# Agricultural Water Consumption in the Australian Border Rivers Catchment: a Preliminary Assessment

June 2018

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**FutureWater Report 177**

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# 1 Introduction

## 1.1 Background

Efforts are being made in the Australian Murray-Darling Basin (MDB) to transfer water from the irrigation sector to environmental flows. However, discussions have been on-going for several years regarding the appropriate way to achieve this goal. Dimensions under discussion include the promotion of improving on-farm irrigation efficiencies, water rights and their buybacks, undocumented use of water for irrigation, and “theft” of water.

A knowledge gap exists regarding the actual amount of water that is being consumed across the MDB, which is the main outgoing component of the basin water balance. Spatial quantification of actual evapotranspiration ($ET_{act}$) would, for example, allow for estimation of irrigation water consumption in relation to water allocation, and thus support identification of locations where theft of water occurs.

Mapping of $ET_{act}$ has been developed by the scientific community for the past 20 years and has now achieved a degree of technological maturity. This has prompted the distribution of several global $ET_{act}$ products in the public and semi-public domains, which offer a revolutionary and cost-effective way for evaluating and monitoring water consumption. Remote sensing data have been used by the Murray-Darling Basin Authority (MDBA) to analyze water extractions and storage (MDBA, 2017), but not yet for quantification of consumptive use.

## 1.2 Objectives

The objective of this study is to apply a global-scale satellite-derived $ET_{act}$ product to provide a preliminary spatiotemporal assessment of water consumption across the Border Rivers catchment, one of the MDB catchments where excessive agricultural water use is an urgent issue. For relevant specific lots / properties, this reports presents monthly water consumption dynamics. As these figures should be viewed as first-order estimates with likely significant error margins, a second objective of this study is to demonstrate the type of information that could be obtained from a more sophisticated, validated and potentially near-real-time system for monitoring and evaluation of agricultural water consumption.

# 2 Methodology

## 2.1 Satellite monitoring of water consumption

Actual evapotranspiration ($ET_{act}$), defined as soil and open water evaporation + transpiration by vegetation[1], is a significant component of the water balance in most river basins. Due to the complexity of measuring $ET_{act}$ in the field, alternative manners to quantify the term have been the subject of research for several decades. Satellite observations have played a key role in these developments since the launch of dedicated earth surface monitoring sensors in the 1980s, particularly due to their capacity to obtain information on vegetation conditions and land surface temperature. This has resulted in several satellite-based techniques for $ET_{act}$, most notably those based on solving the surface energy balance (e.g. Bastiaanssen et al., 1998) and the Penman-Monteith equation (e.g. Mu et al., 2013).

With recent progress regarding computer processing power, cloud computing and big data analytics, several institutes around the globe are applying $ET_{act}$ algorithms to populate operational data services available in the public domain. These $ET_{act}$ products are typically available on the global scale at a relatively course spatial resolution (500m – 5km), although this level of detail suffices for many applications related to river basin management. Examples of algorithms currently applied globally include e.g. SSEBop (Senay et al., 2013), MOD16 (Mu et al., 2013), SEBS (Chen et al., 2013), and GLEAM[2].

This study uses data from the operational version of the Simplified Surface Energy Balance (SSEBop) model, which relies on land surface temperature (LST) from the MODIS sensor for determination of the latent heat flux. Global data are distributed by USGS with a cell size of 1 x 1km.

## 2.2 Study area

The Border Rivers catchment is located in eastern Australia, in the upstream portion of the MDB (Figure 1). The main agricultural use of land is for grazing and dryland cropping, which covers around 90% of the catchment. Irrigation for the production of cotton occurs on the western plains (NSW Department of Primary Industries Office of Water, 2012).

[1] Following definitions of the FAO, in this study, the term actual evapotranspiration is used interchangeably with the terms water consumption and consumptive use. All these terms indicate the sum of water consumed under non-irrigated conditions (water balance under natural conditions) and consumptive use of irrigation water.

[2] https://www.gleam.eu/


**Figure 1. Location of the Border Rivers Catchment in the Murray-Darling Basin (source: MDBA[1]).**

## 2.3 Mapping water consumption in the Border Rivers Catchment

Monthly SSEBop $ET_{act}$ data for five selected years were obtained from the USGS data server[2]. The years of specific interest were defined as 2011, 2013, 2016, 2017, plus an additional dry year. This dry year was selected based on satellite-derived CHIRPS rainfall data, accessible through Google Earth Engine (Funk et al., 2015). As shown in Figure 2, the year 2006 was particularly dry with a basin-averaged annual rainfall of 480 mm. This year was added to the period of analysis.

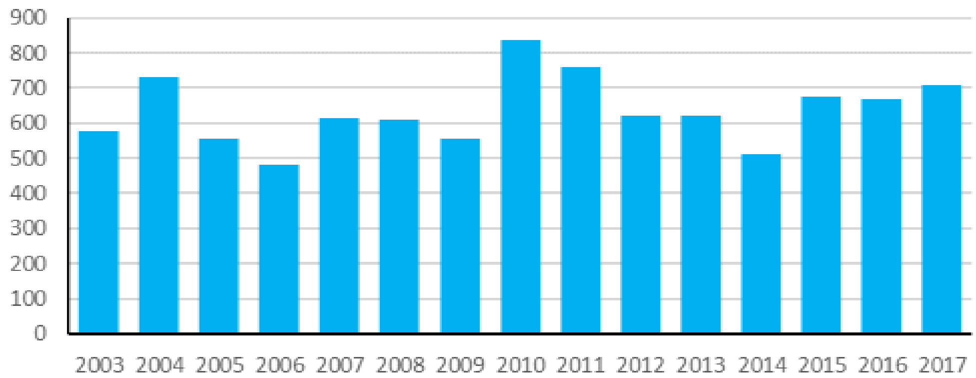


**Figure 2. Basin-averaged annual precipitation in mm/yr in the Border Rivers Catchment for the last 15 years (CHIRPS data).**

[1] https://www.mdba.gov.au/discover-basin/catchments
[2] https://edcintl.cr.usgs.gov/downloads

A number of agricultural lots on the western plains were selected to demonstrate the opportunities for mapping of agricultural water consumption for individual properties. These lots were grouped in four clusters, as shown in Figure 3. Cluster A includes western Kalanga and Tegege, cluster B contains eastern Kalanga, cluster C corresponds with Taraba / Whynot, and cluster D comprises Mobandilla.

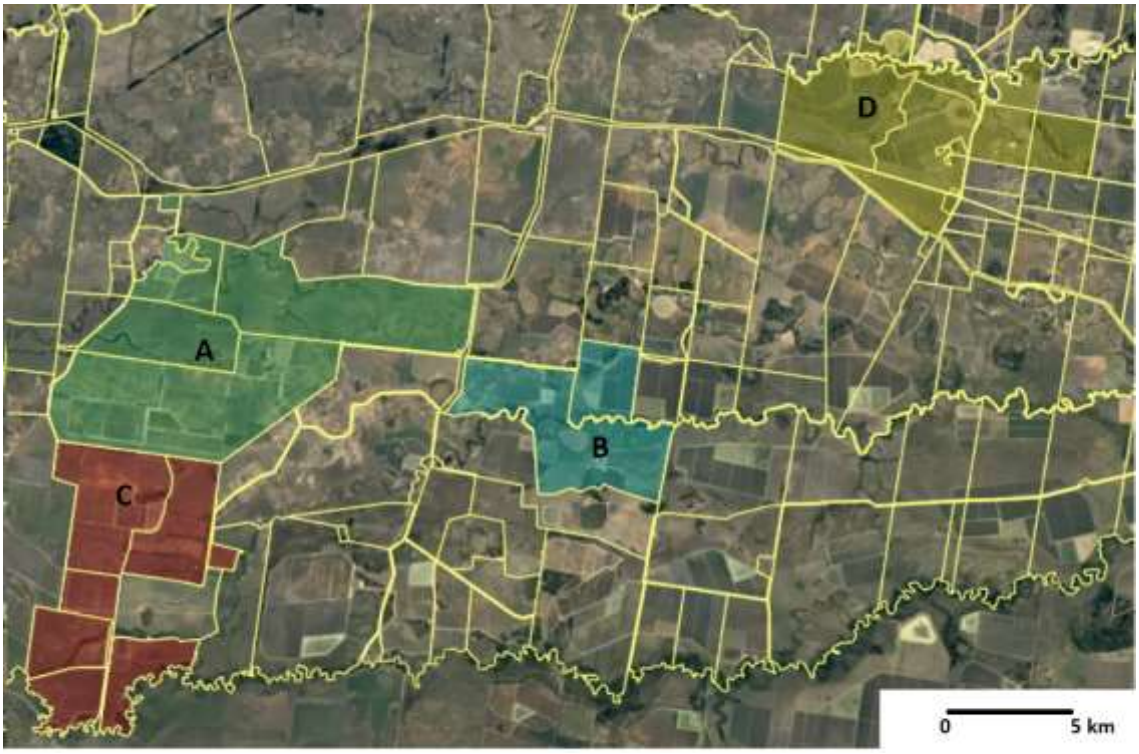


**Figure 3. Locations of selected properties and grouping of clusters A, B, C and D (parcel boundaries obtained from Queensland Globe[1]).**

[1] https://qldglobe.information.qld.gov.au/

# 3 Water consumption in the Border Rivers Catchment

## 3.1 Basin-wide water consumption

Maps of annual water consumption are depicted for a dry year (2006) and an average year (2013) in Figure 4 and Figure 5 respectively. $ET_{act}$ map classes are kept consistent for comparison purposes. Spatial patterns are generally in agreement with land cover types, with higher values of yearly consumptive use typically found for forestry and conservation. Water consumption markedly decreases in a western direction with patches of higher values found along the river, representing irrigated fields. The East-West trend is consistent with long-term average maps produced by the Bureau of Meteorology based on station observations, although absolute values seem somewhat on the low side of their estimations (Chiew et al., 2002). High-resolution versions of all annual maps produced in this study are included in Appendix I.

Table 1 shows basin-averages of annual water consumption for each of the five years. Inter-annual dynamics follow the temporal patterns of rainfall (Figure 2), with highest and lowest $ET_{act}$ found for the wettest (2011) and driest (2006) year respectively. Interestingly, the standard deviation is generally higher for drier years, implying that some locations do have alternative sources of water during otherwise stressed conditions, e.g. by means of irrigation water or groundwater.

Monthly basin-average water consumption for each of the selected five years is presented in Figure 6. On average, maximum monthly $ET_{act}$ occurs in January and minimum $ET_{act}$ in June, with seasonal dynamics following rainfall patterns.

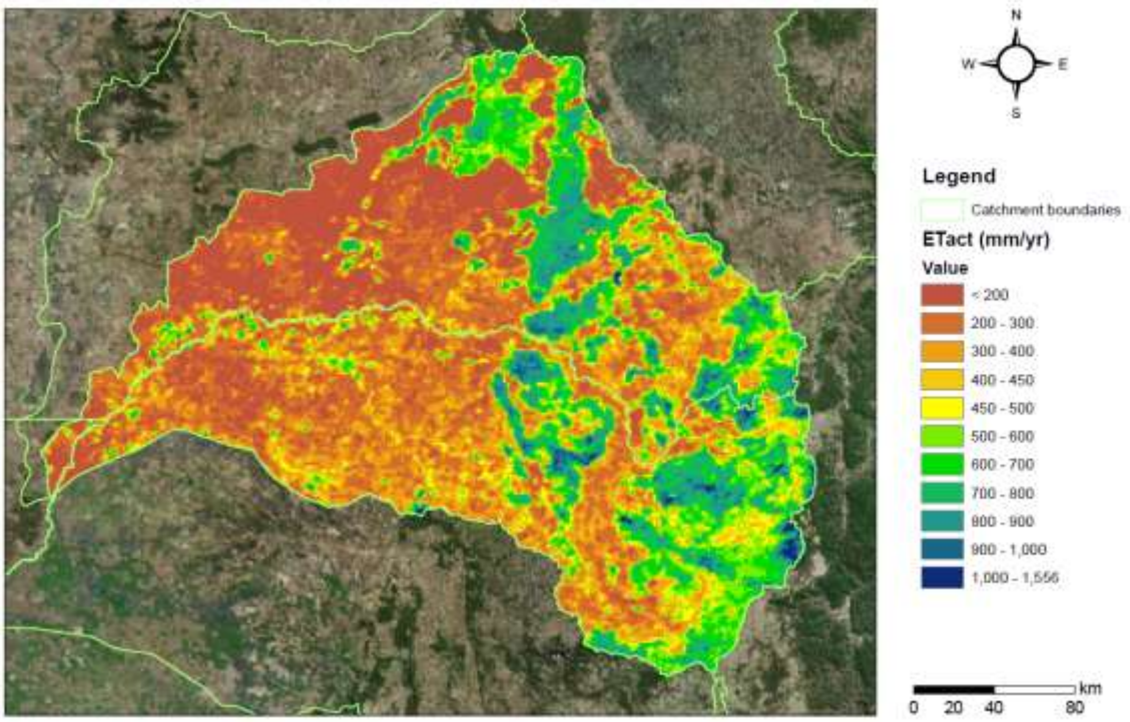


**Figure 4. Annual water consumption in the Border Rivers Catchment in the dry year 2006.**

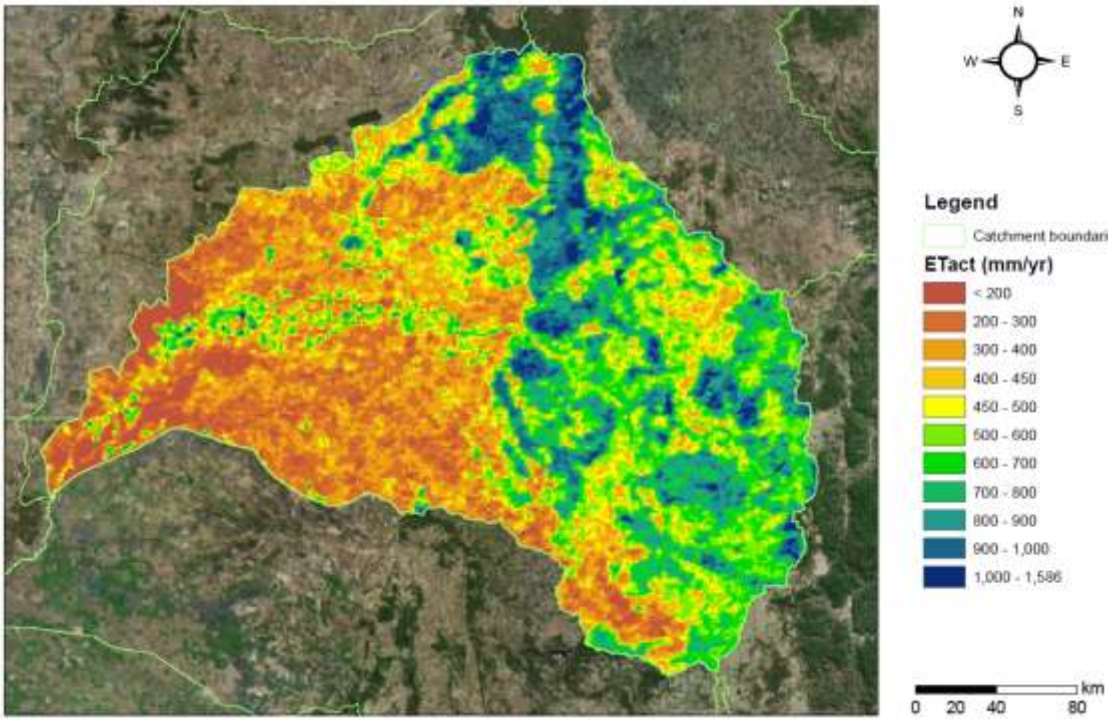


**Figure 5. Annual water consumption in the Border Rivers Catchment in 2017.**

**Table 1. Basin-scale statistics of annual water consumption of the Border Rivers Catchment. 1 BCM is 1 Billion Cubic Meters, which equals 1,000 GL (gigalitre).**

| *Year* | *$ET_{act}$ (mm/yr)* | | *$ET_{act}$ (BCM/yr)* | |
|---|---|---|---|---|
| | *Average* | *Standard deviation* | *Average* | *Standard deviation* |
| 2006 | 401 | 218 | 19.3 | 10.5 |
| 2011 | 713 | 211 | 34.3 | 10.1 |
| 2013 | 518 | 232 | 24.9 | 11.2 |
| 2016 | 522 | 181 | 25.1 | 8.7 |
| 2017 | 465 | 244 | 22.4 | 11.7 |

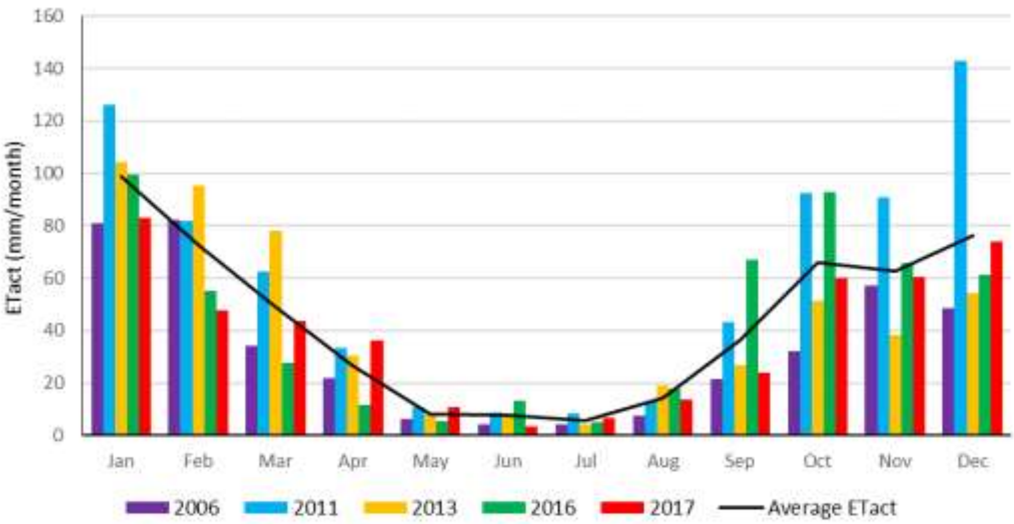


**Figure 6. Monthly basin-averaged water consumption for the five selected years.**

## 3.2 Water consumption of specific properties

As illustrated by Figure 7, the cell size of 1 $km^2$ of the global SSEBop product allows for distinction of spatial $ET_{act}$ patterns within the boundaries of the selected properties.

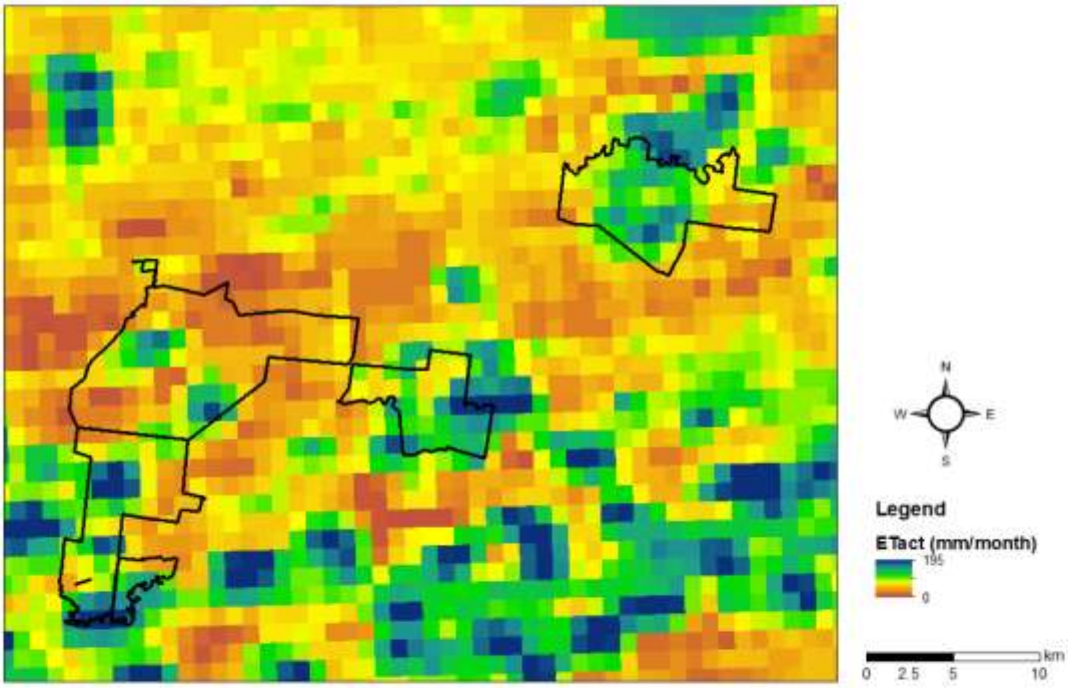


**Figure 7. Monthly water consumption of the selected properties in February, 2017.**

Table 2 gives an overview of annual $ET_{act}$ in 2006, 2011, 2013, 2016 and 2017 for each of the clustered properties. These values indicate that water consumption varies strongly from year to year, generally following precipitation dynamics. In addition, differences between the clusters can also be significant, particularly in 2017. Figures 8 to 11 show the monthly dynamics of $ET_{act}$ for each of the clusters. The fulltime series of monthly values for all properties can be found in Appendix II of this report.

**Table 2. Annual water consumption of the selected properties. 1 MCM = 1 Million Cubic Meters, which equals 1 GL (gigalitre).**

| *Cluster* | *Area ($km^2$)* | *Annual $ET_{act}$* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *2006* | | *2011* | | *2013* | | *2016* | | *2017* | |
| | | *mm* | *MCM* | *mm* | *MCM* | *mm* | *MCM* | *mm* | *MCM* | *mm* | *MCM* |
| A | 84.9 | 204 | 17.3 | 622 | 52.8 | 365 | 31.0 | 337 | 28.6 | 231 | 19.6 |
| B | 30.5 | 228 | 7.0 | 697 | 21.3 | 398 | 12.2 | 494 | 15.1 | 475 | 14.5 |
| C | 52.3 | 179 | 9.3 | 668 | 35.0 | 407 | 21.3 | 450 | 23.6 | 330 | 17.3 |
| D | 51.4 | 304 | 15.6 | 660 | 33.9 | 381 | 19.6 | 437 | 22.5 | 333 | 17.1 |

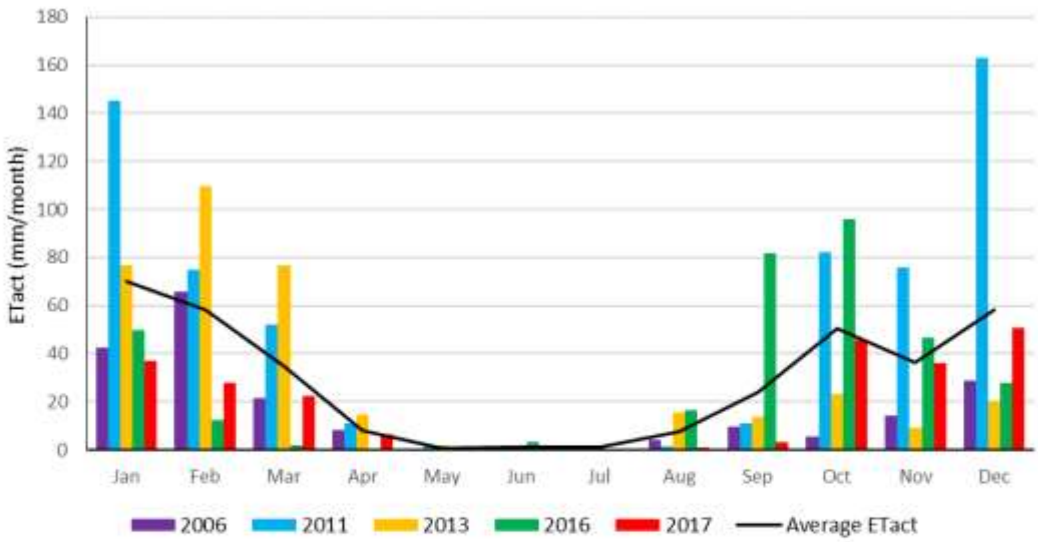


**Figure 8. Monthly water consumption of cluster A.**

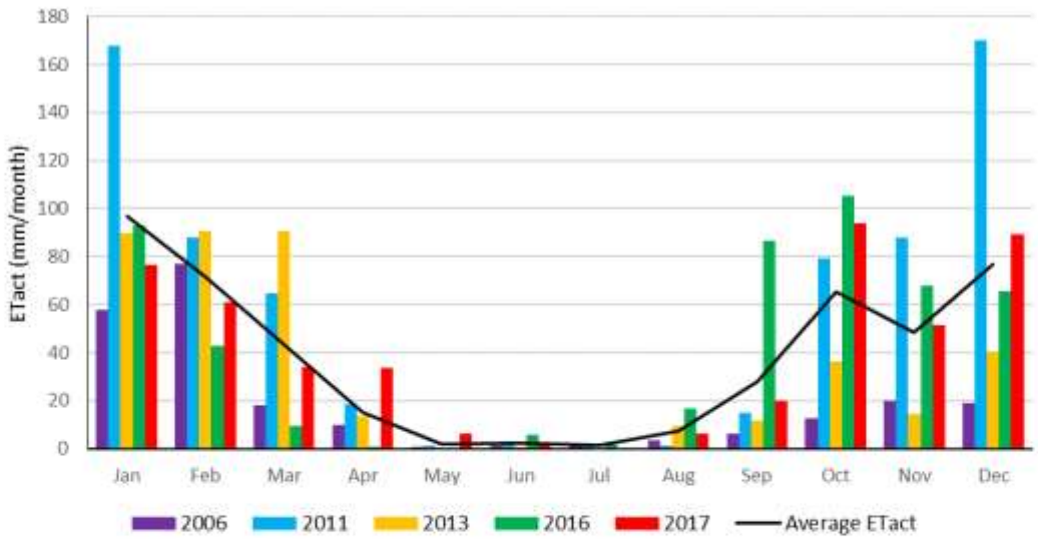


**Figure 9. Monthly water consumption of cluster B.**

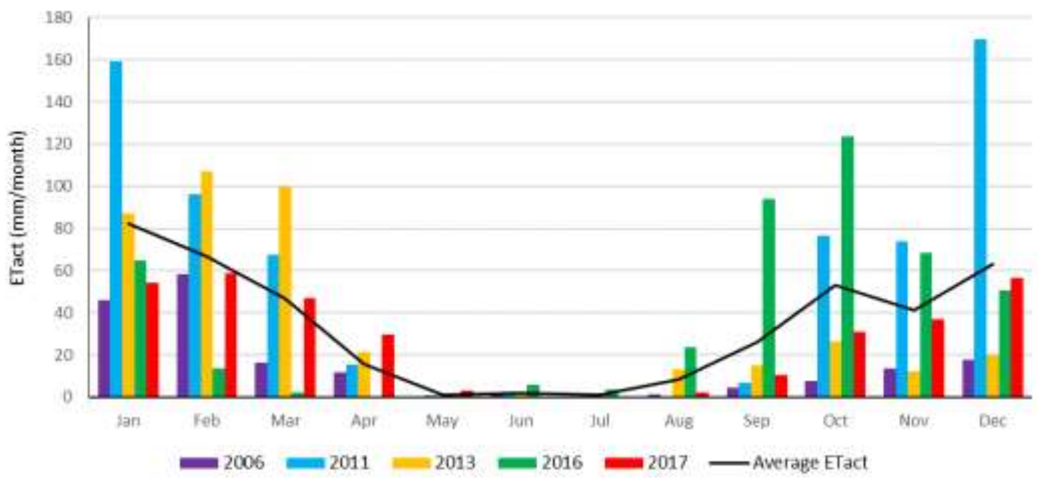


**Figure 10. Monthly water consumption of cluster C.**

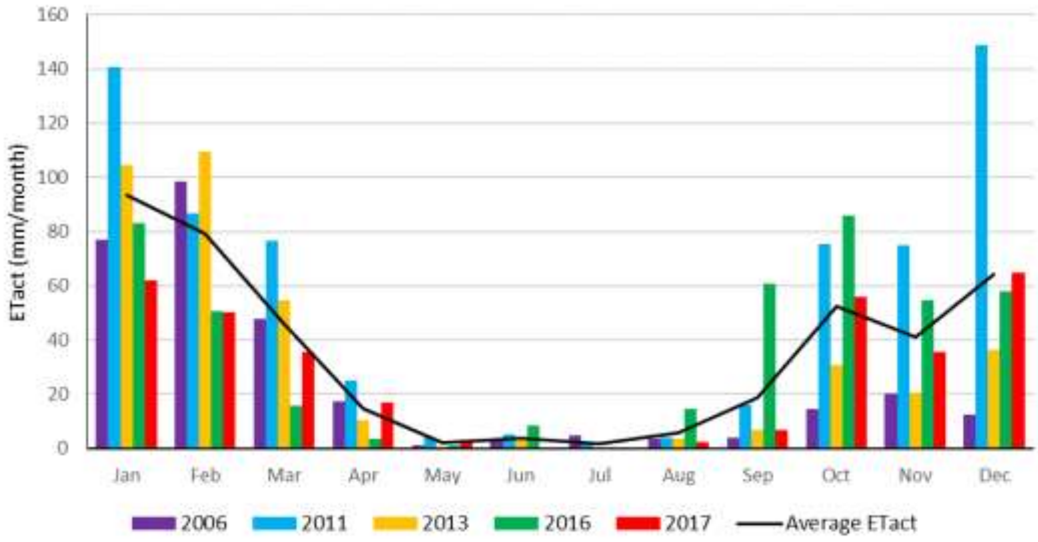


**Figure 11. Monthly water consumption of cluster D.**

# 4 Conclusions and recommendations

Satellite-derived data on water consumption have the potential to support activities and policies targeted towards sustainable management of river basins, such as water accounting at various scales, water rights systems, caps on water consumption, and assessments of irrigation performance and efficiencies (by relating consumptive use to measured volumes of abstracted water for irrigation).

This brief report provides a preliminary spatiotemporal assessment of water consumption in the Border Rivers catchment, focusing on specific properties in particular, as well as a demonstration of the type of information that can be obtained by application of remote sensing techniques. The SSEBop $ET_{act}$ product of USGS was used in this study. First impressions of spatial and temporal patterns are not contradictory to what might be expected. However, no activities related to validation or quantification of accuracy were performed.

With regards to future work, the following recommendations should be taken into account:

- Global $ET_{act}$ products all have their own strengths and weaknesses, and their relative performance will depend on factors such as land cover, cloud cover frequency, and topography (Bhattarai et al., 2016; Simons et al., 2016). Before applying $ET_{act}$ data for supporting or evaluating water management in the MDB, it is essential to review the performance of different $ET_{act}$ products for selecting the most appropriate dataset;
- A more comprehensive assessment including multiple $ET_{act}$ products will allow for the assessment of errors in absolute values of consumptive use and the quantification of inaccuracies of the findings presented in this study. Such an assessment should also include validation of satellite-derived water consumption by involving rainfall and outflow estimates to solve the catchment water balance;
- Although a low-cost and satisfactory option for many water management applications, the use of global $ET_{act}$ products does, by definition, not offer a tailor-made solution for a specific basin or region. In addition, due to storage and computing limitations, global-scale datasets will be limited to relatively course spatial resolutions for the foreseeable future. Specialized companies offer the set-up of calibrated operational $ET_{act}$ monitoring systems of spatial resolutions < 100 m based on satellites such as Sentinel 2 and Landsat 8;
- For a quantitative evaluation of upstream-downstream impacts of water abstractions, return flows, and evaluating different scenarios and policy options, it is essential to link satellite-derived evapotranspiration to hydrological models.

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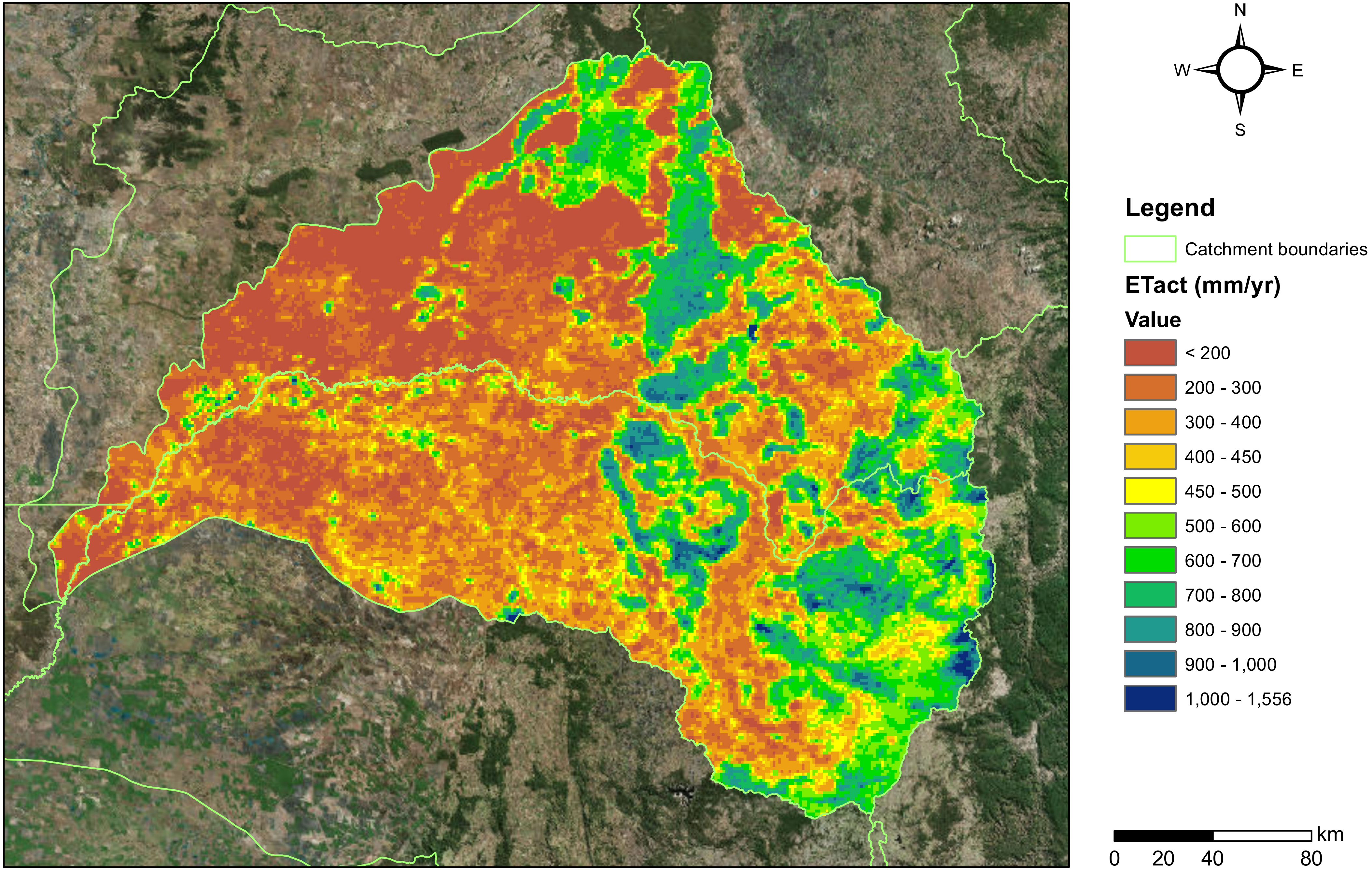
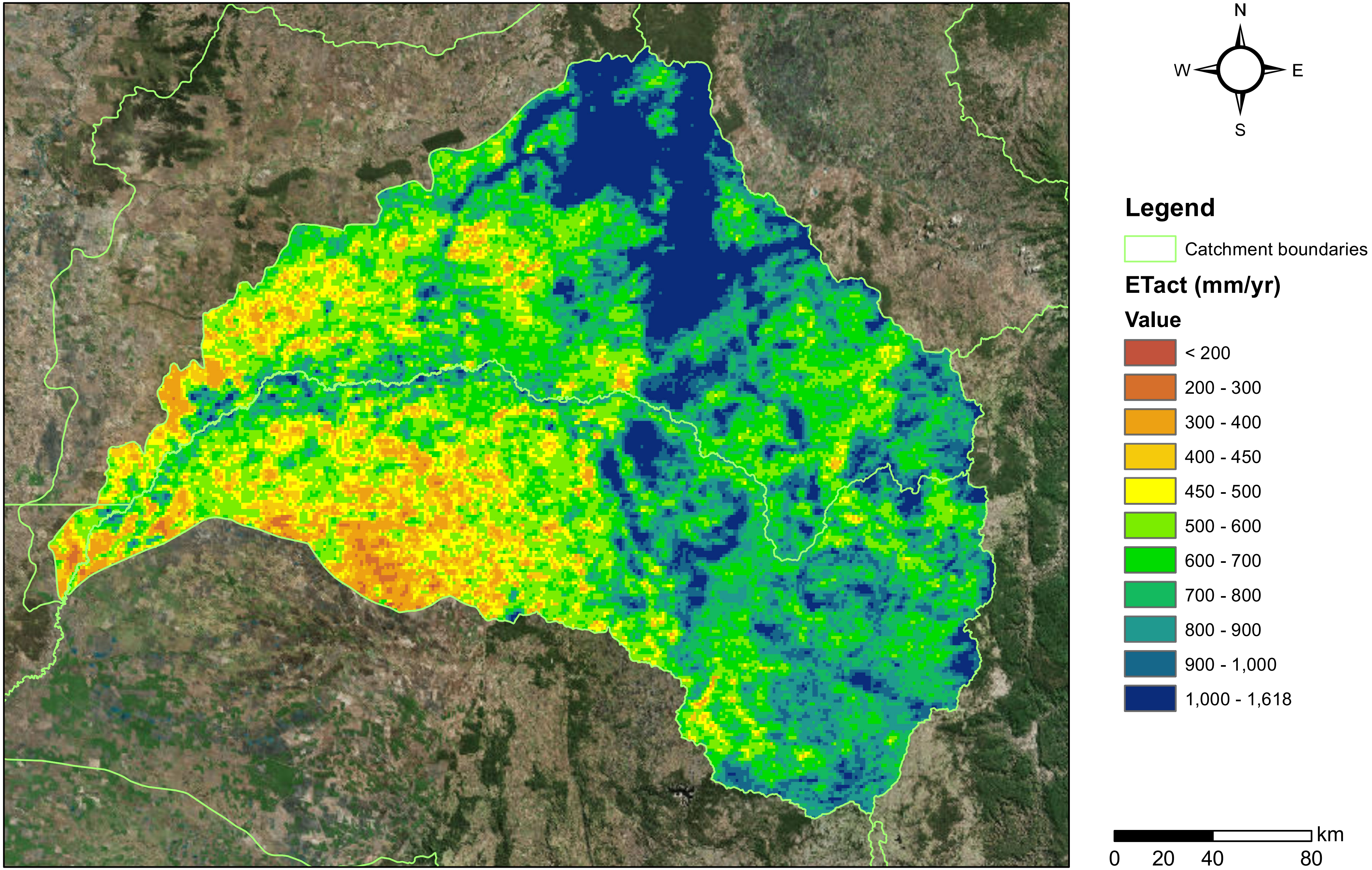
Simons, G., Bastiaanssen, W., Ngô, L., Hain, C., Anderson, M. and Senay, G.: Integrating Global Satellite-Derived Data Products as a Pre-Analysis for Hydrological Modelling Studies: A Case Study for the Red River Basin, Remote Sens., 8(4), 279, doi:10.3390/rs8040279, 2016.

# Appendix I Maps of annual water consumption

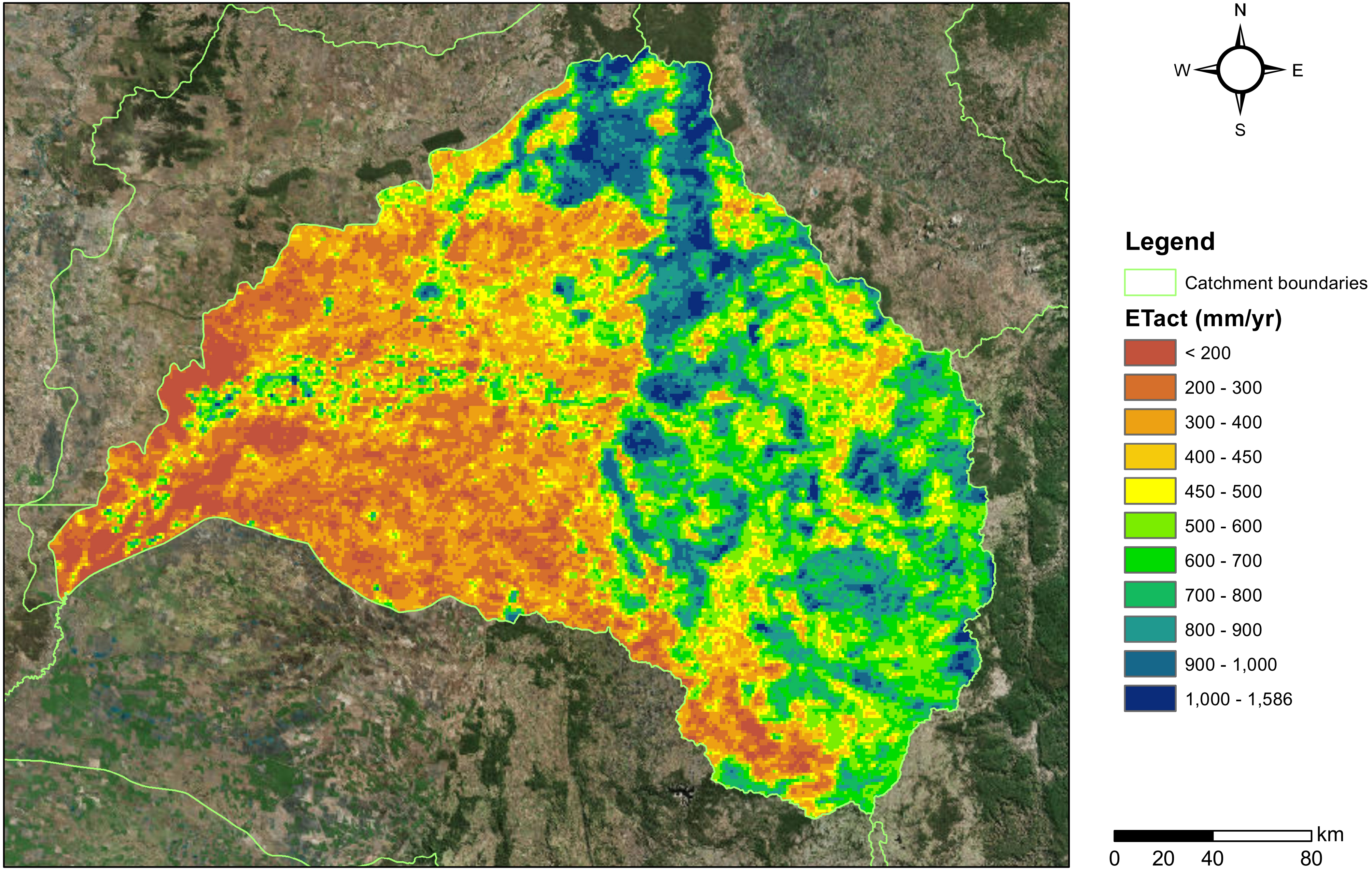
# Border Rivers: Actual Evapotranspiration in 2006



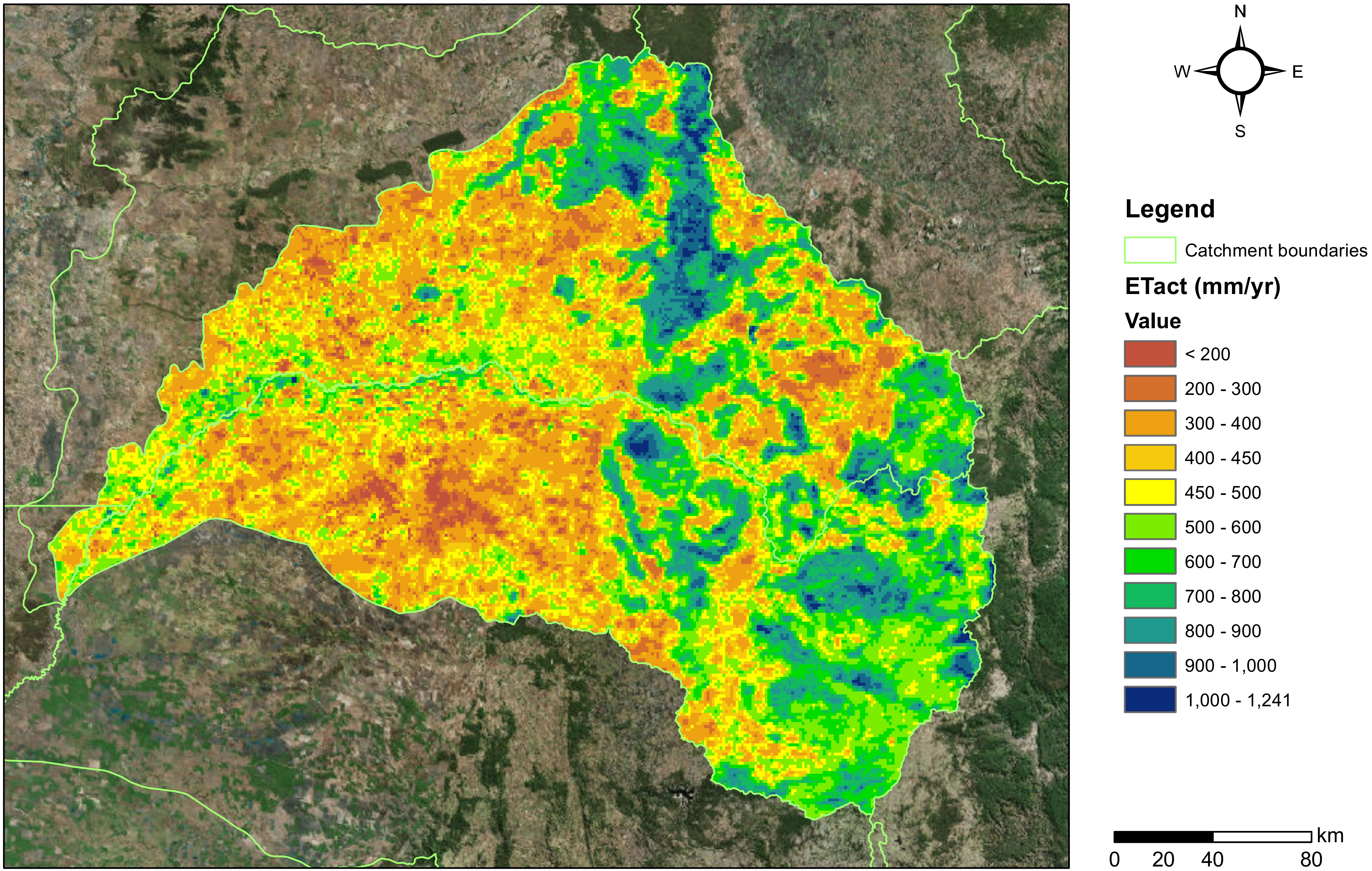
# Border Rivers: Actual Evapotranspiration in 2011



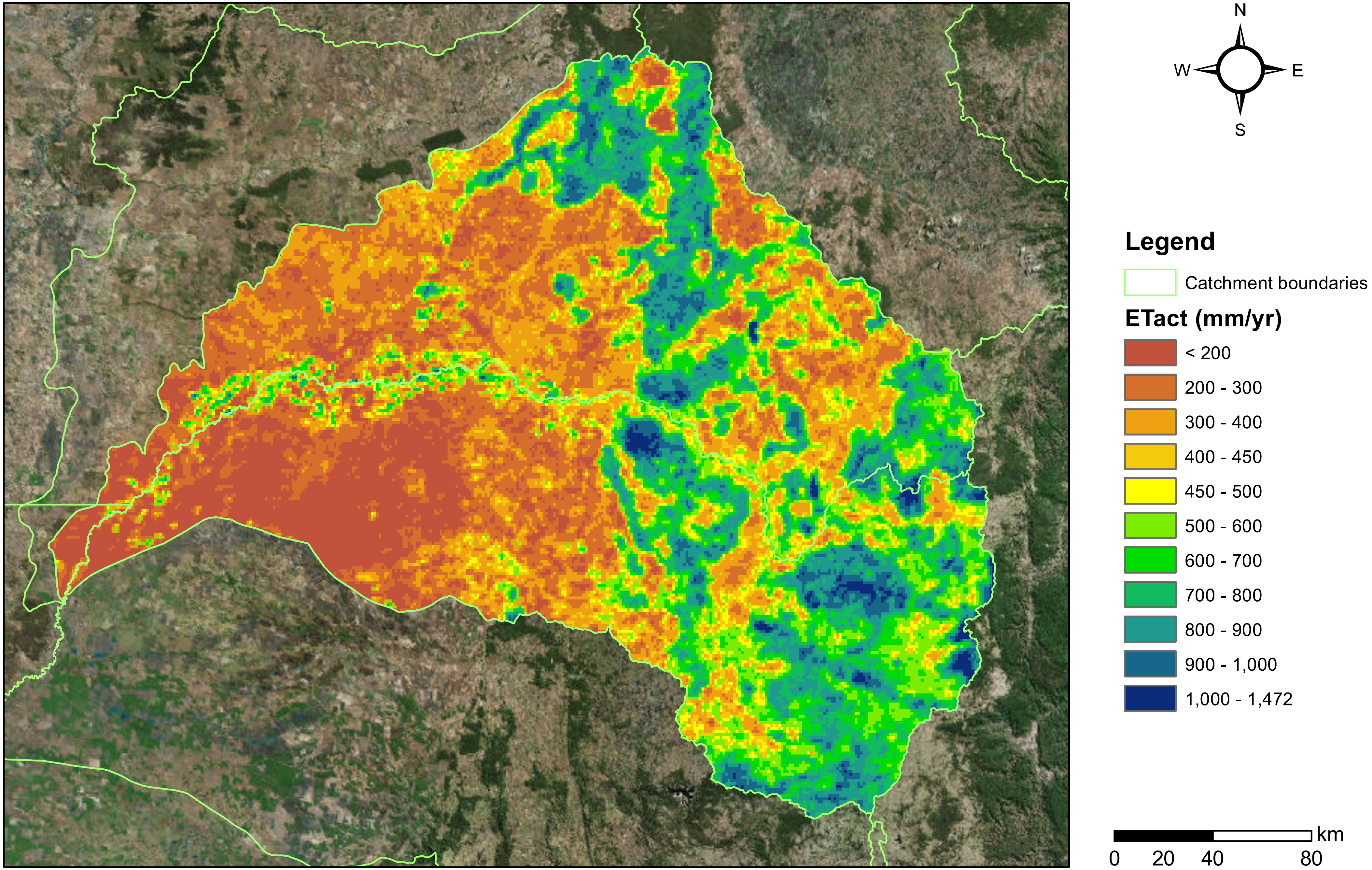
# Border Rivers: Actual Evapotranspiration in 2013



# Border Rivers: Actual Evapotranspiration in 2016



# Border Rivers: Actual Evapotranspiration in 2017



# Appendix II Monthly water consumption of selected properties

| Month | Area-averaged $ET_{act}$ (mm/month) | | | | | |
|---|---|---|---|---|---|---|
| | Basin | A | B | C | D | E* |
| Jan-06 | 81.1 | 42.5 | 57.8 | 46.0 | 76.8 | 58.1 |
| Feb-06 | 82.3 | 66.0 | 77.0 | 58.3 | 98.6 | 90.9 |
| Mar-06 | 34.2 | 21.3 | 18.0 | 16.2 | 47.9 | 24.3 |
| Apr-06 | 21.7 | 8.5 | 10.0 | 12.0 | 17.4 | 16.9 |
| May-06 | 6.1 | 0.3 | 0.9 | 0.0 | 1.3 | 0.0 |
| Jun-06 | 4.3 | 1.6 | 1.3 | 1.1 | 3.0 | 0.9 |
| Jul-06 | 4.0 | 1.0 | 1.9 | 0.1 | 4.9 | 3.6 |
| Aug-06 | 7.7 | 4.2 | 3.4 | 1.5 | 3.7 | 0.1 |
| Sep-06 | 21.5 | 9.8 | 6.1 | 4.4 | 3.9 | 1.0 |
| Oct-06 | 32.2 | 5.5 | 12.6 | 7.5 | 14.4 | 13.6 |
| Nov-06 | 57.4 | 14.3 | 20.0 | 13.7 | 20.0 | 26.9 |
| Dec-06 | 48.4 | 29.0 | 19.2 | 17.9 | 12.6 | 25.6 |
| Jan-11 | 126.2 | 145.4 | 168.0 | 159.1 | 140.6 | 131.4 |
| Feb-11 | 81.9 | 74.8 | 88.1 | 96.0 | 86.6 | 85.6 |
| Mar-11 | 62.5 | 52.2 | 64.5 | 67.5 | 76.5 | 79.1 |
| Apr-11 | 33.4 | 11.2 | 18.7 | 15.5 | 25.2 | 29.0 |
| May-11 | 10.7 | 1.8 | 1.2 | 0.9 | 3.9 | 6.4 |
| Jun-11 | 8.7 | 1.5 | 1.6 | 1.3 | 5.2 | 1.4 |
| Jul-11 | 8.2 | 1.4 | 1.7 | 0.5 | 2.4 | 0.0 |
| Aug-11 | 12.8 | 1.4 | 1.2 | 0.2 | 4.1 | 0.0 |
| Sep-11 | 43.1 | 11.0 | 14.8 | 7.0 | 16.1 | 6.6 |
| Oct-11 | 92.3 | 82.2 | 79.2 | 76.8 | 75.3 | 90.3 |
| Nov-11 | 90.7 | 76.0 | 88.0 | 73.7 | 75.1 | 71.9 |
| Dec-11 | 142.9 | 163.2 | 170.2 | 169.8 | 148.6 | 160.3 |
| Jan-13 | 104.5 | 76.7 | 89.8 | 87.2 | 104.7 | 81.1 |
| Feb-13 | 95.4 | 109.6 | 90.7 | 107.3 | 109.2 | 101.1 |
| Mar-13 | 78.0 | 76.6 | 90.6 | 99.7 | 54.8 | 74.1 |
| Apr-13 | 30.3 | 14.7 | 13.7 | 21.2 | 10.3 | 11.7 |
| May-13 | 7.7 | 1.8 | 0.3 | 1.4 | 0.9 | 0.0 |
| Jun-13 | 8.1 | 0.7 | 0.8 | 1.6 | 2.6 | 3.3 |
| Jul-13 | 4.4 | 2.1 | 0.3 | 1.7 | 0.4 | 0.0 |
| Aug-13 | 18.8 | 15.4 | 9.6 | 13.3 | 3.6 | 0.0 |
| Sep-13 | 26.8 | 13.6 | 11.6 | 15.2 | 6.9 | 2.0 |
| Oct-13 | 51.5 | 23.5 | 36.3 | 26.4 | 30.6 | 18.1 |
| Nov-13 | 38.3 | 9.4 | 14.5 | 12.4 | 20.8 | 14.1 |
| Dec-13 | 54.1 | 20.4 | 40.3 | 20.0 | 36.3 | 36.7 |
| Jan-16 | 99.3 | 49.7 | 92.9 | 64.8 | 83.0 | 77.3 |
| Feb-16 | 55.0 | 12.6 | 42.6 | 13.4 | 50.5 | 14.3 |
| Mar-16 | 27.8 | 2.1 | 9.2 | 2.3 | 15.7 | 26.1 |
| Apr-16 | 11.6 | 0.5 | 0.8 | 0.2 | 3.6 | 1.7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| May-16 | 5.4 | 0.1 | 0.0 | 0.0 | 1.3 | 2.0 |
| Jun-16 | 13.2 | 3.0 | 5.6 | 5.7 | 8.5 | 20.4 |
| Jul-16 | 5.1 | 0.5 | 1.8 | 3.5 | 0.5 | 0.3 |
| Aug-16 | 17.6 | 16.4 | 16.5 | 23.5 | 14.7 | 9.9 |
| Sep-16 | 67.0 | 81.8 | 86.4 | 94.1 | 60.6 | 73.4 |
| Oct-16 | 92.9 | 95.8 | 105.1 | 123.5 | 86.1 | 87.0 |
| Nov-16 | 65.6 | 46.7 | 67.7 | 68.6 | 54.8 | 38.0 |
| Dec-16 | 61.2 | 28.1 | 65.5 | 50.7 | 58.0 | 44.9 |
| Jan-17 | 83.2 | 37.2 | 76.6 | 54.2 | 62.0 | 40.6 |
| Feb-17 | 47.9 | 28.0 | 60.8 | 58.7 | 50.3 | 53.4 |
| Mar-17 | 43.6 | 22.3 | 34.2 | 46.9 | 35.6 | 47.7 |
| Apr-17 | 36.3 | 6.4 | 33.5 | 29.8 | 16.9 | 21.3 |
| May-17 | 10.9 | 0.4 | 6.4 | 3.3 | 3.0 | 2.0 |
| Jun-17 | 3.4 | 0.3 | 1.7 | 0.4 | 0.1 | 0.0 |
| Jul-17 | 6.8 | 0.1 | 0.4 | 0.0 | 0.1 | 0.0 |
| Aug-17 | 13.8 | 0.8 | 6.3 | 2.4 | 2.1 | 2.3 |
| Sep-17 | 23.9 | 3.1 | 20.1 | 10.4 | 6.7 | 9.4 |
| Oct-17 | 60.2 | 45.6 | 93.7 | 30.8 | 55.8 | 69.9 |
| Nov-17 | 60.6 | 36.0 | 51.5 | 37.0 | 35.6 | 68.6 |
| Dec-17 | 73.9 | 50.8 | 89.4 | 56.4 | 64.7 | 66.7 |

**Area E was added to the analysis at a later stage, and represents lot 1/SP276749 located directly to the north of cluster D.*