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REVIEW ARTICLE

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Poverty reduction through water interventions: A review of approaches in sub-Saharan Africa and South Asia

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Abstract

Water is a key factor in attaining the Sustainable Development Goals (SDGs) of poverty elimination and hunger eradication. The regions of sub-Saharan Africa (SSA) and South Asia (SA) are stricken with absolute poverty, with 70% of the world's poor. These regions are mainly dependent on agriculture for their livelihood. Diverse rural livelihoods in SSA and SA demand water interventions with more fruitful and effective outcomes in terms of poverty reduction. Existing water resources are not yet fully exploited in SSA and SA as these regions have a significant potential of 43 and 169 million ha, respectively, for irrigated agriculture through various water interventions. Various water interventions to alleviate poverty through better agricultural productivity across SSA and SA have been identified in this study. Major water intervention options identified include actions to: improve rain water management in rain-fed agriculture, facilitate community-based small-scale irrigation schemes, development and management of groundwater irrigation, interventions to upgrade and modernize existing irrigation systems, facilitate and improve livestock production and promote multiple uses of water. Investment in these water interventions will certainly help to break the poverty trap across diverse rural communities of SSA and SA.

KEYWORDS

agriculture, poverty, rural livelihood, South Asia, sub-Saharan Africa, water interventions

Résumé

L'eau est un facteur clé pour atteindre les objectifs de développement durable (ODD) de l'élimination de la pauvreté et de l'éradication de la faim. Les régions de l'Afrique subsaharienne (ASS) et de l'Asie du sud (AS) sont frappées par la pauvreté absolue, ayant 70% des pauvres du monde. Ces régions dépendent essentiellement de l'agriculture pour leur subsistance. La diversité des moyens de subsistance ruraux en Afrique subsaharienne et en Asie du sud exige des interventions dans le domaine de l'eau pour avoir des résultats plus fructueux et plus efficaces en ce qui concerne la réduction de la pauvreté. Les ressources en eau existantes ne sont pas encore pleinement exploitées en

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Afrique subsaharienne et en Asie du sud, ces régions ayant un potentiel significatif de 43 et 169 millions d'hectares respectivement de l'agriculture irriguée grâce à diverses interventions dans le domaine de l'eau. Diverses interventions dans le domaine de l'eau visant à réduire la pauvreté par une meilleure productivité agricole en Afrique subsaharienne et en Asie du sud ont été identifiées dans cette étude. Les principales options d'intervention dans l'eau identifiées comprennent des actions visant à: Améliorer la gestion des eaux pluviales dans l'agriculture pluviale, faciliter les projets communautaires d'irrigation à petite échelle, développer et gérer l'irrigation des eaux souterraines, faciliter les interventions pour améliorer et moderniser les systèmes d'irrigation existants, faciliter et améliorer la production de bétail et animaux de basse-cour et promouvoir les utilisations multiples de l'eau. Les investissements dans ces interventions dans le domaine de l'eau contribueront certainement à briser le cycle de la pauvreté des diverses communautés rurales de l'Afrique subsaharienne et de l'Asie du sud.

MOTS CLÉS

interventions dans le domaine de l'eau, agriculture, moyens de subsistance ruraux, pauvreté, Afrique subsaharienne, Asie du sud

1 | INTRODUCTION

Water resource management is fundamentally necessary for human development and in attaining the Sustainable Development Goals (SDGs) of eliminating poverty and hunger. It will safeguard environmental sustainability and also prevent overexploitation of water resources (Hanjra et al., 2009; Mugagga & Nabaasa, 2016). Irrigated agriculture has been perceived as one of the fundamental components of global food security and explicitly as a tool to reduce rural poverty (Magistro et al., 2007; Polak & Yoder, 2006). Today about 20% of global irrigated cropland produces approximately 40% of the world's food supply (Unver et al., 2018). Water has great significance for the livelihoods of nearly 1 billion people living on less than $1 a day, especially for the 850 million rural poor predominantly associated with agriculture (Namara et al., 2010). Irrigation contributes enormously to ensuring global food security, livelihood improvement and expanding economic development in the world (Lipton et al., 2003). Yet water resources and irrigated agriculture are not exploited to their maximum potential in poverty-stricken regions, particularly in sub-Saharan Africa (SSA) and South Asia (SA) (Morita, 2021). More than 70% of African and South Asian rural poor are principally dependent on agriculture for their livelihood which could eventually be improved through targeted water interventions or investment in irrigation developments.

In SA 44% of the people have per capita income of $1 per day (ADB, 2019; Namara et al., 2010), whereas in SSA nearly 70% of poor people earn less than $1.25 per day (Burney et al., 2013). Both SSA and SA are highly food insecure, especially SSA, which has only 4% (7.3 out of the 40 million ha) area under irrigation; food production, therefore, is mainly dependent on rainfall (Bishwajit, 2014; Burney et al., 2013). On the other hand, South Asia has the largest proportion of irrigated agriculture estimated at 40% of the total cultivated area (Hasanain et al., 2013). Despite having the oldest and largest irrigation system, irrigated areas in SA have become stagnant in terms of productivity due to poor management of water resources (Hasanain et al., 2013). The rural areas with low productivity in both regions remain mired in poverty. Thus, without making a substantial change in their development strategy these agriculture-dependent populations have little opportunity to escape poverty and become food secure due to insufficient water resource development (Burney et al., 2013). Many low-productivity areas can be categorized as 'economically' water-scarce since they have enough water but do not have sufficient funds for the development of irrigation. Examples of this include the Indo-Ganges basin and several areas of SSA (Molden et al., 2001; Shah et al., 2000). It is noteworthy that African Water Vision's goal for 2025 is to double the irrigated area from 12 to 24 million ha and increase productivity (yield produced per unit of water use) from both irrigated and rain-fed agriculture by

60% to fulfil future food demands (Li et al., 2016; United Nations Economic Commission for Africa [UNECA], 2006). Development of water resources for poverty eradication can have a global as well as regional focus.

There is a general consensus that enhancing agricultural growth and productivity is clearly a key strategy to alleviate rural poverty in low-income countries and can make a significant contribution in accomplishing the SDGs of eradicating extreme hunger and poverty (Mugagga & Nabaasa, 2016). Poverty exists in all farming systems and in all regions of the developing world but with variable intensity and severity. With more than 70% of the world's rural population and having huge potential for irrigated agriculture in SSA and SA, demand that water for agriculture needs to be better managed to achieve SDGs of poverty reduction and zero hunger. Therefore, there is a need to look keenly into the biophysical and socio-economic limitations of irrigation and find some promising water interventions which can help to alleviate poverty through better agricultural productivity in SSA and SA. Thus this review study was proposed to help breaching this knowledge gap. We will first give an overview of the agriculture and water resources in SSA and SA, then explain the irrigation and poverty nexus, biophysical and socio-economic limitations of irrigation development and conclude with appropriate water interventions for these regions.

2 | WATER AND LAND RESOURCES OF SSA AND SA

The basic land and water resources of SSA are presented in Table 1. Total land area here is 2.429 billion ha with 10% of this under cultivation (about 234.273 million ha) (FAO, 2008). This cultivated area is 12.6% of the global cultivated area. About 62% of the total population in SSA live in rural areas and 80% of this population is directly or indirectly dependent on agriculture for their livelihood (Food and Agriculture Organization of the United Nations [FAO] & World Bank, 2001). About 40% of global poverty exists in SSA (International Institute for Applied Systems Analysis [IIASA] & FAO, 2000; UNDP, 2006). The total annual internal renewable water resources (RWR) of SSA are estimated to be 3880 $km^3\ yr^{-1}$ (about 9% of the global RWR) and per capita RWR availability is 5696 m^3 $inhabitant^{-1}\ yr^{-1}$ (FAO, 2006). Total water withdrawal in SSA is 120.9 $km^3\ yr^{-1}$ of which agriculture uses 86% (104.7 $km^3\ yr^{-1}$), the domestic sector 10% (12.6 $km^3\ yr^{-1}$) and industry about 3% (3.6 $km^3\ yr^{-1}$). The present

TABLE 1 Water and land resources of sub-Saharan Africa and South Asia

Resource category	Variables and units	Sub-Saharan Africa	South Asia
Land	Total area (000 ha)	2 428 795.00	447 884.00
	Cultivated area (000 ha)	234 273.00	204 500.00
	% of total area	10.00	45.70
Population	Total (1000 inhabitants)	732 836.00	1 621 320.00
	Rural population (1000 inhabitants)	454 358.32	1 128 670.00
	% of total population	62.00	69.60
	Population density (inhabitants km^{-2})	81.00	362.00
	% active population in agriculture	27.00	52.10
	International poverty rate	40.99	15.00
Water and irrigation	Precipitation mm yr^{-1}	1 136.00	1 114.00
	Total internal renewable water resources (RWR) $km^3\ yr^{-1}$	3 880.00	3 725.00
	Total internal RWR per capita (m^3 $inhabitants^{-1}\ yr^{-1}$)	5 696.00	1 194.00
	Total water withdrawal ($km^3\ yr^{-1}$)	120.90	1 003.50
	Agricultural sector ($km^3\ yr^{-1}$)	104.70	914.10
	Domestic withdrawal ($km^3\ yr^{-1}$)	12.60	69.90
	Industrial withdrawal ($km^3\ yr^{-1}$)	3.60	19.50
	Total area equipped for irrigation (000 ha)	7 117.00	93 139 770
	% of cultivated area	4.00	46.00
	Irrigation potential (m ha)	43.00	169.60

irrigated area in SSA is 7.1 million ha which represents only 4% of the total cultivated area, while there is potential for 43 million ha (FAO, 2008). Over the past 30 years the average annual expansion rate of irrigated area was 2.3% in both SSA and total Africa. This expansion rate has dropped to 1.1% annually from 2003 to 2009 but with the cooperation of different foundations and renewed investment from multiple donors, the expansion rate has gone up (You et al., 2011). Despite the slow progress of irrigation development, irrigated agriculture is responsible for 38% of the value of total agricultural production (Svendsen et al., 2009).

South Asia, including Afghanistan, Bangladesh, Bhutan, India, Nepal, Maldives, Pakistan and Sri Lanka, is quite densely populated and is the poorest region of the world (Rasul et al., 2021) This region covers 4.478 million ha of which 2.045 million ha are under cultivation encompassing about 46% of the total land area (Table 1). The total population in SA is estimated at 1.621 billion people with a density of 362 people per km^2 and approximately 69.6% of the population living in rural areas (Food and Agriculture Organization of the United Nations [FAO], 2014). According to a World Bank report the international poverty rate in SA is 15% and nearly 33.4% of world's poor people live in this region (World Bank, 2018). The region receives 1114 mm annual precipitation, having a total internal RWR of 3725 km^3 yr^{-1} and an annual per capita RWR of 1194 m^3. Total water withdrawals per year are 1003.5 km^3, with agriculture accounting for 91% (914.1 km^3 yr^{-1}), domestic use 7% (69.9 km^3 yr^{-1}) and industrial use 2% (19.5 km^3 yr^{-1}) (Food and Agriculture Organization of the United Nations [FAO], 2011). The area under irrigation in SSA is approximately 93.140 million ha, which accounts for 46% of the total cultivated area, whereas there is a huge irrigation potential of 169.6 million ha.

3 | IRRIGATION WATER AND POVERTY

Irrigation development and poverty reduction are strongly correlated according to an extensive review of various empirical studies regarding surface irrigation systems (large and small scale) from Africa and Asia (Hussain & Hanjra, 2004). Findings from these studies strongly suggest that irrigation can play a vital role in poverty reduction via different pathways.

Irrigation enhances crop productivity by increasing yield increments, intensifying cropping and land use, and improving the use of agricultural inputs (seeds, fertilizers and pesticides), consequently improving overall productivity (Evenson & Gollin, 2003; Huang et al., 2006).

Irrigation stabilizes the labour force by increasing the demand needed for construction, development and subsequent maintenance of irrigation infrastructures (Hussain & Hanjra, 2004). Higher economic activity in the crop-growing season and dry season (low rainfall and irrigation are needed for crop production), also has a promising impact on employment and labour wages (Narayanamoorthy & Deshpande, 2003; Van Imschoot, 1992).

Increased production results in rising incomes, ensures food availability and affordability for the poor due to a consistent food supply, and improves buying power by lowering prices (Hussain & Hanjra, 2004; Smith, 2004). The urban poor and low-wage labourers also see a substantial benefit from the resulting higher wages and low food prices (Van den Berg & Ruben, 2006; Von Braun et al., 1989).

Access to irrigation allows farmers to replace subsistence production with market-oriented crop production which results in crop diversification and greater demand for rain-fed crops (Hanjra et al., 2009; Lipton et al., 2003), thus imparting indirect effects on poverty alleviation within and outside these irrigated areas (Binswanger & von Braun, 1991; Smith, 2004).

Higher agricultural production and improved incomes boost the local economy by creating demand for non-farm goods and services (Lipton et al., 2003). Typically each dollar received as farm income translates to additional dollars in non-farm rural income due to multiple connections in the local economy (Delgado et al., 1998).

Irrigation substantially decreases inter-seasonal fluctuations in yield, prices and employment which reduces vulnerability and poverty through stabilizing the effects of yield and income and diversification of risk (Barrett et al., 2001; Berhanu et al., 2007; Kurosaki, 2006; Lipton et al., 2003).

Irrigation significantly improves human nutrition and health by improving accessibility and an abundant supply of staple foods, clean water and better distribution of food among the population (Hanjra et al., 2009; Smith, 2004).

A well-developed infrastructure to supply water for irrigation can serve various uses and demands in many aspects of society (Bjornlund et al., 2017). These include agriculture, livestock, recharge of groundwater, home gardens, drinking, personal hygiene and washing, aquaculture, fisheries, recreation, artisanal mining and rural industry, which are all vital for the rural poor (Boelee & Laamrani, 2003; Meinzen-Dick & Bakker, 1999; Showers, 2002).

Irrigation has turned the tables in favour of the poor through the dispersal of limited water and public investment among a major sector of the society. Irrigation also promotes the poor in labour markets as service providers which help them to improve their negotiating ability and public relations (Gidwani, 2002; Prasad et al., 2006; Sampath, 1984).

A review (Hussain & Hanjra, 2004) based on 120 published studies on irrigation and poverty showed that irrigated areas have higher cropping intensities (111–242%) compared to rain-fed regions (100–168%); in the case of crop yields significant differences exist regarding rice yields in irrigated areas (3.0–5.5 t ha^{-1}) and rain-fed areas (not higher than 4.0 t ha^{-1}). Likewise, wage and employment rates are also higher in irrigated areas, having a difference of more than 50% above rain-fed areas (Hanjra et al., 2009). The outcomes of all studies included in the review using econometric models reveal that irrigation has a positive effect on income and a negative effect on poverty. The major pathways which contribute to poverty reduction through irrigation include higher agricultural productivity and better distribution of economic returns among the poor, mainly because of intensive labour demands and low-cost food (Namara et al., 2010; (Bjornlund et al., 2017).. Thus irrigation remains the most essential and powerful component in the growth vs poverty equation (Parikh, 1992). On the other hand, a comprehensive set of policies, institutions, relevant technologies and good infrastructure is highly desirable to curtail poverty among the rural poor (Rijsberman, 2003). The anti-poverty effects of irrigation are also regulated by a number of factors given below (Hussain, 2005):

- Equality-based land distribution;
- Irrigation infrastructure management, water distribution policies, practices and programmes;
- Adoption of resource conservation practices, cropping patterns and high-value market-oriented crops;
- Accessible complementary facilities for instant information, input and output markets;
- Availability of basic life necessities such as good health care, education and other social facilities.

Regions having these kinds of services have low poverty rates, in contrast to higher poverty areas where there is an unequal allocation of water and land resources (Hussain & Hanjra, 2003; Saleth et al., 2003).

4 | BIOPHYSICAL AND SOCIO-ECONOMIC LIMITATIONS OF IRRIGATION

Irrigation in SSA and SA is still confronting numerous challenges which are responsible for the slow development in these regions. In the next section we will look into major biophysical and socio-economic constraints that critically influence the development of irrigation in SSA and SA.

5 | FRESHWATER USE TRANSGRESSING PLANETARY BOUNDARIES

Planetary boundaries (PBs) represent the biophysical boundaries for the processes and systems at planetary scale which regulate the state of the Earth system (ES) (Rockstrom et al., 2009). If these biophysical boundaries are crossed, then unexpected environmental changes can occur, which may potentially destabilize the ES and human existence. The basic objective of PBs is to set the environmental limits within which humanity can safely operate (Steffen et al., 2015). Freshwater use is one of the nine PBs which have been recognized to date (Rockstrom et al., 2009). The global freshwater cycle is in an anthropocene phase as human activities are dominantly influencing the global river flow, spatial patterns and seasonal occurrence of vapour flows (Meybeck, 2003; Shiklomanov & Rodda, 2003). Estimations revealed that 90% of global green water (rainwater) flows are necessary for sustainable critical ecosystem services (Rockström et al., 1999), while to sustain aquatic ecosystem functioning 20–50% of the mean annual blue water (water from rivers, lakes, reservoirs and aquifers) flows are needed in river basins (Smakhtin, 2008).

The current PB for freshwater use has been set at 4000 km^3 yr^{-1} blue water consumption, with a lower limit ranging between 4000 and 6000 km^3 yr^{-1}. This lower limit is regarded as a danger zone because it will lead to blue and green water-induced thresholds which may cause catastrophic effects on the ES (Rockstrom et al., 2009). Quantification and monitoring of freshwater PB are becoming controversial. Initially it was proposed that PB should be compared against blue water consumption, but due to the complementarity of blue and green water, the PB of fresh water should be monitored based on total consumption of blue and green water rather than only blue water (Jaramillo & Destouni, 2015). If we consider this point of view and look at the global consumption of fresh water by humans during the twentieth century and at the start of the twenty-first, we may have already transgressed the planetary boundary of 4000 km^3 yr^{-1} (Destouni et al., 2013; Jaramillo & Destouni, 2015).

Agriculture is the largest sector which accounts for nearly 70% of worldwide freshwater use (World Water Assessment Programme, 2012). It is estimated that water availability will decrease, whereas future global water consumption in agriculture will increase by 19% by 2050 (World Water Assessment Programme, 2012). There is a need to increase water use-efficiency in agriculture and reduce its consumption. Policy reforms, water management and investment in infrastructure development can play a vital role in this context. Moreover, increase in efficiency of conveyance, distribution and field application can potentially reduce the consumption of irrigation water (Rosegrant et al., 2009).

6 | HIGH COST OF IRRIGATION DEVELOPMENT

Investment in irrigation development is decreasing in both regions (SSA and SA) due to the increasing cost of construction (Lipton et al., 2003; Ofosu et al., 2015). In SSA the average cost of constructing a new irrigation scheme is about 141.67% higher compared to other developing parts of the world (Inocencio et al., 2007). This high cost may be attributed to the relative quality of feasibility and appraisal studies, use of outdated technologies, ineffective design and lack of implementation capacity (Namara et al., 2010). A similar challenge of increasing construction cost is also faced by SA because possible new project sites are less appropriate for irrigation, which further reduces the cost–benefit ratio of these projects. Furthermore, limited competition among contractors, more attention on building new schemes rather than rehabilitating existing infrastructure and incompetence in recognizing the potential of alternatives to traditional irrigation in water management are possible reasons which also influence irrigation development (You et al., 2011).

7 | POOR INFRASTRUCTURE AND MAINTENANCE

Many areas of SSA and SA lack proper infrastructure to provide easy access to water resources for irrigation. In SA various irrigation schemes are stagnant or even declining due to poor management (Bjornlund et al., 2017; Inocencio et al., 2003; IWMI & FAO, 2009). Traditional irrigation structures mainly fail due to poor design, poor quality of construction material, vandalism and floods (Aberra, 2004; Morita, 2021; Plusquellec, 2002). Seepage losses due to unlined canals and silting problems also contribute towards the poor efficiency of irrigation systems (Amede, 2015; Turral et al., 2010). Failure to properly maintain irrigation infrastructure causes their deterioration which ultimately leads to their abandonment.

8 | ACCESS TO FINANCIAL AND CREDIT SERVICES

Access to affordable credit or financing is instrumental for the purchase of new irrigation technologies and farm inputs (Hanjra et al., 2009; Piemontese et al., 2021; Watts & Scales, 2020). However, farmers have limited access to long-term affordable financing in both SSA and SA (Kelly et al., 2003; Mashnik et al., 2017). The latest irrigation technology usually requires high initial capital which without good lending facilities could be a challenge for many small farmers (Nakawuka et al., 2018). Financing institutions hesitate to do business in rural areas mainly due to operational, technological and financial risks (Grimm & Richter, 2008; Mashnik et al., 2017; Turral et al., 2010). Operational risk means that farming systems may not be handled correctly and might result in poor productivity and cash flow (Karlan et al., 2014). Technological risk is associated with the inappropriate working or failure of equipment which subsequently prevents the farmer from getting the expected extra cash flow from irrigation (Komarek et al., 2020. Financial risk represents the failure of the farmer to return the loan instalments and service fees (Komarek et al., 2020; Mashnik et al., 2017; Nakawuka et al., 2018).

9 | LIMITED AWARENESS OF, AND ACCESS TO, TECHNOLOGY

Irrigation technology refers to pumps (treadle pumps, motorized pumps, wind pumps, solar pumps and rope and washer pumps) and water distribution technologies (drip, sprinkler and watering cans/buckets) that facilitate easy access to irrigation (Burney & Naylor, 2012). In SSA nearly 80% of smallholder farmers use watering cans and buckets for irrigation because they cannot buy or rent a pump powered by fossil fuel (Acheampong et al., 2018; de Fraiture & Giordano, 2014). In this situation, demand for relatively cheap and environmentally friendly technologies to replace traditional irrigation systems is increasing in developing countries (Grimm & Richter, 2006; Mashnik et al., 2017; Postel et al., 2001). Farmers require affordable, innovative and easy to implement technologies to get better irrigation efficiency and performance (Grimm & Richter, 2006; Turral et al., 2010). Adoption and use of new technologies require education and experimentation by farmers in order for them to be successful (Gyimah-Brempong et al., 2006; Weir & Knight, 2007). With appropriate demonstration and passage of time farmers start to adopt the new technology (Nakawuka et al., 2018). However, there is an absence of technical trainers such as research organizations, government agents and non-governmental organizations (NGOs) to provide assistance to farmers on a long-term basis (Bjornlund et al., 2017; Merrey & Sally, 2008). Governments also pay less attention to disseminating information or promoting new technologies (Turral et al., 2010). Consequently farmers remain unaware of these helpful services and products such as technologies, financial services and markets (Lefore et al., 2019; Nakawuka et al., 2018).

10 | LACK OF RELIABLE MARKETS

Most small farmers in SSA and SA sell their surplus commodities in the local markets near to their communities (Nakawuka et al., 2018; Ofosu et al., 2015). It is a common practice where most farmers grow the same crop in the same season which results in local markets becoming saturated and produce prices decline (ASFG, 2003; Sakaki & Koga, 2013). Because of this saturation local markets become inadequate for farmers; however bigger and more reliable markets are located further away and transportation is too expensive and unreliable (Beddow et al., 2015; Nakawuka et al., 2018). Also farmers do not have storage facilities, but they need to sell their perishable produce after harvest (Bjornlund et al., 2017). Consequently farmers sell their produce to middlemen at relatively low prices (Mati, 2008; Oguoma et al., 2010). Selling at a cheaper price does not cover the costs of production, leading to discouragement to further invest in irrigated agriculture (Magesa et al., 2020). Farmers require assistance to get better access to market buyers, along with training to meet quality standards and fulfil market demand (Reardon et al., 2003; Turral et al., 2010). This would certainly result in better produce prices, low transaction costs and high farm incomes (Hanjra et al., 2009; Lefore et al., 2019).

11 | INADEQUATE FARMER KNOWLEDGE AND SKILLS

The majority of the small farmers in SSA and SA lack knowledge of many issues linked to irrigation (Briscoe, 2007; Kadigi et al., 2013). This includes awareness about optimum crop water requirements, groundwater potential of their area, and skills required to operate and manage complex irrigation equipment (drip and sprinkler irrigation systems) (Mati, 2008; Walters & Groninger, 2014). Consequently large amounts of water are wasted as well as there being inefficient use of labour and fuel (Bjornlund et al., 2020). Farmers' knowledge of can be improved through farmer to farmer contact, farmer field schools and by exploiting mobile phone and radio services (Frank et al., 2008; Magesa et al., 2020; Nakawuka et al., 2018). Moreover, training about proper on-farm water management and optimum use of agricultural inputs help to improve the water use efficiency, crop yield and overall livelihood of farmers (Bjornlund et al., 2017; Evans et al., 2012; Nakawuka et al., 2018).

12 | INSTITUTIONAL GAPS

Technical and government institutions play a vital role in the planning and impact mitigation of irrigation development, policy making and its implementation, and funding for sustainable irrigation development (Ofosu et al., 2015). Unfortunately, the institutional frameworks regulating irrigation systems in SSA and SA are weak and have serious capacity shortcomings (Ofosu et al., 2015). There is confusion about their respective roles regarding policy design and a lack of harmonization of laws, while implementation is unclear which leads to inefficient and low rates of project execution (Moyo et al., 2017; Turral et al., 2010). Consequently it will discourage farmer cooperation and cause less investment in irrigation technologies (Mutambara et al., 2016). Institutional reforms backed by strong political support are required for sustainable development of irrigation in SSA and SA (Merrey et al., 2007).

13 | TRANSBOUNDARY, UPSTREAM AND DOWNSTREAM WATER CONFLICTS

Transboundary water means surface or underground water that crosses or is situated at the borders of two or more countries (Choudhury & Islam, 2015; McCracken & Meyer, 2018). Consequently any kind of upstream development and overextraction of water supplies can negatively affect the welfare of downstream users, thus creating international conflicts (Grünwald et al., 2020; Zeitoun & Mirumachi, 2008). Several countries in SSA and SA have had transboundary disputes (Boadu, 2016; Williams, 2018). For example, in SSA transboundary issues among co-riparian countries such as Ghana (Volta basin), Gambia (Gambia basin), Nigeria (Nigeria basin), Uganda (Nile basin) and Zambia (Zambia basin) are quite significant (Boadu, 2016; Nijsten et al., 2018). Construction of the Grand Ethiopian Renaissance Dam on the Nile River is a bone of contention between Ethiopia and Egypt (Yihdego et al., 2017). Similarly in SA, transboundary disputes of India with Pakistan, Bangladesh and Nepal, as well as between Bhutan and Bangladesh, are quite significant (Saklani et al., 2020; Williams, 2018). Failure in cross-boundary water-use coordination leads to flash floods, loss of agricultural lands and fisheries, energy shortfalls and transportation problems which ultimately damage the agricultural productivity and livelihood of the poor (Hussain & Hanjra, 2004; Salmoral et al., 2019; Williams, 2018). Negotiations over transboundary water conflicts and cooperation regarding the management of water resources between stakeholders can result in irrigation development, increase income of farmers through better utilization of water in agriculture, hydropower generation, increase in regional trade and more job creation (Gupta et al., 2021; Salmoral et al., 2019).

14 | SOCIO-ECONOMIC IMPACTS OF IRRIGATION

Despite having several benefits, there is a flip side to irrigation development. It can also cause severe health and environmental problems among poor communities (Lipton, 2007; Nkhoma, 2011). Construction of dams (large and small) is often correlated with the incidence of water-borne diseases, for example malaria in Ethiopia and elsewhere (Ersado, 2005; Keiser et al., 2005; Lautze et al., 2007). Moreover, construction of dams also results in the displacement of a large number of people (Akanmu et al., 2019). Irrigation development also induces salinity, waterlogging and land degradation along with pollution of surface and groundwater due to mixing of chemicals and fertilizers in irrigation water (Khan & Hanjra, 2008). Irrigation-induced land degradation is more severe in SA (Hussain, 2005). Unequal distribution of water from head to tail (tail-end farmers) in large-scale canal irrigation systems (Pakistan and India) and inequality in the distribution of land resources in SSA and SA have negative impacts on the productivity and livelihood of small farmers (Hanjra et al., 2009; Hussain & Hanjra, 2003). The negative health and environmental problems are serious concerns because the poor in SSA and SA rely solely on their land and water resources for their subsistence and often they do not have enough of their own resources to tackle these ills, owing to very low income, lack of political power and their highly vulnerable social status (Akanmu et al., 2019; Hanjra et al., 2009). There is a need to adapt various management approaches to solve these problems and help the poor.

15 | ECONOMIC WATER SCARCITY

Economic water scarcity (EWS) refers to a situation where countries have abundant water according to hydrological indicators but face difficulties in proper utilization of water in agriculture owing to absence of institutional and material resources for proper governance and management of water (Cofie & Amede, 2015; Vallino et al., 2020). Much of SSA and parts of SA are suffering from this type of water scarcity (Molden et al., 2007). Reasons for EWS include lack of investment in water development (Hanjra et al., 2009), poor infrastructure to access, manage and store water (Bjornlund et al., 2017; Cofie & Amede, 2015), inadequate human capital and the weak standing of societal institutions to address these problems which are directly responsible for unequal distribution of water resources (Sadoff et al., 2015; Vallino et al., 2020). Poor cost recovery from previous irrigation projects and weak institutional set-up mainly restrict financial investment in new irrigation projects in developing countries (Lipton et al., 2003; Unver et al., 2018). These constraints limit the reliable access of existing water for farmers which negatively affects their ability in water management and overall productivity (Giordano & Barron, 2019; Sadoff et al., 2015). Water scarcity can be mitigated through strengthening key institutions, investing in infrastructure development, water storage systems, improving the water distribution system, rehabilitation of existing irrigation schemes, efficient use of ground water resources, water recycling and adjusting cropping patterns (Cofie & Amede, 2015; Facon, 2013; Mutambara et al., 2016; Unver et al., 2018).

16 | KEY WATER INTERVENTIONS TO IMPROVE RURAL LIVELIHOODS IN SSA AND SA

Investment in water interventions or development projects has played a key role in the economic progress of rural populations (Lipton et al., 2003; Turral et al., 2010). To address the issues of poverty and hunger, sustainable water resource management is a prerequisite (Cofie & Amede, 2015; de Fraiture & Giordano, 2014). Improvement in agricultural productivity and sufficient food production are the key challenges to achieve food security and reduce poverty in these countries because in the near future rural people will continue to rely upon agriculture (Namara et al., 2010). Investment to improve water accessibility provides opportunities to reduce poverty and uplift rural livelihoods, but these investment decisions are influenced by prevalence of rural subsistence farming, climate and agro-ecological zones (de Fraiture & Giordano, 2014; Hanjra et al., 2009) Therefore any decisions regarding water development for agriculture must consider the socio-economic and biophysical aspects of water resource availability and management (Sauer et al., 2010; You et al., 2011). In the next section we will discuss different water interventions which can enhance the productivity of irrigated as well as rain-fed agriculture to improve rural livelihoods in the SSA and SA regions.

17 | IMPROVE RAINWATER MANAGEMENT IN RAIN-FED AGRICULTURE

Rain-fed agriculture has great potential for higher agricultural output through better management of water that would contribute towards poverty reduction (Cofie & Amede, 2015). There is a need to invest in rain-fed agriculture particularly in arid, semi-arid and dry sub-humid parts as they are hotspots of poverty and hunger (Falkenmark & Rockström, 2004; Wani et al., 2009). In SSA a major challenge is to decrease water-related threats occurring in semi-arid regions due to rainfall variability (Rockström et al., 2007). Many rain-fed areas receive sufficient precipitation to support rain-fed cropping, however high-intensity rainfall, spatial variability and dry spells constrain productivity in many locations (Biazin et al., 2012). Consequently a large portion of the rainfall is wasted via unproductive evaporation or in the form of runoff which leads to soil fertility loss and erosion (Araya & Stroosnijder, 2010). Farmers in such areas are in need of capital and technical assistance for better management and control of such erratic water supplies (Douxchamps et al., 2014). These investments would optimize use of seed, fertilizers and other important inputs under rain-fed conditions while developing soil moisture management strategies (Mupangwa et al., 2006; Rockström, 2000).

To manage soil moisture at the field level requires specific management practices with the clear objective of retaining water in the root zone (Bouma et al., 2016). Such practices would consist of soil and water conservation and runoff farming, which is a technique to capture water as it falls on the ground; consequently water infiltration rate increases and runoff decreases (Biazin et al., 2012; Cofie & Amede, 2015; Sietz & Van Dijk, 2015). Runoff farming is becoming popular in areas such as western Sudan where positive results can be seen in the form of better agricultural production and improved livelihoods (Osman-Elasha et al., 2006). Farmers also achieved better outcomes when they combined effective water control methods with soil fertility management. For instance in Burkina Faso (Slingerland & Stork, 2000), Niger (Kabore & Reij, 2004) and Mali (Mupangwa et al., 2006), sorghum yield showed an increase when the capture of more scattered rainfall and addition of dung/compost in *zai*/*tassa* planting pits facilitated the efficient use of water and nutrients. *Zai* or *tassa* is a farming technique where small planting pits (20–30 cm long and deep and 90 cm apart) are dug in the soil during the preseason to catch water and concentrate compost (Danjuma & Mohammed, 2015). In SA farmers use simple water management methods such as small-scale diversion and water-harvesting techniques (Reddy et al., 2017). These techniques are largely followed by small-scale farmers in SA. Contour farming, terracing and other suitable water retention techniques are widely adopted for *in situ* water harvesting (Anantha et al., 2021). Also small ponds and dams are constructed for better storage of available runoff which can be used for supplemental irrigation, livestock and other purposes (Doolette & Smyle, 1990; Reddy et al., 2017).

Conservation agriculture is a promising approach becoming popular in SSA (Hobbs et al., 2008; Sietz & Van Dijk, 2015). These conservation practices aim to improve soil quality by increasing organic matter build-up and soil water-holding capacity while reducing tillage and burning of residues (Giller et al., 2009; Pannell et al., 2006; Piemontese et al., 2021). Agroforestry, mulching, crop rotation and minimum tillage practices are an important part of conservation agriculture, particularly in scattered rainfall and rangeland livelihood systems in SA (Anantha et al., 2021; Sarvade et al., 2019). However, the potential benefits of conservation agriculture take time to bear fruit and farmers may require financial support to adopt conservation agriculture. Subsidies may be appropriate to promote conservation agriculture practices as they can also provide wider environmental benefits (FAO, 2008).

18 | FACILITATE COMMUNITY-BASED SMALL-SCALE IRRIGATION SCHEMES

Community-based small-scale irrigation schemes contribute towards poverty reduction through development of local markets and stimulating the rural economy (Bjornlund et al., 2017; FAO, 2008). However, success of these irrigation projects is dependent on certain conditions. Political instability or unnecessary interference can lead to inappropriate decision making, unequal access to irrigated land and destruction of infrastructure due to poor maintenance (de Sousa et al., 2017; Nalmu et al., 2021). Key elements for the success and sustainability of community-based irrigation systems include good design of these irrigation systems, operational simplicity, low initial cost and fewer maintenance expenses (Mutambara et al., 2016; Yami, 2016). Additionally, community involvement in the design of small-scale irrigation systems generally increases the probability of sustainable management of investments and the realization of subsequent benefits (Turral et al., 2010; Yami, 2016). Adoption of community-based small-scale irrigation schemes can show higher economic returns compared to large irrigation schemes with respect to poverty reduction in rural communities (Hussain & Hanjra, 2003). *Dambos*, a seasonally waterlogged, grass-covered depression near a stream, river or other lowland valley areas have shown potential for large-scale rice production in SSA. In SSA nearly 555 000 ha area got direct benefit from external investments (FAO, 2006). Similarly in Nepal for example, farmer-managed irrigation schemes (FMIS) are quite common, while tank irrigation is popular in Sri Lanka and India (FAO, 2014; Khanal, 2003). In South Asia, FMIS encompass a large area and are a major focus for donor agencies, where improvement of current FMIS and establishment of new schemes will remain the priority in many SA livelihood systems (Merrey et al., 2007). Overall, small-scale community-based irrigation systems are good options under all livelihood zones as they are well suited to areas where water is a limiting factor in crop production.

19 | GROUNDWATER INTERVENTIONS

Groundwater is an important source of irrigation and serves about 112 million (40%) ha of the total 275 million ha of irrigated land in the world (Chaudhuri et al., 2021; Unver et al., 2018). In SA groundwater supplements more than 50% of the irrigation needs while in SSA its share is only 6% of total irrigated land (GWP, 2012; Unver et al., 2018). Groundwater interventions are especially important for poor farming communities and disadvantaged segments of society in SA and SSA regions (FAO, 2008, 2014). Groundwater resource management needs improved control to sustain economic returns and to improvise future benefits (Alauddin & Quiggin, 2008). In SA opportunities exist to extend groundwater irrigation particularly in rain-fed dry tropical and subtropical zones along with lowland rice-based systems through shallow wells (Morita, 2021). These areas are poverty stricken but have the potential for economic improvement through effective water interventions (FAO, 2014). For example, provision of electricity for groundwater extraction can give relief to poor farmers, as rising fuel costs for diesel pumps make groundwater utilization difficult (Mukherji et al., 2013). SSA also has abundant groundwater resources but their potential for irrigation has not yet been fully realized (Villholth, 2013). Estimated extraction of groundwater in SSA is about 17% of the total renewable groundwater resources and a large part of this is for domestic use (Svendsen et al., 2009). The available volume of groundwater in SSA is nearly 100 times higher than renewable surface water resources (Villholth, 2013). Hand-operated boreholes are the best-suited instrument in the context of SSA hydrology (MacDonald et al., 2012). A recent study of 13 SSA countries indicated that 13.5 million ha land can potentially be developed through groundwater irrigation that would improve the living standards of about 27 million rural people (Pavelic et al., 2013). Options are available at local and national policy levels that would enhance the development of groundwater irrigation in both SSA and SA. Improved education of local farmers regarding groundwater management would improve utilization and avoid overexploitation of this resource (Burney & Naylor, 2012; FAO, 2014). Attention should be paid to finance and credit schemes that help poor farmers reduce their economic burden (Bjornlund et al., 2017; Cobbing & Hiller, 2019). Specifically, farmers need support for drilling, pump sales and repair services and better access to energy resources (Mutambara et al., 2016; Shah et al., 2013). To develop deep groundwater resources, public–private investment is needed as current private investment is confined to shallow groundwater resources (Amjath-Babu et al., 2016). There is a need to utilize the latest technology for updating and monitoring groundwater resource data through application of remote sensing at local and national levels in SSA (Bjornlund et al., 2017; Villholth, 2013). For instance in Bangladesh (SA), water user associations control and regulate groundwater resources by controlling pumps with smart cards (Zaman, 2019). These smart cards are used by individuals for tracking water usage and are overseen by water user associations. More organizational entities like this are needed in these regions to improve future groundwater management (Rasul & Neupane, 2021). They would serve to coordinate education, research and policy development for better groundwater management. These organizations can also address the negative impacts of groundwater development on the environment through proper assessment at local and regional levels (World Bank, 2018).

20 | INTERVENTIONS FOR UPGRADING AND MODERNIZING OF EXISTING IRRIGATION SYSTEMS

Considerable potential exists in SSA and SA to reduce poverty by means of large-scale irrigation systems; however, existing irrigation systems are not being utilized to their fullest extent (Cobbing & Hiller, 2019; Rasul & Neupane, 2021). The principal reasons for their low performance have been extensively studied and are found to be economic, technical, social and institutional in nature (Aw & Diemer, 2005; Morardet et al., 2005). Irrigation systems should be considered as a socio-technical system that must operate within a set of agro-ecological constraints Given these parameters, engineering solutions alone cannot solve the problems associated with these irrigation systems (Huppert, 2009; Vincent & Khanal, 2003). Various interventions are needed within this setting to improve irrigation performance to effectively reduce poverty. For instance, technical measures can be initiated that include water saving and conservation practices (Walters & Groninger, 2014), increased diversification of agricultural commodities, promotion of high-value crops (Hussain, 2005), rehabilitation of relevant infrastructure (Namara et al., 2010), integrated management of ground and surface water, use of water regulatory structures and better drainage management operations (Bjornlund et al., 2017; Burney et al., 2013). The above-mentioned technical interventions are fully complemented by various institutional interventions, for instance better collection of water charges (Mutambara et al., 2016), equal water distribution to farmers from source to end-user (Lautze & Giordano, 2006), extending the process of irrigation management transfer, and enhancing the capacity of institutional officials and farmers through specific training programmes (Merrey et al., 2007). Rice-based and rice–wheat-based surface irrigation livelihood systems in SA could be the potential beneficiaries of these interventions (FAO, 2014).

21 | WATER INTERVENTIONS TO FACILITATE AND IMPROVE LIVESTOCK PRODUCTION

Livestock rearing is an essential part of the socio-economics of rural populations in SSA and SA (Amede et al., 2009; Valbuena et al., 2012). They provide a cushion against income shortfalls for most of the rural poor and thus strongly contribute to rural livelihood systems through continuous cash flow (FAO, 2014). Global experience has shown that developing water and livestock together results in more stable livelihoods and better economic returns (Molden et al., 2007). Investment in water development to support livestock production varies according to the livelihood zone, depending upon livestock's importance in the system and the climatic conditions (FAO, 2008). Less investment is required in the humid tropics due to sufficient water availability, while in arid regions water for livestock becomes a highly important issue because livestock play a major role in those regions. Keeping in view the above points, the following water interventions for livestock can be adopted;

Sufficient and easy access to water supply is essential for livestock production (Doraeu et al., 2012). Regardless of how plentiful and palatable the forage may be, the livestock consuming it must have the water they need, or they will not thrive (Peden et al., 2007). Water deprivation may cause appetite loss, resulting in animal death (Naqvi et al., 2015). To ensure an ample supply of water for livestock production a wide range of surface and groundwater possibilities exist (Peden et al., 2007). Under natural ponding conditions surface water is available for drinking but for groundwater development, wells must be dug, which is usually quite expensive (FAO, 2008). However, local people can collectively invest in digging wells and thereby reduce the cost of groundwater development (Food and Agriculture Organization of the United Nations [FAO], 1986).

Proper management of rainwater in grazing lands can include the capture and storage of water and nutrients on grasslands, watersheds and farms (Amede et al., 2011). Good management could also be achieved through rotational grazing and employing community-based pasture management practices (Peden et al., 2009). Such interventions need a clear policy and framework regarding pastureland use and land tenure rights, particularly for the poor who are not landowners (Nkonya & Anderson, 2015). These interventions would be suitable in sparse land and pastoral-based livelihood systems (Amede et al., 2009).

There is a great potential to increase water productivity through better utilization of crop residues in livestock feeding (Descheemaeker et al., 2010). Investment in new technologies such as biofuel production can greatly increase animal feed availability through conversion of lignin into digestible compounds (Wright, 2010). Animal productivity can be increased to narrow the yield gap through better feeding, balanced nutrition and improved breeding techniques with good health and lower mortality rates with the same quantity of water (Peden et al., 2009; Thornton, 2010). To prevent water and environmental contamination from animal waste a well-designed waste management strategy is required covering all aspects of livestock management from production, collection, storage, processing and utilization (Singh & Rashid, 2017).

22 | PROMOTE MULTIPLE USES OF WATER

A multiple-use approach is the smart way to utilize water more effectively in order to alleviate poverty (Smith, 2004). Water infrastructure constructed in rural areas is usually used for many purposes by the poor (Namara et al., 2010). These multiple uses include water for drinking and sanitation, cropping, horticulture, fisheries and aquaculture, beer production, tree plantation, ceremonial purposes and other water-dependent small businesses (Nguyen-Khoa et al., 2005; Van Koppen et al., 2006).

Investments that ensure water availability for multiple domestic purposes and substantially improve local livelihoods are much better than single objective-oriented investments (Hanjra et al., 2009). For instance, investments to construct a village pond or tube-well for irrigation and household purposes decrease the time spent by house members bringing water from faraway areas (FAO, 2008). This allows time to be spent on other productive activities (Lane, 2004). Availability of water is also important for processing of agricultural products domestically which adds value to these agro-products (Namara et al., 2010). This agro-processing may involves simple washing, drying, canning and packaging of the produce (Boelee et al., 2007). Maintaining necessary hygienic conditions during the packing of vegetables for export purposes results in overall health gains for the rural poor (Faour-Klingbeil & Todd, 2018). Aquaculture provides another avenue of development under current irrigation set systems or in conjunction with new irrigation plans which can enhance small business enterprises and rural incomes in SSA (Domènech, 2015). In West Africa and other fish-producing areas integrated irrigation aquaculture is a popular practice (Mafwila Kinkela et al., 2019). Extending aquaculture development, fish processing and trading to small-scale irrigation areas can improve rural livelihoods with better utilization of water resources (Namara et al., 2010). Evidence from South Africa shows that productive uses of domestic water represent 17–31% of the average household income in different villages (Moriarty et al., 2004). Periurban crop production is another avenue for rural farmers to produce and sell their crops to nearby urban populations (Drechsel & Varma, 2007). Key investment areas to facilitate periurban producers include drilling for groundwater, check dams, provision of small pumps and irrigation kits for local gardens (FAO, 2008; Woodhouse et al., 2016).

23 | CONCLUSION

Water is an essential requirement for poverty alleviation and hunger eradication. With more than 70% of the world's poor people, SSA and SA are core areas facing absolute poverty. More than 70% of African and South Asian rural poor are principally dependent on agriculture for their livelihood. The water– poverty nexus indicates that irrigation alleviates poverty through various transmission effects, such as better agricultural production, job creation, food availability at low prices for the rural and urban poor, nutritional gains, equity impacts, better human health and environmental effects. The diversity of rural livelihood systems in SSA and SA demands context-specific and objective-oriented interventions where rural people have the opportunity to actively participate in decision-making process for more fruitful and effective outcomes. The major water interventions having the potential to alleviate poverty through improvement in agricultural productivity identified in this study include:

- Improve rainwater management in rain-fed agriculture;
- Facilitate community-based small-scale irrigation schemes;
- Development and management of groundwater irrigation;
- Interventions to upgrade and modernize existing irrigation systems;
- Water interventions to facilitate and improve livestock production;
- Promote multiple uses of water.

The applicability of these interventions depends on the livelihood and biophysical settings and the availability of water resources. Furthermore, these interventions involve technical options, management choices and coordination of institutional and sociopolitical frameworks to consolidate the intervention process. Any intervention package must have a consensus of all stakeholders without which these fundamental water interventions might falter.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTION

Conceptualization (Zeeshan Ahmed and Dongwei Gui), original draft preparation (Zeeshan Ahmed); review and editing (Zhiming Qi and Yi Liu).

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N/A.

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