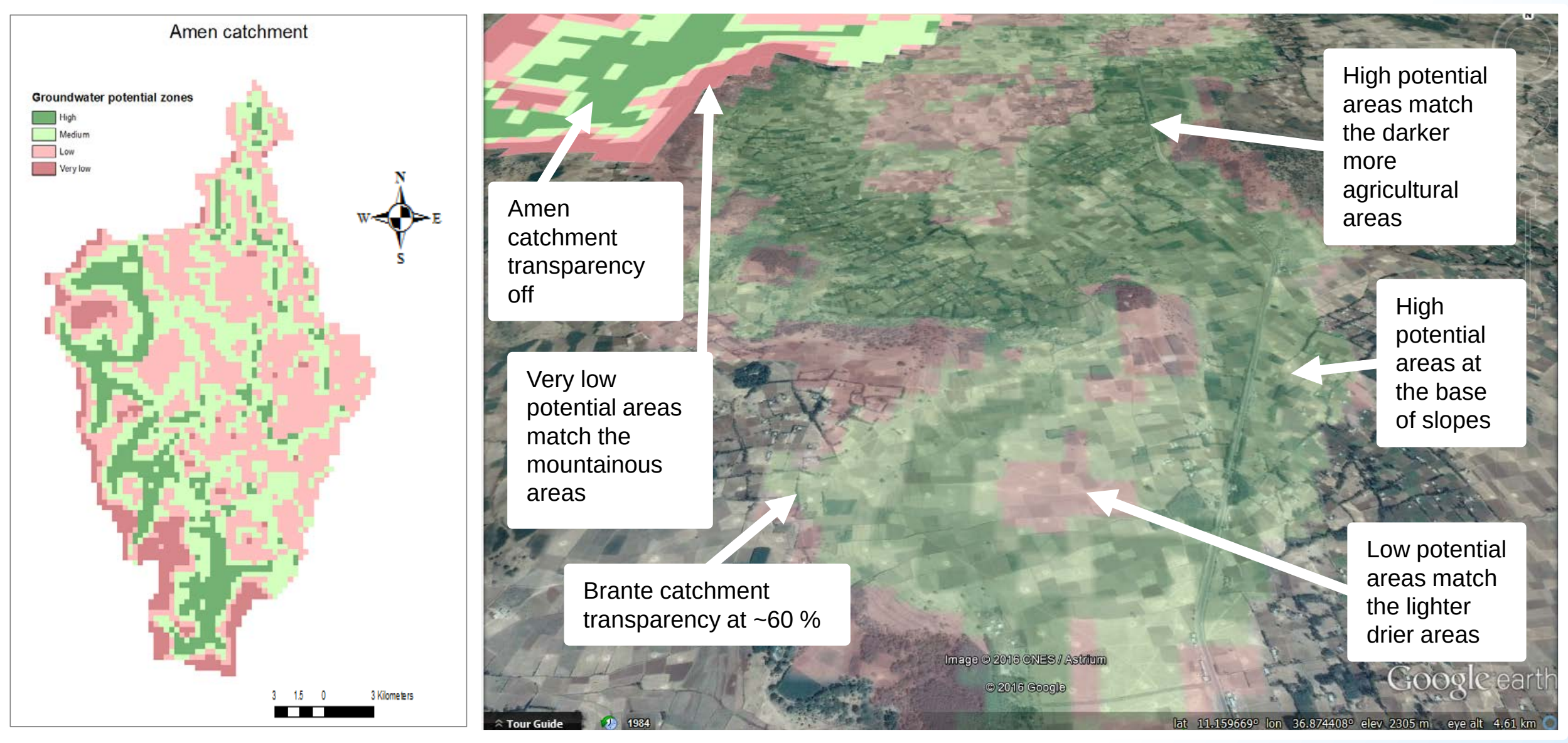
SHETRAN modelling

Four catchments at different scales have been modelled using SHETRAN, a physically based spatially distributed finite difference system for modelling coupled surface and subsurface water flow in river basins. SHETRAN is freely available at www.research.ncl.ac.uk/shetran/. Models were constructed using data from field visits and calibrated against river flow and groundwater level time series. Modelling revealed that, rather than being an impermeable barrier, properties of the basalt bedrock are very important in the control of groundwater and baseflow.



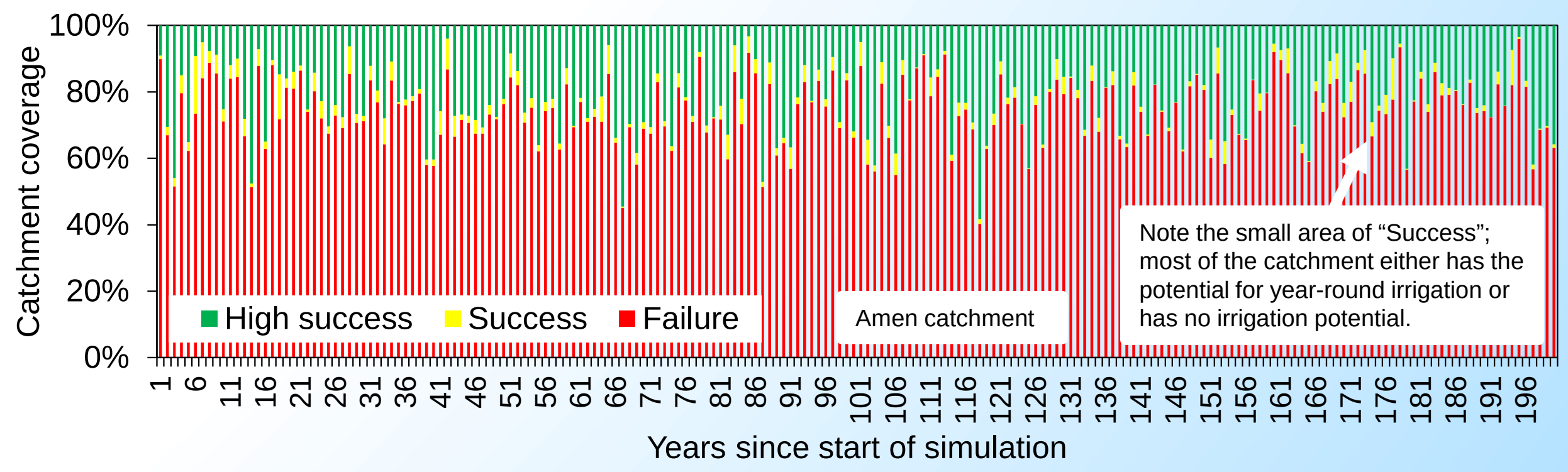
Map of Brante catchment and Shetran model outputs showing depth to water table at peak of wet season through to dry season and transition back to wet.

SHETRAN outputs (as shown above) were processed using Python to produce maps of potential for irrigation from shallow groundwater. Areas of highest potential are where groundwater remains accessible all year. The maps have been ground-truthed and provided to local stakeholders.

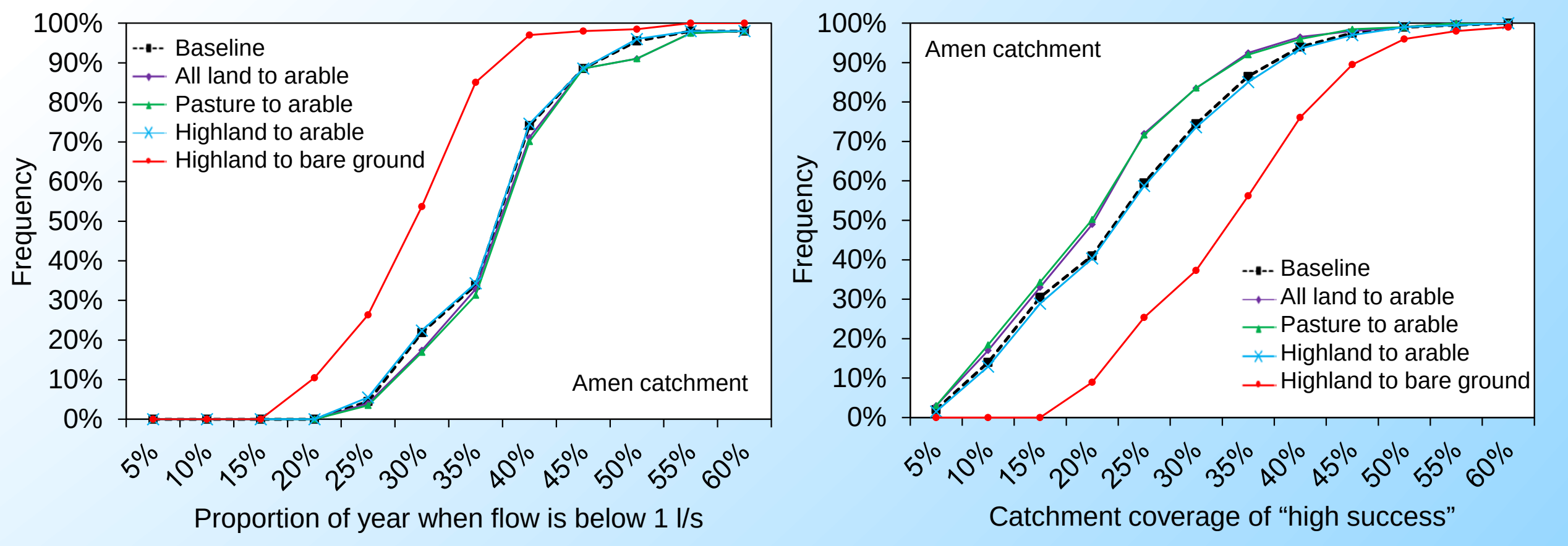


Groundwater irrigation potential map of the Amen catchment (left) and the Brante and Amen maps overlain on Google.Earth.

Observed historic climate variability is greater and less speculative than a synthetic time series produced by downscaling global circulation models; the observed rainfall range is 890-2035 mm/a. Observed rainfall years were randomly ordered into a 200 year sequence for SHETRAN. Model outputs were processed to show percentage area of a catchment where a second growing season using shallow groundwater for irrigation after the main rainfed season was impossible ("failure"), possible ("success"), and where shallow groundwater was available year-round ("high success"). Subsequent model runs involved land cover change to arable and/or bare ground to simulate pressures on pasture and non-agricultural land, in addition to abstraction scenarios with 10-100 % of arable land abstracting at 1-2 l/s/ha during a second growing season (November to January).



The impact of climate variability on shallow groundwater irrigation potential



Cumulative frequency curves of river low flows (left) and irrigation potential for various land use conversion scenarios. The abstraction scenarios had zero impact on the baseline (note the abstracted water is reapplied for irrigation).

Conclusions and ongoing work

Zones of the catchments have been identified with the greatest potential for shallow groundwater irrigation. Typically, these areas are at the foot of slopes. The variable climate means the extent of the "high success" (groundwater available all year) area varies interannually from around 5 to 50 % of the catchments. A change in land use to an increased area of arable land reduces the "high success" area due to increased evapo-transpiration, though has little effect on low flows. The reverse is true if highland areas are reduced by deforestation and overgrazing to bare ground and low flows occur less frequently. Having a second growing season from November to January, abstracting at 1 or 2 l/s/ha over 10, 50 or 100 % of arable land has zero impact when the water is reapplied as irrigation rather than removed from the model.

Model runs are ongoing for four catchments running 200 and 1000 year simulations. A 1000 year simulation takes 6 weeks to run; 200 years takes 5-7 days. Additional scenarios are further testing the resilience of the shallow groundwater resources.

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