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Efficiency and productivity terms for water management: A matter of contextual relativism versus general absolutism

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ABSTRACT

Growing water scarcity and increasing demands for agricultural products generate much debate about improving the agricultural sector's water use efficiency and productivity. Agricultural engineering traditions feed this debate with notions such as agricultural yield gaps and low water use efficiencies that draw attention to potential improvements. However, when perspectives are shifted from an irrigated field to a river basin, someone's (water) loss may be another's (water) gain. Such shifts in perspectives complicate the applications of our concepts of irrigation efficiency (IE), water use efficiency (WUE) and water productivity (WP). This paper studies the use and abuse of definitions and applications of concepts of IE, WUE and WP and examines their appropriate application for different scales and domains of water use. In this paper we argue that water management decisions are best informed by using IE and WP at the irrigation scheme and catchment level, respectively. This use can identify context specific opportunities and potentials for increased water use efficiency and productivity as well as the potential trade-offs in water re-allocations between diverse water users and uses.

1. Introduction

As competition for water increases and commitments to sustainable ecosystems grow, there has been an ongoing search for increasing water efficiencies, and the use of appropriate variables that relate the supply of irrigation water with the consumptive use of this water, as well as the benefits gained from this supply and use. The oldest of these variables is irrigation efficiency (IE). First coined in the 1950s (Israelson, 1950; Jensen, 2007), it stems from studies of water applied to and consumed from the soil root zone first described as field application efficiency (e_a) (Israelson et al., 1944). However, with the rapid increase in irrigation construction after World War 2, IE, the ratio of water consumed to that diverted or applied, quickly became a factor in engineering to use in design of irrigation technology and operations. It has gained a new field of use from the 1990s in irrigation performance studies and basin water accounting (Seckler, 1996; Lankford, 2006). Since the 1990s, there has also been a shifting focus on productivity, which goes beyond the scale and perspective of irrigation alone. These interests in water productivity (WP) take on 'global' and cross-sectoral concerns, viewed at the basin or resource scale. This paper sets out to unravel the concepts and notions of efficiency from productivity, and irrigation engineering perspectives from multiple use perspectives.

We argue that this emphasis on technical perspectives and what criteria are the most appropriate at which scale of analysis, provides additional insights and structure to critiques on efficiency studies already done for water resources planning (Seckler et al., 2003; Perry, 2007), and improves understanding for scientists modeling agricultural water productivity (Bluemling et al., 2007). Three sections follow that in turn examine: (a) the shifting uses of IE in engineering studies; (b) different approaches to studying water productivity and problems arising in their operational use; and (c) non-fertile crossbreeds emerging between these concepts through notions of water use efficiency that tend to confound productivity gains with efficiency gains. The merits and limitations of each of these notions are discussed with the aim of delineating their utility in demarcated contexts and scales in resolving specific irrigation and water management questions. We argue that the notion of water productivity is the most suited to address the multifaceted context of multiple uses at the river basin scale, through its specific application in building 'water productivity mosaics'.

Both efficiency and productivity terms are nowadays widely applied, frequently outside the original contexts for which they were initially defined, at different scales and comparatively in ways never intended originally. This is often done with political and social purposes in mind. Thus efficiency factors can be taken up by engineers in comparative performance studies to justify modernization programmes (Kahlown et al., 2006). Scientists of various fields may show that irrigation users thought wasteful at local scale can be seen as more efficient at basin scale (Guillet, 2006; Clark and Aniq, 1993; Molden and Sakthivadivel, 1999), or comparative

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studies of water use are framed in 'good' and 'poor' performers (Molden et al., 1998). On the other hand, concerns arise with misuse of the water productivity concept, when, often with the aim of providing a new 'social' mandate for irrigation, engineers and scientists argue the need to improve the productivity of irrigation water. Frequently water productivity is imbued with a persistent engineering efficiency perspective, rather than productivity *per se*, when it is argued that water savings are possible while maintaining and increasing yields, and making savings available for other uses. This argument confuses 'dry' with 'wet' water savings, when efficiency gains lead to reallocation of water use rather than true water savings of the resource base in the basin (Seckler, 1996).

It is the social claims made around studies of irrigation efficiency or agricultural water productivity, to support new public action and new policies, which make them relevant to study through political ecology perspectives that focus on the allocation and regulation processes governing natural resources management. However, in this paper we stay focused on the confusions in terminology in place, to encourage better discussion of practical water management options. We argue that practical needs and decisions are better served by keeping the contextual relativism of IE and WP clear. More confusion and scope for abuse comes from general absolutism, where comparative data is scrutinized in relation to supposed good norms argued to be scientifically derived and neutral.

2. Irrigation efficiency and agricultural engineering traditions

The notion and concept of irrigation efficiency – defined as the ratio IE = [water beneficially used]/[total water applied] – is the traditional concept of efficiency in irrigation engineering (Israelson, 1950; Jensen, 2007). It focuses on the amount of water released from a source to ensure beneficial uses are achieved – both in terms of water consumption by crops and, more recently, allowances for agronomic needs such as leaching (Burt et al., 1997). In line with its predecessor *irrigation duty* (Buckley, 1920), IE provides a measure of the overall functioning of irrigation. Where high duties and efficiencies are deemed desirable and indicators of good performance, low efficiencies indicate room for improvement. The attractiveness of IE subsequently lies embedded in its constituent parts that distinguish conveyance efficiencies (e_c) from application efficiencies (e_a). This neatly distinguishes the irrigation engineering/management efficiency from the farmer/agronomic efficiency.[1] It provides thereby a demarcated focus on water 'losses' that may occur within the irrigation "engineering" domain in conveying a given amount of water from A to B (Bos and Nugteren, 1982). Conveyance efficiencies, as indicators of how much water is needed to deliver water, can then be regarded as 'classical engineering efficiencies' (Perry, 2007).

This does, however, not hold true for the application efficiency component, where water changes from object to subject of transformation when passing from irrigation canals (conveying water) to farm (growing crops) (van Halsema, 2002). IE thus becomes 'contaminated' with an indicator of efficacy (see next section) that introduces complications and scope for confusion of interpretation. This has led to numerous adaptations of formulae for IE for farm/plot level that introduce complications in the definition of [beneficial use]. These definitions can be subjected to farmers', agronomist's and soil-chemist's perspectives and values, on top of the traditional irrigation engineering definition (Burt et al., 1997; Keller and Keller, 1995).

As succinctly argued by Perry (2007), the widespread application of IE and its associated terminology of water losses can provide a false sense of water wasted. We argue that IEs are defined from a proprietor's perspective – e.g. the allocated water belongs to (or, is associated with) the irrigation system, and IEs provide a measure of how well the system handles/uses this water and is able to convey it without 'waste' (efficiency component) and convert it to productive use (efficacy component). The water leaving the system's management/engineering domain is subsequently regarded as a loss to the proprietor.[2]

However, once we shift perspective to the river basin, 'wasted water' is (in the majority of cases where there is no direct outflow to the sea) used elsewhere in the basin/aquifer for multiple other purposes and productive uses. So, rather than being wasted, water is left unutilized for other people/purposes.[3] If subsequently such 'wasted' fractions of irrigation water are recaptured for utilization within the irrigation scheme this frequently, especially in closed river basins (Molle et al., 2010; Seckler, 1996), leads to depletion of water resources downstream. Thus in effect, resulting in a reallocation of water from downstream use(r)s (back) to the irrigation scheme (Molden, 1997; Molden and Sakthivadivel, 1999; Seckler et al., 2003; Guillet, 2006; Lankford, 2006; Perry, 2007). This generally has the overall result that production and water consumption (i.e. ET) increase, as well as the overall scarcity and competition for water resources in the river basin. Thus, where effective improvements in IE may suggest significant efficiency gains at the level of the irrigation scheme, they essentially equate to the appropriation of water by asserting irrigation claims on the water resources base, as expressed in the gross water allocations or permits.

In principle 'good' or preferred practices are feasible when improved IEs diminish irrigation's gross water intake and water consumption in accordance with the implied efficiency gains (Lankford, 2006). However, these often prove difficult to establish and implement (van Halsema et al., 2011). Moreover, these require the re-assessment and deliberation of water resources allocation that cannot be genuinely informed in the absence of hydrological water accounting at the basin level (Molden, 1997; Perry, 2007). IEs are too limited in their scope and purpose in this regard, if their 'wasted' fraction is not verified against actual reuse by other uses and users in the basin.

When applied at the scale of irrigation schemes, classical IEs have become indicators for, and measures of performance of, irrigation technology (Brouwer et al., 1989; Bos and Nugteren, 1982; Kahlown et al., 2006). For example, the following ranges are common estimates in text books that are widely applied for design and calculation of gross water allocations:

- Open channel – surface irrigation schemes 30 < IE < 60
- Modern irrigation (open-closed) 50 < IE < 70
- Trickle irrigation system 70 < IE < 90

As such they have frequently been applied to indicate poor performance of irrigation schemes, followed by quick recommendations for technological upgrades or irrigation modernization – e.g. increase performance by increasing IE, improve water deliv-

[1] Strictly speaking this is not a neat divide, as the agronomic performance of crop production and water consumption is influenced not only by the quantity of water but also by its timing, which falls under the irrigation operator's management domain of irrigation scheduling.

[2] This proprietor's perspective is probably as much informed by the investor's perspective – irrigation systems traditionally require huge capital outlay, especially in relation to canal carrying capacities, which one would wish to optimize in terms of conveyance efficiency. Similarly, a climate perspective may inform the improvement of IE to save energy, when irrigation water is supplied by pumping.

[3] Exceptions to rule are non-utilized water flows that seep into poor quality water sinks (e.g. saline aquifers) that render their further utilization impossible or non-productive – e.g. non-recoverable flows.