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Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme

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SUMMARY

This study shows how community-based hydrometeorological monitoring programmes can provide reliable high-quality measurements comparable to formal observations. Time series of daily rainfall, river stage and groundwater levels obtained by a local community in Dangila *woreda*, northwest Ethiopia, have passed accepted quality control standards and have been statistically validated against formal sources. In a region of low-density and declining formal hydrometeorological monitoring networks, a situation shared by much of the developing world, community-based monitoring can fill the observational void providing improved spatial and temporal characterisation of rainfall, river flow and groundwater levels. Such time series data are invaluable in water resource assessment and management, particularly where, as shown here, gridded rainfall datasets provide gross under or over estimations of rainfall and where groundwater level data are non-existent. Discussions with the local community during workshops held at the setup of the monitoring programme and since have demonstrated that the community have become engaged in the project and have benefited from a greater hydrological knowledge and sense of ownership of their resources. This increased understanding and empowerment is at the relevant scale required for effective community-based participatory management of shallow groundwater and river catchments.

1. Introduction

Continuous time series of rainfall, river flow and groundwater level vary in their availability. For many areas of, particularly the developing, world, such data is patchy or non-existent. Unfortunately, the areas of greatest data scarcity typically coincide with areas that suffer the greatest impacts from adverse hydrological conditions where more data could be used to better assess the current situation and to forecast future scenarios allowing for better mitigation and adaptation strategies. The importance of quantitative information on the rainfall which controls spatially and temporally variable water resources and of measurements of the surface/groundwater resources themselves is not in doubt (Bonsor and MacDonald, 2011; Conway et al., 2009; Washington et al., 2006). Satellite and reanalysis rainfall products are often promoted as the solution to low-density gauge networks, however, the greatest accuracy of such products is achieved in areas with abundant ground observation data to aid calibration (Dinku et al., 2008; Fekete et al., 2004; Symeonakis et al., 2009). What's more, the necessary spatial averaging means spatial resolution is commonly insufficient for smaller than regional scale hydrological and hydrogeological studies. Datasets at the relevant scale to inform local resource management strategies are increasingly being obtained by local communities providing a low-cost and highly useful source of hydrometeorological time series data where they would be otherwise unavailable (Gomani et al., 2010; Liu et al., 2008). The numerous additional benefits of such community-based monitoring programmes include the engagement and empowerment of local communities in their own water resources (Buytaert et al., 2014; Conrad and Hilchey, 2011). A recent editorial in *Nature* discussing the rise of "citizen science" in various fields states that data quality is the prime concern of critics (Nature, 2015). The majority of the literature presenting community-based monitoring programmes has sought to detail the benefits brought to the community though few (if any) papers have attempted to quantitatively validate the collected data in a statistical manner akin to the abundant literature validating

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remote sensing products against ground observations. It will be determined here whether community-based monitoring can provide data which can be satisfactorily validated against formal sources to provide improved spatial and temporal resolution, and whether it can supply reliable hydrogeological data where there are no formal alternatives. As formal monitoring networks continue to decline in many parts of the world, we determine if community-based monitoring programmes can be a viable complement.

1.1. Sub-Saharan Africa context

Rain gauge distribution across sub-Saharan Africa (SSA) is sparse, particularly in comparison with Europe, North America and South Asia. There are 1152 World Meteorological Organization (WMO) World Weather Watch stations in Africa at an average station density of just one per 26,000 km^2, 8 times lower than the WMO minimum recommended level (Washington et al., 2006). Fig. 1 shows the network of WMO stations clearly indicating the sparsity of stations in Africa and their uneven distribution resulting in substantial areas going unmonitored. Within SSA, rain gauge densities are highest in coastal West and Southern Africa, and the East Africa Highlands of Kenya and Uganda, whereas areas of greater aridity are underrepresented. Furthermore, it is widely reported that rain gauge networks in SSA are in decline as weather services make cut backs (Maidment et al., 2014; Nicholson, 2001; Washington et al., 2004). Willmott et al. (1994) report a peak in African rain gauge density occurring in the 1950s and a sharp decline after 1970. South Africa has generally been commended for its relative abundance of rain gauges although Pegram and Bardossy (2013) report that even South African rain gauge records are dying off; after mid-2000 they found that out of the 279 gauges in the 5 regions only 180 survived until 2008. A more extreme example is Angola which had over 500 meteorological stations as a Portuguese colony which were all but destroyed during four decades of civil war until a government rebuilding programme had increased the number to eight by 2007 (Cain, 2015).

River flow monitoring networks in SSA are unfortunately experiencing a similar decline to meteorological monitoring networks. Monitoring stations globally have been decreasing in number over the last few decades. Tourian et al. (2013) note that among the 8424 identified gauging stations in the Global Runoff Data Center (GRDC) database only 40% of stations provide discharge data after 2003. Many of these monitoring stations going offline were located in SSA. The requirement to reverse the trend of decreasing hydrological monitoring is a widely held view (Kundzewicz, 1997; Owor et al., 2009; Taylor et al., 2009).

Even so, surface water is densely monitored in comparison with groundwater. There is general agreement that a better understanding of the shallow hydrogeology of SSA from the point of view of potential agricultural use is a necessity (Evans et al., 2012; Giordano, 2006; Namara et al., 2011; Pavelic et al., 2013). Lapworth et al. (2013) state the issue succinctly; "Ideally, a thorough quantitative understanding of aquifer properties and recharge mechanisms under a variety of climate, land use and geological environments is required to confidently assess current groundwater availability, and forecast future availability under different scenarios". A recent review of groundwater conditions in 15 SSA countries (Pavelic et al., 2012) concluded that: "Quantitative information on aquifer characteristics, groundwater recharge rates, flow regimes, quality controls and use is still rather patchy".

Invariably simultaneously reported alongside comments on the need for greater understanding of SSA hydrogeology is the dearth of observations of groundwater systems, in particular sustained time series data (ATA, 2013; Calow et al., 2009; MacDonald et al., 2009; Martin and Van De Giesen, 2005; Taylor et al., 2009). The situation with groundwater data is different to the aforementioned decreasing meteorological and hydrological time series data because there have never been many monitoring systems in place. For example; considering the hydrogeology atlas of the SADC region (the Southern African Development Community which includes fifteen member states south of and inclusive of the Democratic Republic of Congo and Tanzania), Robins et al. (2006) report that only six of the member states (Lesotho, Mauritius, Namibia,

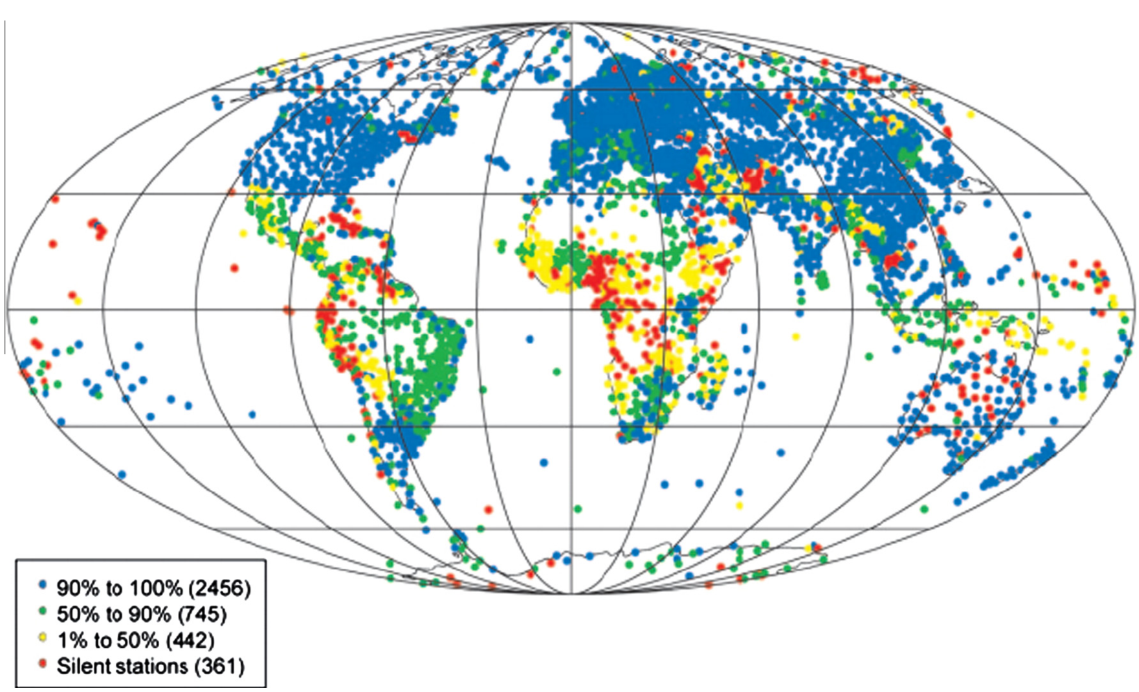

Fig. 1. The global network of World Weather Watch stations colour-coded to show reporting rates (WMO, 2003).