Agri-vector water: boosting rainfed agriculture with urban water allocation to support urban–rural linkages

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Abstract

This discussion paper adds to the literature on rural-urban water linkages by proposing a novel concept termed 'agrivector urban water' (AVW). AVW is water that supports rainfed agriculture by supplying water to towns to maintain urban-based agricultural services that support rainfed farming in surrounding areas. Rather than allocating limited freshwater resources directly to water-consumptive irrigation, this 'blue' water may be more agriculturally productive by ensuring agricultural services in urban centres are maintained. In making these linkages, we see 'blue water' as an input to 'green water' rainfed agriculture via its consumption within urban, human and technical services. Thus 'agrivector urban water' captures the idea that scarce blue water may be reserved to support the productivity of green water and responds to the concern that limited quantities of surface and groundwater, especially during droughts or dry seasons, should be allocated judiciously to ensure desirable economic, livelihood, food and environmental outcomes. By rethinking water allocation in this way, AVW adds to integrated water resources management (IWRM). Using pilot studies from Ethiopia, this initial work suggests the concept has merit in guiding agricultural water policy for subcatchments where irrigation and small towns compete for limited blue water.

Introduction

We argue that water given to urban areas supports urban services which in turn can bolster rainfed agriculture surrounding those areas. This urban water allocation in times of scarcity, such as drought, aims to boost urban–farming linkages to generate greater agricultural output than if that same water was used for irrigation. Our reasoning resides with Tiffen (2003) (p. 1343) regarding the interrelationships between urban areas and rainfed agriculture: 'Each provides a market to the other.' In arguing for 'agricultural water' to be seen via urban water use, we emphasize the centrality of water allocation within integrated water resources management (IWRM) (Smith & Clausen, 2018). Here, IWRM conventionally sees physical volumes of water in rainfed and irrigated agriculture as ways of thinking about catchment allocations of water. But by using 'agri-vector water' (AVW), we suggest that water also acts via vectored means; water given to urban areas transmits benefits to rainfed farmers in the form of urban-based agricultural inputs, services and demands.

Pressures on water allocation for food production

Major pressures driven by markets, population growth and climate variability converge on the use of limited water resources in semi-arid environments such as those typically found in Sub-Saharan Africa (Stephens et al., 2018). These pressures include the need to boost food production (van Ittersum et al., 2016), sustain environmental services

(King & Brown, 2006) and grow the economies of rural areas via agricultural development and small- and medium-sized town expansion (Diao et al., 2010; Güneralp et al., 2017; Showers, 2002).

Each of these objectives requires the non-consumptive and consumptive use of freshwater resources. This results in increased competition for common pool water resources between irrigated and urban systems (Flörke et al., 2018) and sets up an allocation problem when water supplies are much smaller than demands. But policies about freshwater allocation in such areas typically respond to these pressures biased towards historical, political and sectoral interests (Hellegers & Leflaive, 2015). Our viewpoint highlights the risks of one such bias: that of promoting small-scale irrigation as a means to produce food and meet food security concerns (Malabo Montpellier Panel, 2018).

It is in this crucible of agricultural production that questions on 'how best to use land and water for agriculture' are debated (Falkenmark, 2018). Thus, low-yielding rainfed agriculture in semi-arid areas has been identified as a 'hotspot' for improving agricultural water management for increased food production (Rockström et al., 2010). But raising the production from rainfed agriculture via water is not straightforward, and for the purposes of introducing this viewpoint we highlight three common policy solutions. First, raise rainfed productivity through better management of in situ soil water achieved via a range of inputs such as fertilizer, tillage/no tillage, planting densities, etc. This option has become known as managing 'green water' (Rockström et al., 2010). Second, raise rainfed productivity by adding more water through local rainwater harvesting (RWH) (Oweis & Hachum, 2006). Third, bring supplementary or full irrigation to rainfed lands by adding surface and/or groundwater (Malabo Montpellier Panel, 2018). The latter two apply 'blue water' to the 'green water' already in the soil profile, requiring a variety of irrigation and soil management strategies (Pittock et al., 2020). In this viewpoint, we identify a version of the first approach: that blue water given to urban areas supports green water management in rainfed agriculture.

Questioning the use of dry season water for irrigation

The argument for adding 'blue' freshwater as irrigation in dry areas appears to be technically and technologically credible (Xie et al., 2021). Furthermore, climate fluctuation has been used as a long-standing rationale for tackling problems of food security and poverty: "Among factors that contribute to risk in Tanzania's agriculture is the unpredictability of rainfall and the recurrence of drought and floods. Soil and water management practises must be improved in order to reduce these risks and improve the productivity and profitability of agriculture." (MAFS, 2001, p. 35)

Arguments to use dry season flows for irrigation are also found throughout the scientific literature and can be traced to the view that rainfed agriculture and irrigation are part of a continuum: 'Time to abandon the largely obsolete distinction between irrigated & rainfed agriculture, and instead focus on integrated rainwater management' (Rockström et al., 2002, p. 949). In these 'pro-watering' views, investment in irrigation is offered as a panacea for, inter alia, hydrological variability, land degradation, population growth and meeting a number of development targets.

However, such views would benefit from further scrutiny. First, we should question the relationship between irrigation withdrawals and required uplift in food security (Hagos et al., 2017), especially if small streamflows consumed by irrigation desiccate catchments but generate little extra or new types of food and nutrition.

Second, the allocation of water for irrigation in semi-arid areas with marked biannual rainfall and river flow patterns is not straightforward and easy to regulate. This concern is expressed by Ngigi et al. (2008, p. 1861): 'Excess water during in the rainy seasons is followed by severe water scarcity during subsequent dry seasons. To enhance crop production, over-abstraction of irrigation water during the dry seasons has been rampant.' Whereas irrigation demand during the wet season may be successfully met by a combination of rainfall and river flows allowing downstream users also to get their share, the continued presence of canals, intakes and fields establishes a propensity to abstract water during the dry season. If aquifers or surface storage cannot meet this demand, then given the much smaller volumes of river water found during dry seasons, abstractions by irrigation disturb a delicate balance of water allocation, exacerbating scarcity and discontent downstream (Aeschbacher et al., 2005; Lankford & Beale, 2007).

Third, while there are policies and laws that recognize 'people/urban' priorities for water allocation when water is scarce (Pedro-Monzonís et al., 2016), fitting these priorities and conditionalities alongside unilateral irrigation growth (or policies for irrigation growth) is not easy (Hellegers & Leflaive, 2015). For example, it was during Lankford's (2005) experience of contributing to the Commission for Africa study that he observed that the Commission sought to rapidly expand the area under irrigation from 11– 12 million to 18 million ha without regard for catchment sharing of limited water and regulatory mechanisms that would accommodate wet and dry season differences. Donors, putting new emphases on irrigated agriculture in Africa (Malabo Montpellier Panel, 2018), should recognize the difficulties of, and limits to, spreading meaningful volumes of 'drought and dry season water' among many irrigating farmers, much less between irrigation and other sectors. It is these concerns that AVW attempts to address.

Urban–rural water connections

We add AVW to the other water connections between rural and urban areas (Civitelli & Gruère, 2017), a sample of which is given here:

- Wastewater from urban areas can play an important role in meeting downstream irrigation demands (Thebo et al., 2017).

- Water quality connects urban and rural areas via impacts on human health from water pollution from either source (Mateo-Sagasta et al., 2017; McGrane, 2016).
- Rural-to-urban water transfers are increasing as large towns and cities grow sufficiently large to exhaust existing allocations, demanding additional allocations often from irrigators, via market transactions or regulation (Garrick et al., 2019).
- Potable water moves from rural areas to urban conurbations (Ruet et al., 2007).
- Virtual water connects rural and urban areas (Hoekstra et al., 2018).
- Ecosystem services link urban and rural areas (Gebre & Gebremedhin, 2019).

Introducing AVW

Using two illustrations, we now introduce the concept of AVW[1]. Figure 1 articulates our argument that urban areas and their surrounding agricultural lands are mutually dependent and supportive. Thus, AVW comprises the allocation and consumption of ‘blue water’ in urban areas, which in turn supports rainfed ‘green water’ via two means: (1) urban demand for agricultural produce and (2) urban services for farming inputs, activities and choices. For the ‘vector’ to function, farmers must respond to urban-sourced signals, markets and services by making cropping and agronomic choices that boost their production[2]. Crucially, freshwater supplies support a viable urban economy so that these agricultural services and markets do not faulter and undermine those farming choices. Furthermore, the opposite might occur; if the town were not to receive its water during a drought or dry season, then economic growth and provision of services would be harmed which in turn deleteriously affects rainfed farmers in the surrounding hinterland.

Figure 2 shows an essentialized map of water competition for river water taking place between an upstream irrigation intake and a small rural town. Nearby to both is a larger area of rainfed agriculture comprising farmers who may or may not have jobs and plots of land in both the irrigation scheme and the rural town. With this map, we see the stark choice between using limited river flows (‘blue water’) between an upstream irrigation system or a downstream urban centre. Figure 2 suggests that the rural town, if economically secured with water, is able to provide a variety of services to the rainfed agriculture in its hinterland.

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[1] It is assumed the idea applies to groundwater as much as surface (river) water, and that environmental flows are safeguarded in all scenarios.

[2] The strength and clarity of this urban-to-farming signal will vary from location to location and over time. Three modifications of this signal might include: where market feedback from nearby urban areas to farmers does not always exist; when farmers are unable to respond to market signals (e. g., due to poverty); and instances when suppliers manipulate the price of inputs resulting in lower levels of trust in the marketplace.

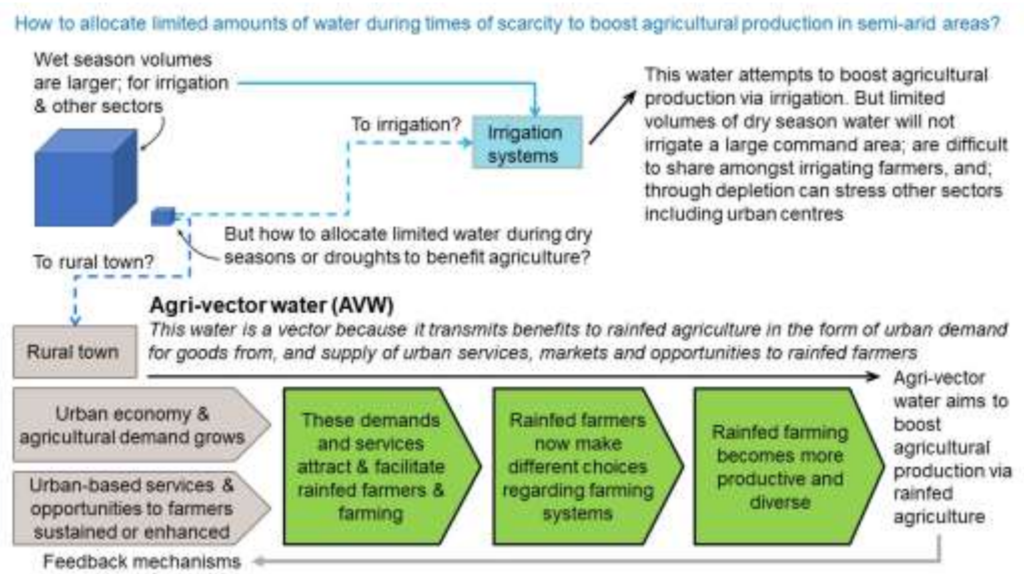

Figure 1. Logic of agri-vector water (AVW) to boost rainfed farming.

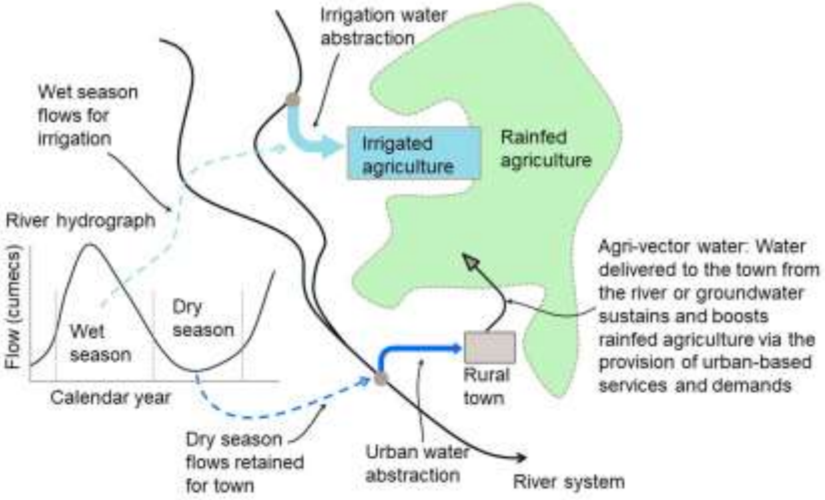

Figure 2. Illustrative agri-vector water (AVW) geography: upstream irrigation, downstream town and rainfed farming.

The term 'agri-vector water' is now explained. Water during times of scarcity, e.g. drought, that would otherwise be allocated physically to irrigation systems is vectored to rainfed agriculture via its retention within the urban centre. This urban water is not directly or hydrologically supplying rainfed agriculture; instead, it operates as a ‘vector’ because it indirectly ‘transmits’ benefits to rainfed agriculture in the form of urban-based services that support rainfed farmers. This vectored transmission of water-based benefits occurs because rainfed communities are reliant on proximal urban areas to access markets, transport services, roads, agricultural inputs and credit services (Davila & Allen, 2002; Satterthwaite & Tacoli, 2003).

Materials and methods

We employed a conceptual approach to this work, conceiving the idea of AVW, contextualizing it within the literature and exploring its potential validity via exploratory field work in Ethiopia. We finish with a brief discussion and recommendations for further research and policy.

Ethiopia was chosen for the pilot testing of the concept because it is a country experiencing unprecedented economic growth and demographic change, leading to increased pressure on water resources. Ethiopia has a fast growing economy, is observing extensive irrigation expansion and is urbanizing rapidly (World Bank, 2015). This is resulting in direct competition between agricultural water and urban populations needing freshwater.

Two towns were selected as pilot studies since they typify the nature of competition for water resources in Ethiopia and give some indication of the challenges of the future under demographic and climate change. First, Harar, where the urban water supply was severely compromised by irrigation expansion; and second, Wenji, where deteriorating water quality from industrial activities and commercial farming upstream was negatively impacting its urban water supply. The location and further details comparing Harar and Wenji can be found in Appendix A.

Results

Introduction

We stress that our exploration of AVW conducted in Ethiopia was exploratory. Based on these tentative findings, we employ this viewpoint to: unpack three types of urban–farming linkages; discuss the role of water in supporting an urban economy; and identify avenues for future research.

Three types of urban–farming linkages

Drawing on the literature that explores urban–rural linkages (Tacoli, 2006; Tiffen, 2003) and the market driven influences on cropping decisions (Kelly et al., 2003; Zeller, 1998), we propose three types of urban–farming linkages: direct, indirect and bridging (see also Figure 3). These are introduced first, before describing some tentative findings:

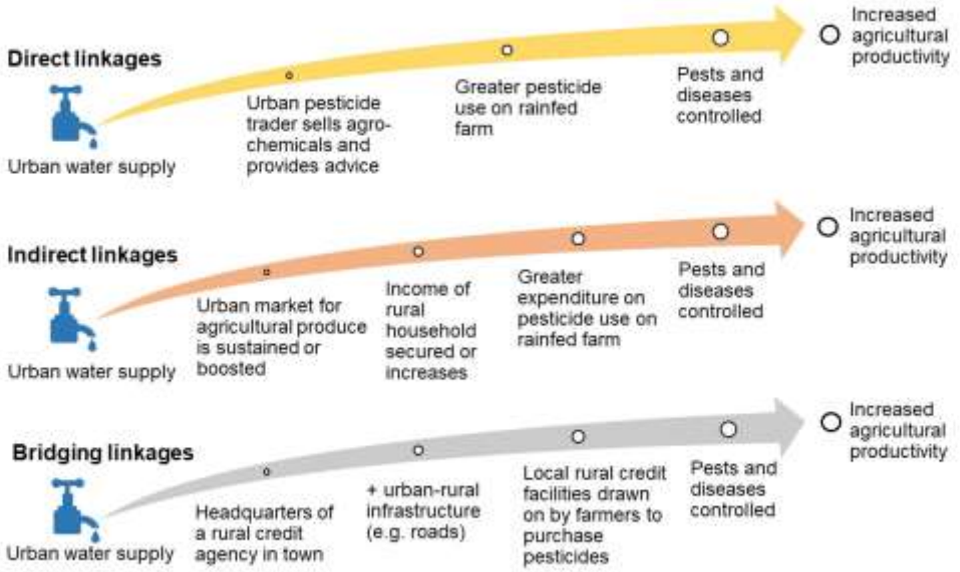

Figure 3. Direct, indirect and bridging linkages between urban areas and farming.

Direct linkages involve farming households accessing services in urban areas that directly support agricultural production. Examples include: an urban supply of labour and skills used on farms; seeds and fertilizers sold from urban shops; the availability of other farm inputs such as sales and repair of equipment; sourcing raw and building materials and energy; veterinary services located in urban centres; the availability of non-material, credit, knowledge, extension and information services from urban centres; and land prices rising near urban areas putting pressure on farmers to raise productivity on remaining land.

Indirect linkages are urban based but facilitate farming incomes and livelihoods that in turn have the potential to indirectly support agricultural intensification and production. The linkage is indirect because farmers and their families have to first benefit from income generation (or reduce the loss of income) in order to make farming investments that boost production. Examples include: urban purchases of farm produce; urban services that support a diverse hinterland economy (e. g., fuel points and electricity); farmers and their families working and earning in urban areas; marketing channels that boost other selling opportunities; and social and civil urban services to farming families that help keep them ‘on the land’ or reduce expenditure by farming families (e. g., nearby schools, churches, clinics and grain mills).

Bridging linkages require the presence of a nearby urban centre for rural communities to access a rural based service. Take, for example, credit services based in a rural village through a village administration office. These credit services can potentially enhance agricultural productivity because farmers can borrow to invest in new agronomic practices. A neighbouring town is essential for this service to exist because money is banked in the town and it is audited and administered by headquarters based in the urban area. Thus, the urban centre ‘bridges’ to the rural-based service. Other examples include: the provision of non-material, credit, knowledge, extension and information services from and by rural administrations to farmers and farming communities; rural electricity managed by engineers working rurally but living in towns; and roads and transport services that connect two or more towns that spill over into rural areas.

Evidence of direct linkages

We found some evidence of direct urban–agriculture linkages in both Harar and Wenji. In Harar, the most commonly accessed urban services included the purchase of herbicides, pesticides and seeds sold in shops (used by 99% of the surveyed rural householders). Farmers also drew on urban-based blacksmith services to sharpen or fix farm tools (e. g., used by 70% of rural households in Harar). In rural farming communities around Wenji and Harar, 25% and 75% households, respectively, were accessing credit services. Furthermore, in Wenji there was a demand for crop inputs to the extent that one third of its rural households using pesticides used public transport to travel to Adama, a city 7 km away, to buy a pesticide not available in Wenji.

Evidence of indirect linkages

We found that rural dwellers and farmers travelled to urban areas in order to secure or boost their income, livelihoods, health and wellbeing. Agricultural and food markets were the most frequently accessed urban service in Harar and Wenji being used by nearly all rural households for selling and buying. There were also indications that urban markets had the potential to influence the ability of farmers to diversify their production into high-value crops. In rural Harari (the region surrounding the town of Harar), farmers were cultivating high-value crops including both irrigated and rainfed khat and coffee. This was being driven, at least in part, by the strength and diversity of the urban markets in Harar and the local khat market in Aweday.

In addition, grain mills in Harar and Wenji were being accessed by more than 95% of surveyed rural households at high inconvenience, requiring the transportation of large amounts of grain and flour, often on foot. In Harar and Wenji, rural households also accessed urban-based health services (40% and 90%, respectively) and schools (1% in Harar and 65% in Wenji) plus some rural households were travelling to town to access electricity, mainly to charge their mobile phones.

Evidence of bridging linkages

Fieldwork discovered that farmers’ access to some rural services was being bridged by the presence of Harar, Wenji and Adama, and the roads and public transport that connect them. Agricultural extension services, fertilizer and credit were being accessed by farmers through the rural kebele administrations coordinated by woreda/regional government departments located in Adama and Harar. In both case studies, rural communities were using public transport services but more so in Harar, attributed to, in part, the presence of better roads and public transport services. We discovered that seasonal farm labourers were using connecting roads to travel from more than 200 km away to work in the rural hinterland around Wenji.

Role of water in connecting urban services to agriculture

Disentangling the roles of water in an urban economy is not straightforward (Hoekstra et al., 2018). Nevertheless, our pilot testing indicated that economic activity and services in the two towns were being constrained by an unsafe, intermittent urban water supply. In Harar and Wenji, urban services reported regularly running out of water and described negative impacts as a result (more severely so in Wenji). Certain urban services (e. g., roadside restaurants) involved in indirect urban–agriculture linkages reported having to cease operation entirely due to a lack of water; this was reported by 20% and 34% of services in Harar and Wenji, respectively. Thus, these services can be described as critically dependent on water. Interviewees managing such services (1.3% in Harar and 8% in Wenji) said that income was being lost due to insufficient water, for example, not being able to make and sell food.

In addition, we determined that the growth of the urban economy was inhibited by urban water scarcity; services reported an inability to expand and diversify income-generating activities due to insufficient access to water. In Harar, one third of services (e. g., hotels, clinics) reported that their income would improve, or their costs would reduce, with improved water access. In Wenji, one fifth of services reported that they would expand their business activities if they had more water.

More specifically, we found that urban health services reported being constrained by an unsafe, intermittent water supply which has implications for rural livelihoods and, indirectly, the productivity of rainfed agriculture. This argument is based on findings that healthier and better educated farmers tend to have more productive farms (Allen et al., 2013; Appleton & Balihuta, 1996). However, health services in Harar and Wenji did not stop operating when they ran out of water but reported being unable to offer patients facilities to wash and drink water, and that their hygiene practices suffered.

Urban services were financially penalized by accessing water through informal vendors. The majority (90%) of urban services in Wenji and 51% in Harar reported accessing water from informal vendors in the week before the water use survey. On average, water from informal vendors cost 50 times more in Harar and 30 times more in Wenji than water accessed through an onsite tap (including transportation costs). Although it is difficult to estimate the wider consequences of these water expenses, they suggest costly and intermittent water supplies can constrain economic growth.

Discussion

Summarizing our pilot work, we believe many of the components of AVW are present in the two case study towns in Ethiopia. For example, we found evidence of direct, indirect and bridging linkages occurring between the urban economies and their surrounding rainfed farmers and farming. We also were able to identify some of the roles of water in supplying and sustaining these urban-based economic activities. These linkages and their water underpinnings are the basis for our argument that water supplied to rural towns supports demand for, and services to, rainfed agriculture. For the remainder of this discussion section, we (1) share some insights on how water use for AVW might be viewed; (2) outline some research limitations of our work; and (3) propose some initial policy insights.

Viewing urban water use for AVW

The urban functions and services outlined above depend on the provision of freshwater. For example, water is used consumptively and non-consumptively for purposes such as drinking, cleaning, cooking, soaking, washing, flushing, cooling, heating and diluting.

However, our argument (and regarding any empirical research on this subject) accepts that the amounts of water used in these functions are individually very small (when compared with say agricultural water consumption or cumulative urban use) and most likely not very elastic. For example, we found that blacksmiths who were fixing farm implements were found to be using very small amounts of water that did not need to be of high quality and the same water could be used repeatedly, hence their consumptive use was very small. In other words, a drought would have to be extremely severe to cut supplies of water that in turn would shrink or close down the work efficacy of a workshop, credit organization or market trader. We therefore accept it is very difficult to detect and quantify a linear or curvilinear correlation between a specific decline in urban water supply and the specific attrition of urban-based agricultural services.

But causal specific event tracing is not how to view the vector transmission of water used in urban areas to support agriculture. Rather we argue for cumulative, net and systemic effects. A town that is consistently water insecure from allocations of water to irrigation, and is consistently at risk from a lack of affordable accessible freshwater, will not over time economically grow or attract investors, and will run the risk of net outmigration. A counterargument applies: that a town that secures and distributes freshwater supplies in the face of drought and/or growing upstream depletion will likely see its people, businesses and organizations continue to invest and participate in urban life and associated services that link through to its agricultural hinterland. These urban linkages and trajectories, we argue, influence surrounding farmers and their farming decisions.

Limitations of the study and suggestions for future research agenda

We accept our research on AVW is preliminary. Scholars from other disciplines will have alternative views on the emerging concept. For now, we discuss five limitations of our early research:

- Our pilot study was limited to two localities in Ethiopia, one of which was producing high value crops. A greater number of studies in different countries would more thoroughly test AVW. Moreover, this study is cross-sectional rather than longitudinal which has limited the capturing of data over time in order to link fluctuations in urban water supply to the growth of urban areas and rainfed agriculture.
- Our theory assumes that small increases in the productivity of large tracts of rainfed agriculture produce more agricultural output than yield gains from small areas of irrigated land. For example, a 10% uplift in rainfed yields from 10,000 ha of rainfed maize is 10 times that generated by a doubling of rainfed maize yields on an irrigation system of 100 ha, the latter requiring 0.5 million cubic metres (MCM) of water (see Appendix A for this calculation). This is clearly a topic for more research.
- Following the discussion above, we accept that quantitatively connecting water use in urban areas to services for rainfed farmers is complicated. Only well-resourced studies will be able to capture these connections and their associated water accounts.
- Implementation of AVW would take water from irrigators or apply other pressures on irrigators such as: enforcing improvements in irrigation practices; controlling downstream pollution; and adopting soil conservation. Further research could monitor these positive and negative consequences of AVW.
- Finally, there is an ongoing need to determine the livelihood, social and economic factors behind farmers' decisions to enter into, expand and exit rainfed and irrigated farming and their cropping choices (Bjornlund et al., 2019; Bunclark et al., 2018).

Policy insights from AVW

We suggest three policy insights for the purpose of summarizing this discussion:

- With increasing urbanization in the Global South, the intensification of agriculture must go hand in hand with urban and industrial development (Dorosh & Thurlow, 2014). Therefore, there needs to be concurrent development of urban and industrial economies alongside agriculture to realize desired local, regional and national outcomes. In this challenging and often locally specific policy environment, AVW says that urban economies, given their priority freshwater allocations, will positively influence surrounding agriculture. Accordingly, careful planning of drought-prone local economies, underpinned by water allocation, should recognize a range of physical- and vector-type relations between agriculture and towns.
- Policies towards RWH and irrigation expansion in Africa must acknowledge the basics of water consumption in contested river basins (Bouma et al., 2011; Molle et al., 2010). Therefore, programmes are required that

sustainably bring irrigation benefits while not desiccating downstream ecological and urban systems.

- Irrigation policy needs to understand the marked differences between wet season supplementary irrigation and dry season full irrigation (further discussed in the conclusion below). Therefore, irrigation programmes should accommodate dynamics of water supply in semi-arid environments (Lankford & Beale, 2007).

Conclusions

We have proposed a ‘water for agriculture’ pathway through a concept called ‘agri-vector water’ (AVW). This pathway or ‘vector’ prioritizes water for urban areas to sustain and grow agricultural services for rainfed farmers and farming. AVW seeks to optimize scarce water for agriculture that gives dry-season or drought water to urban areas against calls for that water to be used to irrigate crops.

While there are many economic, political, social and cultural reasons that urban economies do not flourish, our evidence from Harar and Wenji suggests that water scarcity is a factor that can constrain urban economies, economic growth and parts of urban life. We found that there were urban services that were dependent on small but critically important volumes of water. We infer from these results (and from the literature) that urban–domestic–industrial services respond to water scarcity and these fluctuations cumulatively affect urban growth which in turn strengthens (or weakens) linkages to their rural farming hinterland.

To be clear, AVW is not against irrigation per se. For example, it could be argued that the expansion of irrigated agriculture, driven by increased urban demand for that produce, is a urban–rural linkage resulting in water consumed by irrigation. However, AVW presents a counterbalance to either an unregulated expansion of consumptive irrigated cultivation or to policies that promote irrigation expansion (Malabo Montpellier Panel, 2018; Xie et al., 2021, 2014). Full irrigation of crops during drought or dry seasons (in contrast to supplementary irrigation during rainy seasons) is difficult because a highly parsimonious spreading of limited water in irrigation, or a drastic regulation of irrigation consumption during dry periods, is not easy to achieve.

Currently, in Ethiopia, there are policies to protect water for urban populations but the open access rivalrous nature of water and a lack of regulation and institutional capacity means that in some cases urban water abstractions are compromised by upstream irrigation and have the potential to be further exacerbated in this regard. Thus, this viewpoint uses the vector term and its ‘AVW’ abbreviation to suggest that scarce water rationed to urban usage can benefit the productivity of rainfed agriculture.

Short of terming the concept as ‘turquoise water’ (mixing blue with green), the notion of blue water acting as a vector to support green water in rainfed agriculture captures the caution required when governing and managing limited amounts of water in mixed urban–rural economies (Sukhwani et al., 2019). The trade-offs of water supply for irrigated produce versus rainfed agriculture may become increasingly important in semi-arid areas where the phenomenon of ‘small town’ growth is increasingly significant. This phenomenon may be even more crucial in contexts of land degradation and population growth which is already resulting in large numbers of landless youth (Schmidt & Bekele, 2016).

We accept there are many systemic factors that influence how farmers engage with rainfed and irrigated land and water during droughts and dry seasons, leading to significant questions regarding urban–rural–agriculture water allocations. However, reflecting on our pilot testing of these ideas in Ethiopia, we argue that AVW as a concept has validity where: a) there is a large area of rainfed land connected to an urban centre; b) where freshwater supplies are small but critically needed for urban uses, and; 3) where farmers cultivating rainfed crops in the hinterland of the urban centre are altering their farming practices in response to urban-based influences.

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Appendix A: Agri-vector water (AVW): exploratory research in Ethiopia and calculations

Introduction

This appendix describes a preliminary examination of AVW via a comparative pilot study in Ethiopia and a simple calculation of potential crop yields and volumes of water involved. Ethiopia was chosen because it is a country experiencing unprecedented economic growth and demographic change, leading to increased pressure on water resources. Two urban centres, Harar and Wenji, were selected as case studies since they typify the nature of competition for water resources in a typically semi-arid part of Ethiopia. Fieldwork was conducted between October 2014 and August 2015. The case studies give some indication of the challenges of the future under demographic and climate change. Figure A1 shows the location of the two towns. Table A1 presents a comparison of the two case studies. In both locations, rainfall is typically seasonal, with low rainfall taking place during the dry season and droughts occurring historically.

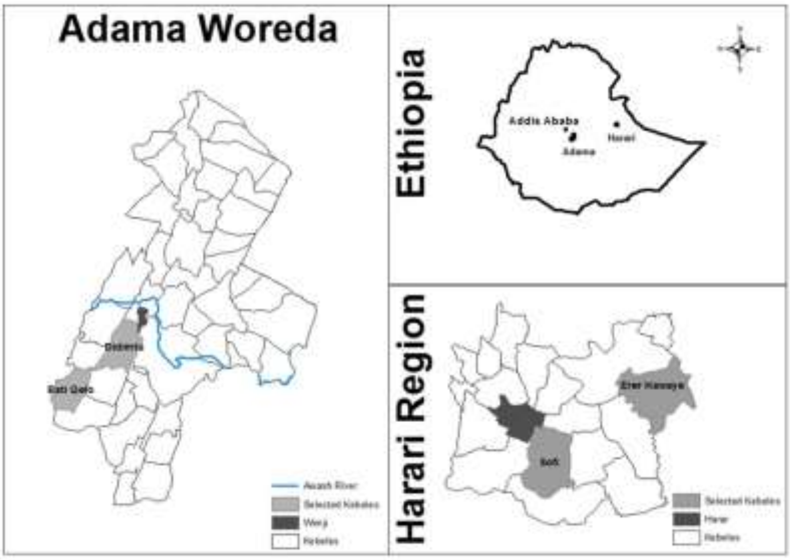

Figure A1. Location of Harar and Wenji in Ethiopia, relative to Addis Ababa.

Table A1. Comparing the Harar and Wenji case study sites.

Statistic	Harar Case Study	Wenji Case Study
Population of Urban Centre	126,000	35,000
Water Source	Dire Jara well-field, Awash River basin (72km away)	Awash river diversion
Average annual rainfall (mm)	800	900
Annual temperature range (ºC)	18-21	18-23
Altitude (m.a.s.l.)	2000	1600
Duration of wet season	*Belg* (short rains April-May) and *kiremt* (long rains July- September)	*Belg* (short rains April-May) and *kiremt* (long rains July- September)
Rainfed farming system	Perennials inter-cropped with seasonal crops during *kiremt*	Crop rotation of seasonal crops during *kiremt*
Main rainfed crops	Khat (*Catha edulis*), groundnut, coffee, sorghum, maize, fruits and vegetables	Teff (*Eragrostis tef*), barley, wheat, maize, sorghum, a variety of beans and pulses
Nature of irrigation competing with urban centre for water	Small-scale irrigation	Small-, medium- and large-scale irrigation
Approx rural households connected to urban centre	~15,000	~7,000
Area of rainfed cultivation connected to urban centre	~8,000 ha	~11,000 ha

Harar

Harar is an ancient walled city with a population of around 126,000 located 500 km east of Addis Ababa. It is the capital of the Harari region in Ethiopia – renowned for its culture of khat chewing and unusual (in Ethiopia) majority Muslim population. It is a flourishing, well connected urban centre with vibrant, diverse markets and services. The khat market of Aweday, the largest in Ethiopia, lies 11 km from Harar. Local irrigation is predominantly for small and micro-scale khat cultivation and rainfed agriculture tends to be khat intercropped with food staples and fruits. Harar is connected to around 8000 ha of rainfed farms cultivated by around 15,000 rural households.

Harar has a complex legacy of urban water supply. In 1966, a water treatment plant was constructed on Lake Haramaya, a water body around 20 km away, to supply Harar with safe water. At that time, the lake's surface area was 3.9 km2 (Setegn et al., 2011). In 2004, Lake Haramaya dried completely. Immediately afterwards, five boreholes were drilled in the lake-bed in a state of emergency to supply water temporarily to Harar until a more long-term solution could be found. In 2012, a project to divert water from a well-field in the Awash River basin was completed; water is pumped along a 72 km pipeline over an elevation of 1000 m. Despite this elaborate undertaking, the urban water supply of Harar remained intermittent and unsafe, in part due to the project's high electricity demand and operation and maintenance (O&M) costs.

In the Harar case, competition for water resources was not an up-/downstream dynamic, but rather direct competition for common pool water resources between irrigation and urban water supply. There were also other compounding factors – the drying of Lake Haramaya has been attributed to biophysical changes in the watershed, increased abstraction for mixed human uses and weak governance (Muleta et al., 2006; Setegn et al., 2011; Tsegaye 2014).

Wenji

Wenji is a small town in the Rift Valley located around 7 km from Adama, a large, sprawling metropolis. Its population is only around 35,000, whereas the population of Adama is more than 500,000. Wenji grew as a distinct urban area due to the construction of a sugarcane processing factory in the 1960s. Since then, the sugarcane factory has closed due to redundant infrastructure and relocated. However, the population of Wenji continues to grow steadily despite being poorly connected – only served by a dry season road to Adama – and with weak urban markets. Wenji is an important urban centre for around 11,000 ha of rainfed agriculture cultivated by more than 7000 rural households.

Wenji lies close to the banks of the Awash River, which is used for the water supply for Adama. At the time of fieldwork, Wenji's water supply was a small quantity of treated water diverted from the Adama water supply system once per week, typically on a Friday. Fieldwork found that in recent times supply was not meeting demand and people were accessing water through other means, including using shallow groundwater wells that contain dangerously high levels of fluoride. In response to this, a compact water treatment system had been donated by a charity and the government had established a new abstraction point from the Awash River for Wenji. However, with an abstraction rate of 10 l/s, this supply was considered insufficient to meet the water demand of Wenji's population.

The competition between irrigation and Wenji's urban water supply centres on water quality. Irrigation expansion upstream in the Awash River is contributing to worsening water quality in the river. Wenji lies downstream of Koka dam by which the river flow is regulated. Hence, future competition for water resources between irrigation and Wenji's water supply will not only be over the quantity of water but rather water quality affected by quantity issues. In recent years, more water has been required to backwash the water treatment system resulting in less water reaching the town. Already the Adama water utility is developing groundwater resources to meet growing demands since treating the river water is expensive.

Support for the results and discussion sections

The results in the viewpoint are supported by this appendix in three main ways. First, the viewpoint introduces the theory of AVW which was influenced by the results of the pilot testing in Ethiopia. Second, the pilot study contributed to the testing of AVW, for example, in defining rural–urban linkages into three categories: bridging, direct and indirect (see Figure 3). Third, the basic calculations employed to think about AVW (see below) were guided by the pilot work.

In terms of the discussion in the viewpoint, the potential utility of an AVW allocation to urban services emerged from the pilot study, in particular the two mechanisms via which AVW can operate: (1) through direct facilitation of the functionality of urban services; and (2) with a cumulative effect that requires all urban water demands to be met in order to support urban services. These mechanisms were uncovered, in part, by framing urban–rural linkages as bridging, direct and indirect, which allowed the role of urban water in supporting such linkages to be unpacked.

Calculations on water to irrigation versus vector water to rainfed agriculture

In the viewpoint we wrote: Our theory assumes that small increases in the productivity of large tracts of rainfed agriculture produce more agricultural output than yield gains from small areas of irrigated land. For example, a 10% uplift in rainfed yields from 10,000 ha of rainfed maize is 10 times (or 1000%) that generated by a doubling of rainfed maize yields on an irrigation system of 100 ha, the latter requiring 500 mm depth equivalent or 0.5 million cubic metres (MCM) of water.

Our calculation is supported by Table A2 using 3 different scenarios: (1) the baseline of rainfed agriculture with no water allocated to irrigation or the urban centre; (2) 0.5 MCM of water is allocated to dry-season full irrigation of maize; and (3) 0.5 MCM are retained by the urban centre to secure and boost economic activity including agricultural services. In other words, Table A2 compares how maize production is affected when this water of 0.5 MCM is either (1) used for the irrigation of 100 ha of maize or (2) allocated to the town to sustain and boost urban services to a hinterland of 10,000 ha of rainfed maize.

Table A2 adopts a baseline of 1.5 t/ha of maize under rainfed conditions, compared with 3.0 t/ha under irrigation and 1.65 tonnes of maize (a 10% yield boost) responding to better farming in turn responding to a more vibrant market and provision of urban services. These yields were selected by reference to the literature on maize in SSA (Abate et al., 2015; Barron et al., 2003; Lebel et al., 2015; Pandey et al., 2000). Assuming a doubling of yield under irrigation applicable to the 100 ha of irrigation, as compared with a 10% uplift in maize when farmers on 10,000 ha see urban services and demand as central to their farming decisions, we can see that it is the larger hinterland that returns the greater total production of 16,500 tonnes of maize. Maize in scenario 3 of 16,500 tonnes outperforms the baseline by 1500 tonnes, while scenario 2 of rainfed plus 100 ha irrigation outperforms the baseline by 150 tonnes.

Table A2. Calculations of three water allocation scenarios.

		Three scenarios of water allocation of 0.5 MCM		
Variable	Units	1) Rainfed farming only (baseline)	2) Water allocated to irrigation	3) AVW water on to rainfed agric.
Area that 0.5 MCM affects	Ha	10000	100	10000
Original unimproved cropped area	Ha	10000	9900	0
Yield on improved cropped area	kg/ha	1500	3000	1650
Yield/ha increase (%)			100%	10%
Yield gain over baseline	kg/ha	-	1500	150
Production (in improved area)	Tonnes		300	16500
Production (in original area)	Tonnes	15000	14850	
Total production (both areas)	Tonnes	15000	15150	16500
Difference in production	Tonnes	-	150	1500
Total production increase (%)		0%	1.0%	10%
Production increase; rainfed over irrigation (%)				1002%

The point of this simple ‘thought experiment’ is to demonstrate the kinds of calculations that can be undertaken to explore how AVW generates agricultural production in lieu of the irrigation of crops during dry seasons or droughts.

Conclusions regarding researching AVW

Successful research of AVW will be related to the strength of the AVW signal alongside the many other factors that influence urban and rural systems and their activities and outputs. From our pilot study and simple modelling, we conclude the strength of this signal lies with the following brief precepts:

- There must be common pool water resources competed over by irrigation and an urban area.
- Small or medium urban areas are more suitable than large urban areas. This is because the economic linkages between the rural and urban areas are likely to become more complex and obscure as the latter grow.
- There must be a large area of rainfed agriculture connected to urban services and urban markets in the urban area.
- Inhabitants of the urban centre are expressing ongoing concerns about the lack of water to serve growing economic needs, especially during periods of shortages of water.

Rainfed farming households in the hinterland of urban centres in Ethiopia were found to be using urban services and input markets – although we think there is scope for more interlinking in both directions. In rapidly developing countries, the further investigation of AVW as a policy option can go some way to enhancing urban–rural linkages and protecting urban water supplies not only for urban dwellers but also to foster rural development and the intensification of rainfed agriculture while continued developments in irrigation take place, using secure volumes of water that do not undermine other users.

References for Appendix A

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