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Livestock and water in developing countries

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Introduction

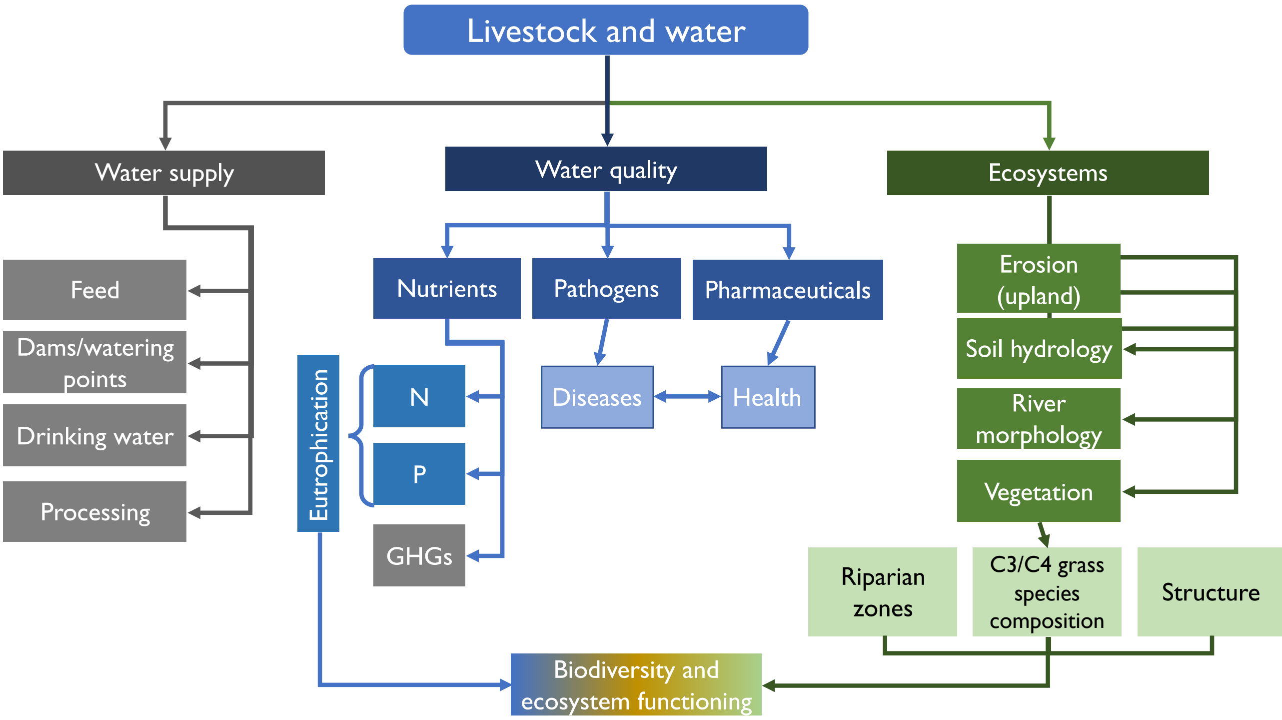
Livestock provides a wide range of economic, nutritional and sociocultural benefits to many communities in developing countries. Often produced on land that is not suitable for other types of food production (i.e. in areas of low rainfall and low soil fertility), livestock can help communities deal with food insecurity and climate variability (Sloat et al. 2018), as well as contribute to asset building (Enahoro et al. 2019). Economically, it contributes as much as 10–45% of agricultural GDP in developing countries (HPLE 2016) and directly employs 600 million poor smallholder farmers (Thornton et al. 2006) and many more through trade and associated economic activities such as sale of manure or other livestock products (Riethmuller 2003). From a nutritional point of view, livestock and livestock products including milk and eggs are important sources of protein, fats and micronutrients essential for human growth and development (Allen 2003; Neumann et al. 2007; Smith et al. 2013; Balehegn et al. 2019), specifically in low and middle income countries (Adesogan et al. 2019; Gupta 2016). Livestock are also culturally valued, perhaps even outweighing the economic contributions in importance and sometimes playing fundamental roles in religious and social relationships such as marriage agreements and dowry payments, funeral rituals and social status (Bettencourt et al. 2015; Quinlan et al. 2016).

Box 1. Livestock and water in developing countries

Livestock is an important component of nutrition, livelihoods and culture in many developing countries. Demand for livestock products is expected to double by 2050 (FAO 2012). The sustainability of livestock systems is vulnerable due to global change and the many environmental impacts associated with its production. Of these, livestock-water interactions in the developing world has been relatively understudied

Despite the importance of livestock to the developing world, there are emerging vulnerabilities of sustainable production associated with global change including population growth, urbanization and climate change, all which affect the natural resources available for and the environmental impacts of livestock production. Water is among the most important natural resources needed for livestock production; it is also one that will be most affected by global environmental change. Yet, water-livestock interactions in the developing world have received relatively little attention in large-scale assessments compared to other environmental impacts (Pelletier and Tyedmers 2010). However, there is increasing recognition of the importance of these interactions (Descheemaeker et al. 2010; Mekonnen and Hoekstra 2012; Otte et al. 2019). There is a large number of ways in which livestock affect water resources that have been documented largely in developed countries (Figure 1). Livestock require water for direct consumption; water is also required to grow feed (either irrigated or rain-fed), to produce feed concentrates and process livestock products. Livestock can also have significant impacts on aquatic and terrestrial ecosystems, including the alteration of soil water infiltration, hydrological flow paths and flooding dynamics through trampling and vegetation change (Ochoa-Tocachi et al. 2016; Byrnes et al. 2018) and the alteration of stream and river geomorphology at drinking water points (Trimble and Mendel 1995; Kauffman and Krueger 1984). Contamination of water resources by zoonotic pathogens (Mawdsley et al. 1995; McAllister and Topp 2012) and nutrients (nitrogen and phosphorus) (Bouwman et al. 2013; Leip et al. 2015) are also well-documented problems, but these issues are relatively understudied in the developing world.

Figure 1. Summary of livestock-water interactions that are reviewed in this report



The demand for livestock and livestock products is expected to increase globally with most of the increase in the developing world (Yitbarek 2019) as a result of population growth and diet shifts associated with increasing GDP, which generally tend to drive increased livestock product consumption. In their global analyses of the food sector Alexandratos and Bruinsma (2012) predict that by 2050, meat production will approximately double and meat consumption per capita will increase by 25% compared to 2005, with most of the increase happening in developing countries. The increased demand compounds pressure on the sustainability of livestock systems from other global phenomena such as climate change and urbanization. Climate change increases variability in water availability resulting in more frequent drought and flooding events, which in turn causes uneven impacts across agroecological zones. Urbanization reduces land available for food production and increases risks of water contamination, including the spread of zoonotic diseases from urban and peri-urban livestock systems. These pressures tend to support recommendations to intensify livestock production. However, industrial systems tend to have higher water demand and higher risk of water contamination (Hoekstra 2012). The relationship of livestock to water is critical to understand increased pressures and demands, but a systematic overview of these issues for the developing world is lacking and deserves more attention.

Objective

The aim of this report is to review livestock-water interactions in developing countries and describe vulnerabilities to sustainable development in livestock production with respect to global change, specifically with expected trends in population growth, urbanization and climate change. This will provide a structured approach that can form the basis of a strategic research agenda which considers the diversity of livestock systems and agroecological zones. This can be developed by the Livestock and Water theme of the Environmental Flagship of the CGIAR Research Program on Livestock (Livestock CRP).

Method and approach

Literature review

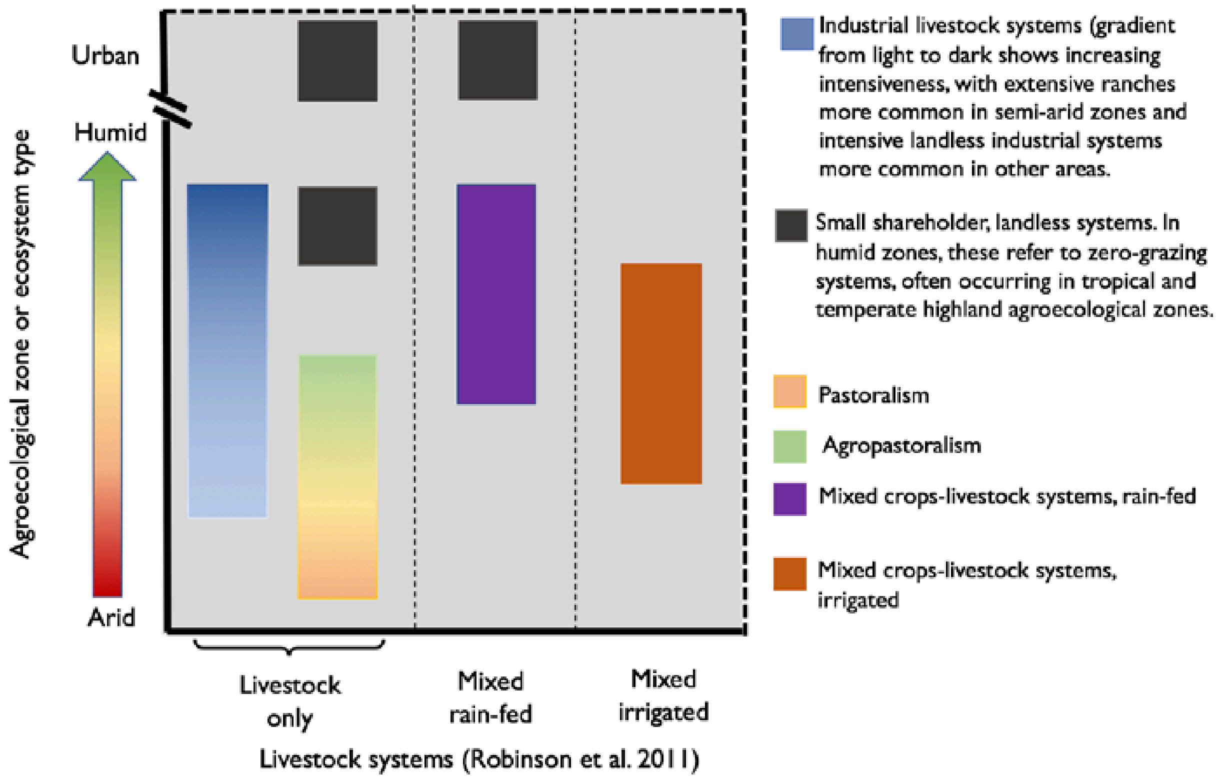
This review was developed based on peer reviewed literature and published reports from reputable international organizations. Peer reviewed literature was surveyed using Web of Science and SCOPUS databases, and more focused searches in SCOPUS were developed as follows: English-language articles and reviews were selected with livestock-related search terms and "water" in the "Title" field. The words, cow*, cattle, dairy, chicken, poultry, sheep, lamb*, goat*, pig* and livestock were used with "OR" operator between each term, and the term "water" was included with the word "AND". In other words, the article must have had one of the words associated with livestock systems and water in the title.

This format was used as the basis for the literature search which was then repeated for each theme related to livestock-water interactions and forms the analysis of this report (Figure 1). These search terms included contamination, pollution, pathogen, riparian zone*, etc., which were included in the fields "title, abstract, keyword." The articles returned from these searches were organized by title and abstract to find highly cited and relevant papers. They were further narrowed by region, selecting the studies that were available for developing and emerging economies based on the 2018 World Economic Outlook Database from the International Monetary Fund. There was also specific focus on International Livestock Research Institute (ILRI) priority countries—Burkina Faso, Ethiopia, Kenya, Rwanda, Tanzania, Uganda and Vietnam. In addition to surveying the literature that resulted in these searches, a snow-ball approach was employed using well-cited articles that were written for first world countries but found relevant for this review.

Conceptual framework of the research agenda

Water-livestock interactions are affected by livestock farming systems and environmental conditions; e.g. grazing vs. non-grazing or small shareholder vs. industrial production; and arid vs. humid vs. temperate ecological zones. Developing countries have diverse livestock systems that encompass these different aspects and it is necessary to take into account this diversity in understanding water-livestock interactions. Therefore, the research agenda was organized according to a livestock classification that was developed by Robinson et al. (2011) which combines the concept of agroecological zones developed by the Food and Agriculture Organization of the United Nations (FAO), and livestock systems initially developed by Seré and Steinfeld (1996). The agroecological zones are defined based on length of growing season (LGA) as well as potential for rain-fed agriculture and soil types. The livestock classification scheme of Seré and Steinfeld (1996) uses the agroecological zone designations as it includes irrigation schemes in its four types: 1) landless livestock production systems; 2) grassland-based systems; 3) mixed rain-fed systems; and 4) mixed irrigated systems. The result is that three livestock systems—livestock only, mixed livestock systems and irrigated livestock systems—are used across arid, tropical humid and temperate and highland ecological zones (Robinson et al. 2011). These livestock systems were summarized alongside a different set of systems (i.e. pastoral, agropastoral and industrial) (Figure 2), which served as a framework for constructing the research agenda. Specifically, classifications based on livestock practice were combined with the agroecological zone approach to better describe water-livestock interactions at regional scales that are relevant to developing countries.

Figure 2. Summary of the livestock systems according to classification system and agroecological zones in Robinson et al. (2011). Temperate and tropical highland systems, which were included in the classification of Robinson et al. (2011 are considered to be "humid" in this figure for the purposes of clarity. Landless systems are considered as one system type, which include industrial livestock production, small shareholder zero-grazing systems and high-density urban systems.



Research priorities

The matrix of research priorities stratified by agroecological zones and livestock systems is presented in Table 1, with red showing highest priority, orange medium priority and blue lowest priority. These assessments were done based on the literature review as described above. The research topics are organized by livestock-water interactions (Figure 1), and priorities for each agroecological zone were determined by assessing the vulnerabilities in each region due to the main threats to sustainability—urbanization, climate change, and intensification.

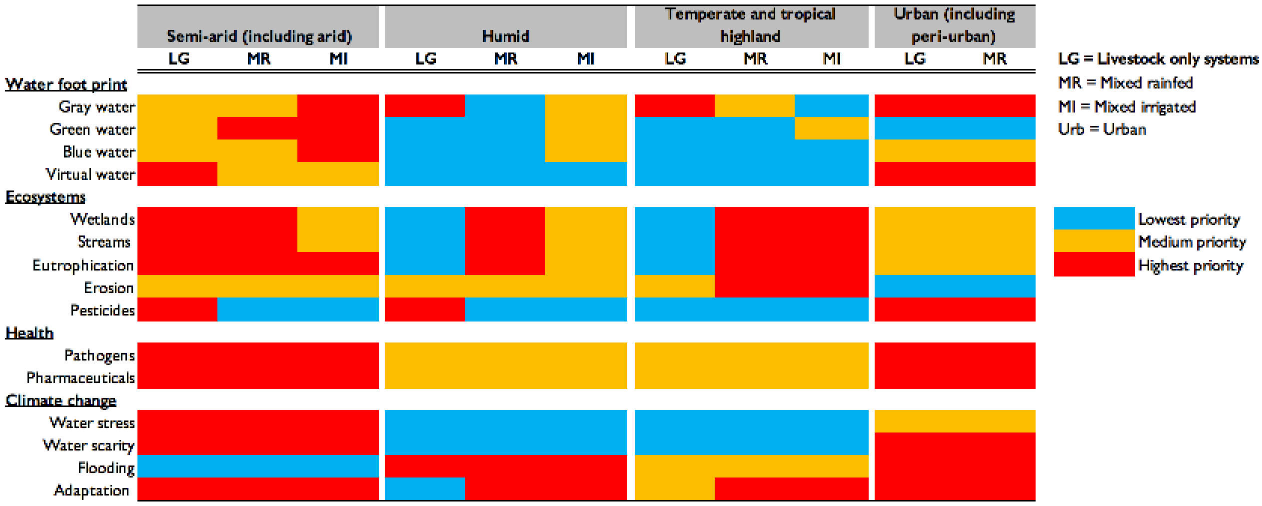
In general, the most urgent priorities for research occur in the semi-arid agroecological zone and urban systems (Table 1), and across all agroecological zones in the livestock-only systems. Major research effort should also be placed on finding ways for livestock systems to adapt to climate change (Table 1), which is mainly focused on mixed rain-fed systems.

Semi-arid zones

Semi-arid agroecological zones, along with the small shareholders that use these marginal lands for livestock production, are considerably vulnerable to water scarcity made worse by expectations of climate change. Thus, understanding how climate change affects water availability in arid and semi-arid zones, including effects on feed availability, is a key requirement for the development of livestock management strategies in those regions. Water scarcity, together with pressures to intensify livestock production, leads to high research priority in water footprint analysis, particularly on blue and green water sources. Given that livestock systems in semi-arid zones tend to have higher water footprints than their counterparts in more humid regions, virtual water (i.e. water that is used somewhere else, for example for feed or feed concentrates) may be a way to mitigate water scarcity. However, this should be carried out following proper planning so as not to transfer water scarcity issues to other regions. Water scarcity also leads to increased likelihood of shared water resources between livestock and people, i.e. using the same drinking water from manmade water pans or river sources, which increases health risks associated with zoonotic diseases and contamination from antibiotics and pesticides that come from dipping points often occuring near surface water sources. Therefore, there is high research priority in understanding how shared water resources between livestock and humans (and often wildlife) lead to human health risks.

Table 1. Research priority areas by agroecological zone or ecosystem type (urban and per-urban) according to topics related to livestock-water interactions. Red indicates highest priority, orange indicates medium, and blue indicates lower priority. LG = livestock only systems; MR = mixed rain-fed systems; and MI = mixed irrigated systems

Livestock in semi-arid systems can have a strong impact on aquatic ecosystems as surface waters (streams, wetlands



and manmade water pans) are used for drinking water with high livestock densities resulting from using a few available water sources. This is strongly associated with seasonality, with densities (and impact) increasing in the transitions from wet to dry seasons as water sources gradually dry up. In wetlands and riparian zones, livestock can alter the vegetation through grazing and trampling, leading to reduced soil water infiltration and increased overland flow, which drives increased erosion. While these changes can be substantial, there is also some evidence that livestock can increase biodiversity in rangeland vegetation, and that impacts of livestock are pronounced in more highland systems where erosion rates are higher due to steeper slopes and higher rainfall. However, soils in arid systems are extremely vulnerable to erosion due to sparse vegetation with erosion leading to siltation of rivers, which may finally result in increased risk of flooding, decrease of water quality and reduction of biodiversity in aquatic habitats. Therefore, the effect of livestock on erosion in semi-arid zones has high priority.

Humid zones

High research priorities in humid zones are mostly related to livestock with systems which are mostly industrial as opposed to small shareholder owned. Industrial systems have a high greywater footprint. Contamination of surface water and groundwater by nutrients and pharmaceuticals represent the highest risks, especially as higher precipitation leads to higher levels of runoff and infiltration to groundwater. Climate change is also predicted to bring increased precipitation and chances of flooding, which can damage land needed for grazing and/or feed production. High research priority should also be given to mixed systems (rain fed or irrigated), as recent research has highlighted the possibility that there are opportunities to manage these systems for a variety of climate-smart benefits, including the efficient use of water resources.

With respect to ecosystems, humid zones generally have higher number of watering points available for livestock, but also higher livestock density due to the greater carrying capacity. This means the impact of livestock on streams, rivers and wetlands is more diffuse than in semi-arid systems, but also more widespread. This highlights the need for research on cumulative effect of livestock on aquatic ecosystems, i.e. along the river continuum (upstream–downstream). Research should also focus on landscape management of watering sources and alternatives to watering, such as off stream watering points.

Temperate and tropical highland zones

Research in highland zones should focus mainly on the effect of livestock on aquatic ecosystems and contamination of water sources. Livestock-only systems tend to be small shareholders under zero-grazing systems, but river systems are more vulnerable to erosion and riparian zone changes due to their steep slopes and high run-off potential. Diffuse use of watering points can lead to widespread contamination of water resources which can be carried downstream to more vulnerable communities, making human health aspects a high priority for research. Mixed livestock systems add risks of vegetation change (deforestation for pastureland) and changes in riparian zone structure, which also increase the risk of erosion and alteration to aquatic ecosystems through high sediment loads and contamination.

Urban systems

Urban systems present a special case in that they can occur in any climate, though in developing countries they predominantly occur in humid zones. They also depend on specific contexts related to setting and socioeconomic conditions. Livestock systems are mostly landless and intensive, especially with livestock holders in low income areas. The close proximity of livestock and people makes it high research priority to study water contamination by pathogens and human health risk mitigation, including manure and waste management and improvements to infrastructure. Climate change is expected to increase the number of extreme events. Depending on the climatic zone and location of cities, either water scarcity or flooding could endanger livestock production. Rapidly growing urban systems can also rely on natural systems such as wetlands for peri-urban and urban food production; but these systems are invariably highly compromised, which also jeopardizes other ecosystem services these systems provide, such as flood protection.

Box 2. Summary of key research questions by agroecological zone for livestock-water interactions in the developing world

Zone	Key research questions
Arid and semi-arid	
	1. Understanding the consequences of climate change on reliability of water resources 2. Water footprint analysis in order to determine best practices for livestock systems for water use efficiency 3. Climate change adapatation strategies related agricultural practice (e.g. changing pastoralism practices, agropastoralism), including strategies for using "virtual water" for producing feed in less water-scarce regions 4. Water contamination and human health risks due to shared drinking-water sources 5. Best practices for livestock management to reduce erosion and damage to riparian zones and wetland ecosystems.

Zone	Key research questions
Humid zones	
	1. Identification of opportunities for mixed livestock systems to maximize water efficiency and other benefits related to climate-smart agriculture 2. Minimizing effects of livestock-only systems (mainly industrial) on graywater footprints, also including reducing the contamination of water resources by pathogens, pharmaceuticals and excess nutrients. 3. Cummulative effects at landscape or basin scales of livestock on aquatic ecosystems, i.e. examining effects of livestock on downstream ecosystems through alteration of flow and sediment load alteration. 4. Assessing and mitigating flood risks associated with climate change, including on both grazing land and land used for feed production
Temperate and tropical highland zones	
	1. Effect of livestock on erosion and on aquatic ecosystems, including effects of vegetation change in uplands (deforstation for pastureland) and on riparian zones, and effects on downstream ecosystems 2. Stategies for climate change adapatation to increased number of extreme rainfall events 3. Effects of contamination of water resources on downstream ecosystems and water users
Urban and peri-urban	
	1. Water contamination and waste mitigation to reduce risks of zoonetic diseases 2. Water footprint analysis to strategize on the best place to produce livestock for urban dwellers 3. Natural systems, particularly wetlands, in urban and peri-urban centres to support livestock production, but also to protect natural systems against degredation so that they can provide other ecosystem services (e.g. flood protection) 4. Climate change adaptation for either water scarcity or flooding, depending on local context

Conclusion

Livestock-water interactions in the developing world are critical to understand in order to ensure sustainable livestock systems in the face of increasing demand for livestock products resulting from population increase and rising incomes, urbanization and climate change. To date, research and comprehensive reviews in this area have focused mainly on the developed world, leaving large knowledge gaps on important interactions in tropical systems. Results of literature review show that research priorities for the developing world need to vary with respect to agroecological zones and livestock systems because the vulnerabilities to sustainable development vary with climate, and different livestock systems have different demands on natural resources and different opportunities to meet sustainability targets. Research on mixed livestock systems has the possibility to synergize with other conservation efforts for multiple benefits for overall sustainability.

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