Table 4. Country comparisons of water availability between present and 2050 scenarios.

<table>
<thead>
<tr>
<th>Country</th>
<th>Total no. of cells</th>
<th>Present situation</th>
<th>Year 2050 scenario (2050 climate; high demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cells with shortage</td>
<td>Cells with severe shortage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(WAI &lt; 0)*</td>
<td>(WAI &lt; –0.75)</td>
</tr>
<tr>
<td>Botswana</td>
<td>205</td>
<td>6 3</td>
<td>0 0</td>
</tr>
<tr>
<td>Kenya</td>
<td>191</td>
<td>58 30</td>
<td>17 9</td>
</tr>
<tr>
<td>Lesotho</td>
<td>11</td>
<td>10 91</td>
<td>3 37</td>
</tr>
<tr>
<td>Malawi</td>
<td>38</td>
<td>1 3</td>
<td>0 0</td>
</tr>
<tr>
<td>Mozambique</td>
<td>293</td>
<td>11 4</td>
<td>4 1</td>
</tr>
<tr>
<td>Namibia</td>
<td>303</td>
<td>7 2</td>
<td>0 0</td>
</tr>
<tr>
<td>South Africa</td>
<td>483</td>
<td>267 55</td>
<td>103 21</td>
</tr>
<tr>
<td>Swaziland</td>
<td>5</td>
<td>5 100</td>
<td>4 80</td>
</tr>
<tr>
<td>Tanzania</td>
<td>316</td>
<td>28 9</td>
<td>2 1</td>
</tr>
<tr>
<td>Uganda</td>
<td>79</td>
<td>38 48</td>
<td>14 18</td>
</tr>
<tr>
<td>Zambia</td>
<td>251</td>
<td>2 1</td>
<td>0 0</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>134</td>
<td>11 8</td>
<td>10 7</td>
</tr>
<tr>
<td>Region</td>
<td>2303</td>
<td>444 19</td>
<td>157 7</td>
</tr>
</tbody>
</table>

*WAI4, water availability index Type 4.

**Water availability estimates: defining water availability indices**

To assess water that is available at any location (i.e., per 0.5° cell) in relation to demand by the three major use sectors, a series of indices of increasing complexity was developed.8 This index is expressed as a value ranging from –1 to +1. A zero value implies that demand equals supply, negative index values designate a shortage of water, and positive values an excess of available water.

**Water availability for current conditions**

Using the Type 4 index of water availability for a combination of both surface and groundwater, Fig. 6d shows that under current demands much of the ESA region has a more than adequate supply of water.8 This has to be qualified, however, as many of the arid zones (e.g., Botswana and Namibia) and other areas possess groundwater supplies that are, as yet, largely untapped. Fig. 6d shows that there are pockets and also larger regions of substantial water shortfalls, however, mainly in Uganda, southwestern Kenya, in Zimbabwe around Harare, and over much of South Africa, Lesotho and Swaziland.8 This is a consequence mainly of high urban population densities combined with high irrigation demands.

Table 4 shows that for the 12 ESA countries a weighted average water shortage occurs over 19% of the region, with a severe shortage (Type 4 index < –0.75) currently over 7%. Countries where over 50% of their respective area currently experiences water shortages include South Africa, whereas seven countries suffer from shortages over 10% of their respective areas.8 The coarse scale of this analysis, however, should be pointed out, and a number of apparently anomalous situations have been identified, notably that Lesotho and Swaziland have areas possessing groundwater supplies that are, as yet, largely untapped. In regard to runoff, its amplification of the rainfall signal is manifested in the large areas with low annual runoff and exaggerated inter-annual variations of runoff, with extremes in the form of droughts and floods being very severe.

**Discussion and conclusions**

This paper has shown that while average precipitation in the ESA region is relatively low over large areas, more important hydrological problems arise out of the unreliability of rainfall and its strong seasonality, compounded by a dominance of very high potential evaporation, which frequently results in low conversion rates of rainfall to runoff. In regard to runoff, its amplification of the rainfall signal is manifested in the large areas with low annual runoff and exaggerated inter-annual variations of runoff, with extremes in the form of droughts and floods being very severe.

Superimposed on this, anticipated climate change will introduce new positive and negative responses into the natural hydrological system. Scale issues dominate uncertainties related to climate change, particularly in regard to local hydrological responses. Anticipated changes in temperature, potential evaporation and rainfall tend to increase constraints on water management, especially south of 15°S, where these changes have been converted to an altered runoff regime, of which even greater flow variability than at present becomes a major concern of water management.

Water demand is still dominated largely by agricultural usage and a large differential between urban and rural users. Much of the ESA region has large reserves of mainly groundwater available for use,8 but projections of demand versus supply to 2050 indicate that substantial additional areas within the region will as well as changes associated with the anticipated UKTR95 future climate for 2050.8
become water-stressed, with a marked increase in those areas that are likely to suffer under severe water shortages. A number of points need to be highlighted, however, regarding the vulnerability of eastern and southern Africa’s water resources, now and especially in the future:

- First, the vulnerability of water resources over many parts of this region can change markedly over a short distance. The analysis presented in this paper has a coarse resolution and therefore cannot give the spatial detail available in more localized studies, especially in the SALS countries.

- Second, the physical infrastructure to make optimal use of available water does not currently exist in many parts of Africa, and may not for several decades to come.

- Third, many rural Africans do not live along the main channels of large, perennially flowing rivers, which derive their water from remote high-rainfall areas, but rather populate the valleys along often ephemeral, smaller tributaries without a sustained supply of runoff.

- Fourth, because of the high variability of runoff within and between seasons, and the severity of extreme events at both ends of the probability spectrum, there are very high costs associated with constructing and operating water projects over much of Africa — often beyond the financial resources of most countries.

- Fifth, the climatic and hydrological unreliability implies that self-sufficiency in food production and socio-economic development can often not be achieved for that reason alone, let alone for reasons of poor management.

- Sixth, too little emphasis to date has been placed on in-depth research into secondary, but often more significant, hydrological impacts of possible climate change, such as

  - the magnitude and frequency of extreme events,
  - the seasonality of runoff in regard to demand and supply of water, and its effect on water infrastructure (e.g., the cost of water storage),
  - inter-annual variability,
  - associated land use changes and shifts in agricultural as well as livestock belts and their influence on runoff generation,
  - reservoir storage drawdown,
  - groundwater recharge, which is so dependent on individual sustained rainfall events as well as on the intensification and extensiﬁcation of land use, and
  - upstream impacts on downstream users.

- Seventh, not enough emphasis to date has been placed on higher order impacts of water resources and possible changes to them. These include

  - changes in water quality and consequences for puriﬁcation costs and human health subject to unsafe water supplies,
  - the effects of present and future effects of climate and land use change on aquatic ecosystems and environmental integrity,
  - increased potential for conﬂict over shared water resources, particularly where there is a growing scarcity of available water and competing demands, especially where fresh water is shared from a river which forms a political boundary (such as the Zambezi and Limpopo), or is shared by upstream and downstream countries.

It has been the endeavour of this paper to summarize some of the important vulnerabilities associated with present and potential future hydrological responses in order to highlight those areas where further research is required.

   ration of Climate Data and Information for Application in Impact Studies of Climate
19. Cambula F. (1999). Impacts of climate change on water resources of Mozam-