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Review

The Significance of Small Reservoirs in Sustaining Agricultural Landscapes in Dry Areas of West Africa: A Review

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Abstract: Water scarcity is a growing challenge in semi-arid and sub-humid areas. There are over 2000 small reservoirs (SRs) with storage capacities of up to 1×10^6 m^3 across West Africa's dry areas. Based on a comprehensive literature review, we found strong evidence that SRs enable improved food security, livelihoods, and income diversification through fishing and livestock production. However, their productivity is far below their potential. Evidence on water quantity and quality is scattered, making deriving conclusions difficult. Review findings suggest that, unlike large dams, SRs have minimal impact on water balance and rainfall-runoff. There is, therefore, considerable potential to develop more SRs. However, high rates of sedimentation substantially reduce reservoir storage capacity. Poor irrigation management and agronomic practices also contribute to low productivity. Water quality is not systematically monitored, so SRs can increase health risks such as malaria and schistosomiasis. With the intensification of settlements, livestock, and agriculture around the reservoirs, it is critical to improve water quality and quantity monitoring. We conclude that SRs are important nature-based solutions, but need more investment to support the climate-proofing of agriculture and livelihoods. We recommend governments develop long-term small reservoir support programs to strengthen local capacities to manage the reservoirs and their watersheds sustainably.

Keywords: small reservoirs; water management; productivity; water infrastructure; agricultural landscapes; nature-based solution; West Africa

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1. Introduction

Landscapes and water resources provide humans with many vital benefits [1]. To enhance these ecosystem services, infrastructures have been developed in river basins for millennia to collect and extract water for agriculture and domestic water. These include small reservoirs (SRs), generally with a storage capacity up to 1 M m^3 (M: million). Small reservoirs are found throughout sub-Saharan Africa, including southern and eastern Africa [2], but are especially important in the dry areas of West Africa where they have existed for many decades or longer [3].

West African SRs are mostly found in the Sudano-Sahelian regions with annual rainfall between 200 and 1000 mm yr^{-1} [4,5]. The development of SRs has increased dramatically, especially in the Volta River Basin, since the 1970s and 1980s droughts [4,6]. In Burkina Faso alone, 195 such projects costing USD 641 M were implemented between 1970 and 2009 [7]. Over 1700 small reservoirs exist in Burkina Faso, providing water for livestock, irrigation and domestic uses [4]. In Ghana, there are over 1000 small reservoirs with almost a quarter found in the Upper East Region alone (UER) [8,9].

The role of SRs is particularly important given the challenges of water resource availability and accessibility. The problem is partly due to the highly variable natural distribution of water, both geographically and seasonally, throughout Africa [10]. Water shortage is a pressing problem, as most people have limited access to freshwater supplies [11]. Long dry spells and droughts affect rainfed agriculture and livelihoods. Rainfall variability has serious impacts on agricultural productivity and national economies, as agriculture is largely rainfed; for example, in Burkina Faso, an estimated 90% of the rural population depend on rainfall [7].

Pressures from population growth, economic development, and urbanization exacerbate the existing water insecurity, leading to increased freshwater degradation as well as abstraction. For example, the population in the Volta Basin is projected to increase from 24 M in 2010 to 56 M in 2050, with Burkina Faso and Ghana seeing most of the growth [12]. Climate change is another factor expected to cause serious drought and worsen the water shortage problem. The agricultural impact from increased dry spells, high-intensity rainfall, and increased temperatures will be huge [13,14]. These trends, especially the extreme dry spells, may reduce crop yields by between 10 and 20% by 2050. This necessitates investing in water infrastructure solutions [14]. Implementing agricultural water management solutions such as dams, small reservoirs, natural ponds, and other nature-based solutions can provide an alternative way to store and use water when most needed [15,16]. This perception has driven the increased development of small reservoirs over the past decades as tools for improving food security and livelihoods during dry seasons, especially in Burkina Faso, Mali, and Ghana [17,18]. Achieving water security and sustainable water resource management are central to the achievement of the Sustainable Development Goals (SDGs), and critical for improved climate resilience of the agriculture sector, as this continues to be a major contributor to the gross domestic product (22–41%) of riparian countries [12].

This review aims to contribute to the long-term sustainability and productivity of agricultural landscapes, which will be beneficial to livelihoods, economies, and human health. The key question that the study addresses is: what are the evidence for and scale of small reservoirs' impacts on the hydrological cycle, on landscapes including sediment traps, water quality, agricultural productivity, and the health and livelihoods of users? We use an approach combining a systematic and qualitative literature review to synthesize the evidence on the hydrology, environment, agriculture, and livelihoods of SR development. Ultimately, we seek to understand if, and how, SRs have the potential to be a nature-based solution with the ability to generate benefits for both people and nature, and contribute to multiple SDGs, such as SDG 2 (zero hunger), SDG 6 (clean water), and SDG 13 (climate action).

2. Materials and Methods

Reviews are important in synthesizing state-of-the-art knowledge and understanding based on peer-reviewed papers [19]. The systematic review method uses a transparent, objective and systematic process to comprehensively search studies and synthesize findings around a specific research question [20–23]. It involves a search method, selection criteria, and screening of the sample obtained. The systematic review was complemented by highlighting the contributions of specific research studies. Most of the cases reviewed were from Burkina Faso, Ghana, Mali, and Nigeria.

Search Method and Selection Criteria

Several databases exist for undertaking a systematic literature search. For this study, the main electronic databases consulted were Scopus, Web of Science (WoS) and the Centre for Agriculture and Bioscience International (CABI) online databases, as shown in Table 1. Studies covering SRs in the dry areas of West Africa published between 1998 and 2018 were searched using a defined string designed to capture relevant studies. Reference lists of publications up to the year 2021 were also manually searched to identify other relevant articles.

Table 1. Search words used for obtaining relevant literature.

Search Words	Synonym Words
Small reservoir	Small reservoir, reservoir, small dam, dam, dugout, barrage, mini barrage, petit barrage
West Africa	Burkina Faso, Ghana, Niger, Mali, Benin, Gambia, Guinea, Guinea-Bissau, Ivory Coast, Cote d'ivoire, Liberia, Mauritania, Nigeria, "Afrique de l'Ouest"
Subject area	Agriculture, hydrological system, hydrology, water balance, catchment, watershed, land, landscape, land use, land cover, sediment, erosion, water quality, reservoir health, nature-based solution, *hydrologie*, *systeme hydrologique*, *bassin versant*, *bilan hydrologique*, *occupation du solutilisation des terres*
Exclusion	Large reservoir, Southwest Africa, petroleum, oil, natural gas, mining, magma, drilling, mine, marine, estuary, hydropower, hydro-power, hydroelectricity, hydrocarbon, etc.
Publication year	1998 to 2018
Language	English; French
Databases	Web of Science (www.webofscience.com, 5 August 2018), SCOPUS (www.scopus.com, 5 August 2018), Agriculture and Bioscience International (www.CABI.org, 5 August 2018)

The defined search string comprised key search words and their equivalent synonyms (Table 1). The key word was small reservoirs, in addition to its synonyms (e.g., dugouts, dam), and the geographical location was restricted to the dry areas of West Africa (including individual countries). Subject areas were defined to cover a wide scope, including hydrology, water balance and land-use, among others. The string was designed to exclude papers covering subjects and journals irrelevant for the study. The search languages were English and French. The search was repeated until all relevant publications were captured.

The initial search of the electronic databases identified over 5000 papers. By excluding irrelevant subject areas and redesigning the string of questions, a subsequent search yielded 849 published papers, while the manual search found 28 additional papers. Duplications were removed and the remaining publications (862) were individually examined based on their title and abstract before the final selection was made from 459 articles assessed for eligibility. In all, 91 papers, including those manually searched, were deemed relevant to the purpose of the study. Most of the papers were scientific publications (n = 65), followed by book chapters (n = 17). These were then grouped under focus subject area(s): agriculture (n = 27), hydrology (n = 22), water quality (n = 11), sedimentation (n = 11), governance (n = 8), and reservoir health (n = 12). The indicators or parameters considered under each subject area are presented in Table 2. A critical review of all the published papers under the focus areas was performed, and the results are presented in the following sections. Figure 1 shows the spatial-temporal representation of the papers reviewed in the study, indicating the scattered evidence from the studies included herein.

Table 2. Indicators considered under each subject area.

Subject	Number of Papers	Indicators
Agriculture	27	Irrigation, livestock, fishing, livelihood benefits, productivity, crop yield, water and labor productivity
Hydrology	22	Evaporation loss, water balance, storage capacity impact, basin and subbasin impact
Sedimentation	11	Catchment yield, reservoir siltation, storage loss, nutrient load
Water quality	11	Physicochemical, biological parameters, land-use effect, weed invasion
Reservoir health	12	Water-related diseases, malaria, V. cholerae, schistosomiasis
Governance	8	Management, operation, maintenance, local committees, water user associations

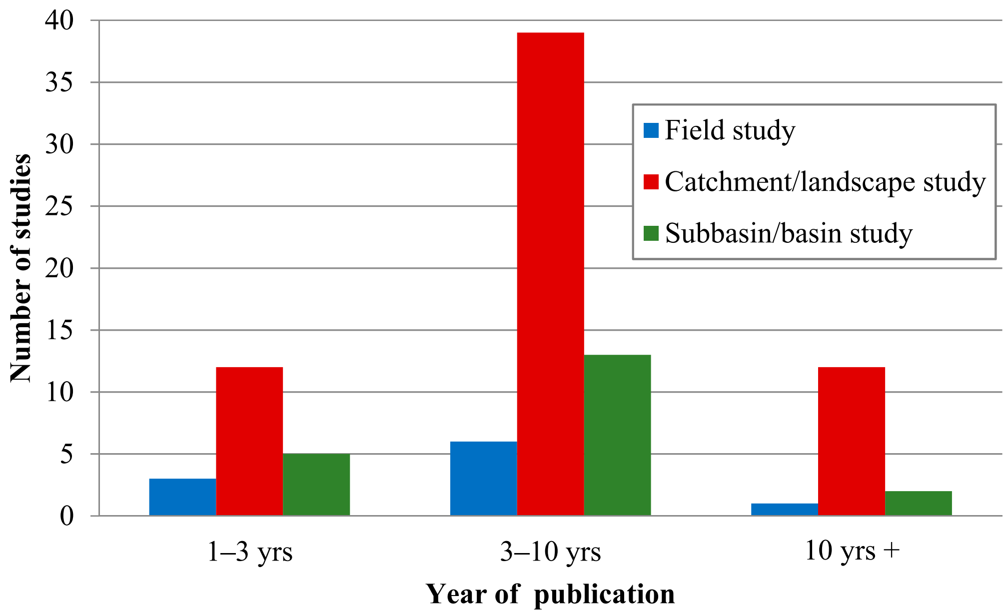

Figure 1. Spatial-temporal representation of the papers reviewed.

3. Results

3.1. Overview of Small Reservoirs

Small reservoirs are widely distributed across the semi-arid and dry subhumid zones of West Africa (Figure 2). Reservoirs are classified as either small or large, depending on the height of the structure, the volume of water it can store, and its surface area [3,24]. SRs are considered to have a height less than 15 m and storage volumes up to 1 M m^3, while large reservoirs have a height and volume of 15 m and 3 M m^3 or more [25].

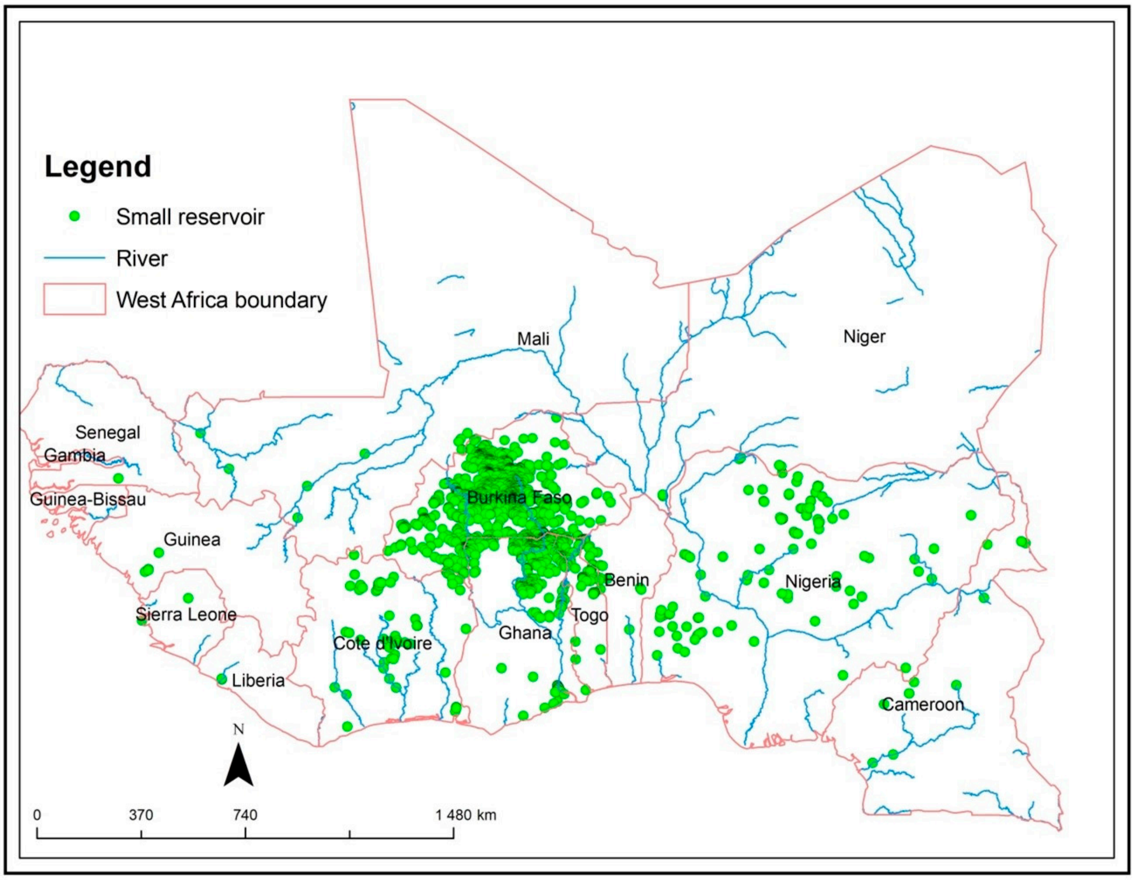

Figure 2. Small reservoir distribution across West Africa (source: prepared for this study).

This review focuses on small reservoirs, i.e., those with a storage volume of 1 M m^3 or less. In Burkina Faso, there are an estimated 1700 reservoirs (Table 3 and [4]). Their total storage capacity, together with large dams, is 2700 M m^3, which is about 36% of the total annual discharge in the country [5,26]. Small reservoirs alone account for a far lower storage volume in the region. The 2000 SRs in the Volta Basin, most of which are found in Burkina Faso (80%), have a total storage capacity of around 232 M m^3. This is less than 1% of the annual discharge of the Volta River [27]. In the UER of Ghana, the number of SRs was reported as 154, with an estimated volume of 185 M m^3 in 2005 [28], increasing to 171 in UER and 254 in the entire northern region of Ghana in 2018 [9]. A recent estimate has claimed that there are now over 300 SRs in UER [29].

Table 3. Estimated number of small reservoirs and their storage capacity in West Africa.

Country	No. of Reservoir	Storage Capacity (M m^3)	Reference
Burkina Faso	1000–2000	2700 *	[4,30–32]
Ghana, UER	154–300	185	[28,29]
Ghana	>1000	n/a	[6]
Ghana	254	n/a	[9]
Ghana and Burkina Faso (Volta Basin)	2000	232	[27]
Ghana and Burkina Faso (Black Volta Basin)	190	6.3	[33]
Ghana and Burkina Faso (White Volta Basin)	239	4.2	[34]
Mali	800	n/a	[6,35]
Niger	100	n/a	[6,36]
Cote d'ivoire	>600	n/a	[6]
Nigeria	937	n/a	[37,38]
Benin	243	n/a	[38,39]

* Not all were small reservoirs.

The number, total capacity, and conditions of SRs have grown over time in West Africa, likely in response to rapid population growth [40]. However, this growth is also a threat to the quality of water in SRs, as is agricultural intensification. In an analysis of land use and societal changes that affect SR capacity over time, Forkuor et al. [31] found that, in Burkina Faso, a majority of SRs experienced higher risk for reduced capacity between 2002 and 2014 due to catchment land-use and land-cover changes.

3.2. Livelihood Benefits of Small Reservoirs

3.2.1. Small Reservoir Effects on Productivity

Several researchers have assessed the performance of irrigation sourced by SRs. They generally document low vegetable yields and water productivity, ranging from 1 to 49 tons ha^{-1} and 1 to 38 kg m^{-3}, respectively (Table 4). Low crop yields and productivity have been recorded in studies in Ghana [41,42]. Based on an assessment of the effectiveness and impact of SRs in Ghana, some authors [43] reported only about a 3% increase in the income of over 300 vegetable farmers participating in irrigated vegetable production using SRs.

Table 4. Crop yield and water productivity of small reservoir irrigation schemes.

Irrigation Scheme	Location	Crop	Yield (tons ha^{-1})	Water Productivity (kg m^{-3})	Reference
Bongo SR	Guinea–Sudano–Savanna agro-ecological Zone. UER, Ghana	Tomato; Leafy vegetables (lettuce, cowpea, roselle)	40–49 9–38	1.5–8 1–9	[44]
Dorongo SR	UER, Ghana	Tomato	12	2.6	[42]
Binaba SR	Burkina Faso	Tomato; Onion	1 4		[41]
39 SRs in the White Volta Basin	UER Ghana Burkina Faso	Tomato	17–19	22–38	[45]

A few studies reporting relatively high yields, for example, the tomato yields at the Bongo Reservoir, can be explained by better agronomic management [44]. A survey of 39 SRs for tomato irrigation in Ghana and Burkina Faso found yields between 17 and 19 tons ha^{-1} and a relatively high water productivity of 22–38 kg m^{-3}, a result of the better management of irrigated plots and the use of fertilizer [45]. However, most studies also underscore that the deterioration and underutilization of SRs are undermining their infrastructure performance.

Various cost-benefit analyses show that the net return of irrigation-sourced water from SRs is highly dependent on crop productivity and market access, with considerable scope for improvement (Table 5). The net benefit varies from negative to positive, depending on market prices [46]. The important role of markets in influencing the returns to SR irrigation was highlighted by Poussin et al. [41], where the difficulty in marketing goods and high variability in sales prices reduced the returns. A study [47] reported that the returns to household labor were $11 and $12 per ha for tomato and onion, respectively, which are relatively high and almost three times the returns on rainfed practices in the study area. In the Upper West Region (UWR) of Ghana, Acheampong et al. [48] reported high economic returns for SR-irrigated crops using multiple indicators, but excluding the cost of labor. The returns varied from USD 300 to USD 1700 ha^{-1} per cultivated season, translating to daily earnings of USD 15–90 per farmer from the UER, and USD 50–750 per farmer from the UWR. Findings from the Binaba reservoir in Ghana show returns of USD 25–773 ha^{-1} for rice, depending on the price, and USD 693 ha^{-1} for vegetable production [41]. The productivity of labor ranged from USD 0.6–17 per day for rice and USD 7 per day for vegetables, respectively. Elsewhere, the Boura reservoir in Burkina Faso recorded a solid net benefit of USD 979–1310 ha^{-1} for rice and vegetables, and a productivity of USD 21 d^{-1} for other crops [41].

Table 5. Small reservoir irrigation returns.

Location	Irrigation System	Crop	Net Benefit (USD ha^{-1})	(USD m^{-3})	Labor Cost Included	Reference
UER, Ghana	Tanga SR Weega SR	Onion Onion	−858 to +2199 −442 to +1475	0.03 to 0.07 0.04 to 0.13	No	[46]
UER, Ghana	SRs	Tomato Onion	11 12	n/a	Yes	[47]
UER and UWR, (Sudan savanna) Ghana	16 SRs	Mixed cropping	UER: 300 to 1400 UWR: 550 to 1700	n/a	No	[48]
UER Ghana Burkina Faso	Binaba Boura reservoir	Rice Vegetable Rice Vegetable	25 to 773 693 979 1310	n/a	USD 0.6 to 17 day^{-1} USD 7 day^{-1} USD 21 day^{-1} USD 21 day^{-1}	[41]

In Yatenga Province of Burkina Faso, substantial benefits were derived from multiple water uses [17]. Livestock watering and vegetable production were the two major competitive users of water [17,49]. SRs, as a major source of drinking water for livestock, were also emphasized by a case study in northern Benin, but high livestock water-use led to conflict with those producing vegetables [50,51]. The integration of fodder into irrigated plots provides an opportunity to improve overall livestock water productivity [52]. A more recent study [53] found that, while the private financial returns on irrigated agriculture were too low to encourage investment in the rehabilitation of SRs, accounting for their multiple uses showed very positive net present values and high returns on capital.

Findings from southwest Burkina Faso document that peoples' perceptions and actual livelihoods have changed as a result of SRs. Most farmers perceived positive impacts on their vegetable and fish production systems [54]. Similarly, Fussillier [55] observed higher living standards of residents around a reservoir, compared to those without a reservoir in the Center-West region of Burkina Faso. Most people around the reservoir had better food security compared to those elsewhere (Figure 3). The study showed that the food processing and marketing of agricultural products generated additional income, which made the most difference in peoples' lives.

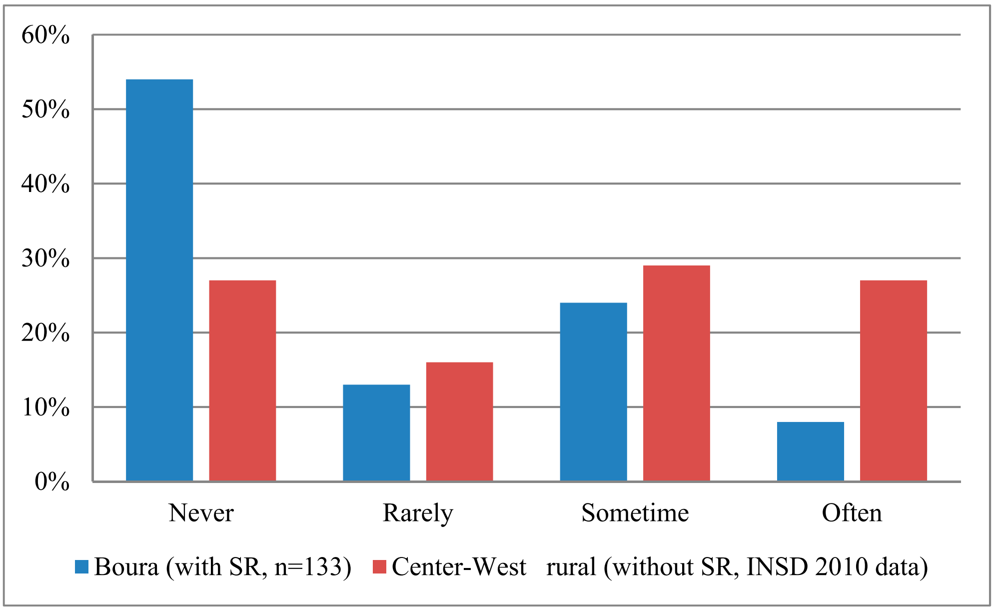

Figure 3. Responses to perceived household problems to satisfy food need: data source ([55]; modified).

3.2.2. Fishing

Small reservoirs support fish farming, another livelihood source. Hauck [56] found that the income derived from fishing was USD 1.02 d^{-1} on average in the dry season, but in some cases can rise to USD 1.36 d^{-1}. These figures are slightly above the national poverty limit of about USD 1.00 cap^{-1} d^{-1}, and were somewhat influential in lifting 15% of the active male population out of the poverty bracket in the study communities.

This review found no estimates of fish yields, but several studies claimed declining fish yields and low aquaculture production across SRs in West Africa [57,58]. Low fish catch can be attributed to several factors, for example, agricultural activities causing reservoir disturbance and poor water quality [59–61]. A model predicting the harvest potential of reservoirs in northern Ghana found that fish production decreased with increasing reservoir size [38]. The Golinga SR, however, with the highest annual fluctuations in surface area and water levels, was more productive than larger reservoirs, with a total catch of 17 tons km^{-2} yr^{-1} [38].

3.3. Hydrological Impact of Small Reservoirs

3.3.1. Evaporation Loss from Small Reservoir Storage

One cause of low water productivity of SRs is the high non-productive evaporation from the open water surface. The rate of evaporation loss can be determined by direct measurement or estimated indirectly. A review of the studies employing these methods showed significant differences in the results (Table 6). Evaporation losses measured using a floating evaporation pan (Eo) in UER, Ghana, ranged from 5.8 to 6.5 mm d^{-1} in the dry season and 4.4–4.8 mm d^{-1} in the wet season [62]. These directly measured values were lower than the results from the estimation methods. The energy budget (EB) results ranged from 6.3 mm d^{-1} in January to 7.8 mm d^{-1} in February and March, while the Penman estimates (ET) ranged from 6 to 7.5 mm d^{-1} [62]. Using the same Penman method, a previous study reported a rate as high as 7 mm d^{-1} in the dry season [63]. The estimated daily evaporation rate of 3.6–9.9 mm d^{-1} reported for the Boura reservoir in Burkina Faso could be an overestimation of the actual evaporation rate [64].

Table 6. Rates of reservoir evaporation in Ghana and Burkina Faso.

Location	ET (mm d^{-1})	Description of Method	Reference
SRs UER Ghana	E_o: 5.8–6.5;4.4–4.8 E_T: 6.0–7.5 E_B: 6.3–7.8	E_o floating evaporation pan E_T after Penman E_B energy-budget-based	[62]
Boura reservoir, Southern Burkina Faso	Dry season: 3.6–9.9 Wet season: 1–7	Pan evaporation	[64]
SRs UER Ghana	Estimated: 3–7	ET after Penman	[63]
Binaba reservoir, UER Ghana	Estimated: 2.5 Assumed neutral: 2	Modeled ET (based on bulk-aerodynamic method)	[65]

Both estimated and derived values are often higher than the actual measured evaporation rates from reservoirs. Unstable climatic conditions (e.g., wind, temperature) can increase evaporation from small reservoirs. A study in northern Ghana recorded high atmospheric instability increasing the average rate of evaporation by ~45%, using the bulk-aerodynamic transfer method [65]. The estimated daily average evaporation of the Binaba reservoir was 2.5 mm d^{-1}, compared to an assumed neutral condition value of 2.0 mm d^{-1}. These values compared to those measured for a similar study area were very low and could result from differences in the study approach [62,65].

3.3.2. Small Reservoir Impact on Local Water Balances

The estimation of water partitioning change in watersheds due to SR development at the local level is based on studies from the Boura reservoir in Burkina Faso and a modeled Kandiga reservoir in Ghana [64,66]. Considering the surface runoff into SR and the spillway overflow as natural flows in the river catchment (shown in Table 7), the construction of the Boura reservoir reduced the flow from 9.7 to 6.24 M m^3 yr^{-1} and from 3.1 to zero M m^3 yr^{-1} over two years [64]. The Kandiga reservoir reduced surface-water flows in the catchment from 0.28 to 0.21 M m^3 yr^{-1}. For Boura, no spillway overflow occurred when surface inflow plus direct rainfall was close to the evaporation and infiltration losses. However, the high evaporation component of the water balance (3 to 4 times the withdrawal for irrigation) requires proper consideration for the expanded water resource use of the SR.

Table 7. Water fluxes in two small reservoirs.

Water Balance Components	**Boura, Burkina Faso [64]**		**Kandiga SR, UER Ghana [66]**
	2012/2013 (M m^3 yr^{-1})	**2013/2014 (M m^3 yr^{-1})**	**2004 (M m^3 yr^{-1})**
Inputs			
Surface runoff/inflows	9.70	3.10	0.28
Direct rainfall	1.64	1.03	0.08
Outputs			
Evaporation	2.76	2.78	0.11
Infiltration losses	1.16	1.06	0.02
Overflow spillway	6.24	0.00	0.21
Withdrawals/irrigation	0.84	0.95	0.04
Change in water storage			
Initial storage	1.46	1.69	n/a
Reservoir end storage	1.69	1.23	0

The low amount of reservoir water demand (20% for Boura and 10% for Kandiga) for irrigation implies that they are designed to allow for the further development of water resources. In both cases, there is significant spillover, with the Kandiga reservoir spilling 56% of its total inflow compared to the relatively low irrigation demand of 11% of the total inflow [66]. Individually, SRs in the White and Black Volta Basins showed insignificant impacts on the total runoff and peak flows [33,34].

The potential cumulative impact of SRs was evaluated using the Water Evaluation and Planning System (WEAP) and satellite imagery [33]. The total water storage of 190 reservoirs in the Black Volta basin was 6.3 M m^3 compared to 12.7 B m^3 (B: billion) of water stored by the Bui dam alone. The overall inflow within the catchment was 65.5 B m^3 and the estimated runoff downstream was 55.6 B m^3. These statistics indicate that less than 1% of the water stored in the basin is actually stored in SRs. Therefore, at basin scale, their development has minimal impact on surface-water runoff and flows [33]. Furthermore, a simulation of the White Volta for 1971–2010 predicted that there could be a marginal reduction in the volume of flows from the White Volta River to the downstream of the basin due to increased SR development [34]. The total storage of 239 SRs was 4.2 M m^3, compared to 1.7 B m^3 total storage in the basin.

The hydrological impact of reservoirs in the White Volta basin was also assessed using different scenarios of increasing reservoir development and storage capacity [67]. The results highlight the cumulative effect of SR development: they decrease mean streamflow and increase the variability of streamflow [67]. The reductions in the mean annual streamflow were minimal for the lowest (1%) and medium level of small reservoir development (3%), having 500 and 1000 reservoirs, respectively (Table 8). However, a scenario which considered 5000 reservoirs recorded a relatively high impact of 14%—more than the effect of the large Bagré dam in Burkina Faso (4%). Seasonal hydrological alterations assessed through streamflow statistics show that the Bagré dam increased dry season flows by almost eight times against zero for small reservoirs [68]. This means that increased SR development is unlikely to cause significant hydrological alterations compared to large dams.

Table 8. Daily flow regime changes for different scenarios [67,68].

Scenario (No. of SRs)	Total Storage Capacity (10^6 m^3)	Mean Flow (m^3/s) *	Percentage of Flow Reduction (%)	Coefficient of Variation (CV)
S1 (500)	116	105.27	−1.39	2.05
S2 (1000)	232	103.78	−2.78	2.07
S3 (5000)	1160	92.23	−13.60	2.18
Post-Bagre dam	1700	102.39	−4.08	1.64

* Baseline flow was 106.75 m^3/s.

The area of the Volta Basin in Burkina Faso is estimated to receive 165 B m^3 of rainfall, with an annual runoff of 9 B m^3 yr^{-1} [69]. This amount of water is minimally impacted by the storage volumes of the dams, and particularly SRs, in the area, which together have a storage capacity of 4.6 B m^3. Leemhuis et al. [70] also report low impacts of SR development on the storage volume of Lake Volta. Climate variability poses a greater threat to storage loss in the lake. The total sum of the storage loss over the period was 6.1 B m^3 for the entire basin, and 1.1 B m^3 for the reservoir development in Ghana [70].

3.4. Impacts of Siltation on Small Reservoirs

3.4.1. Catchment Generation of Sediment Yield

The design life of SRs is a function of the siltation and sediment flows from their upstream landscapes. Various studies have estimated sediment yields between 0 and 1 t ha^{-1} yr^{-1} depending on the catchment size for West Africa [71]. Multiple studies confirm the range of sediment yields on SRs in Burkina Faso and Ghana [71–74]. The findings on sediment yields do not depict a distinct pattern. Sedimentation rates are likely to be the results of factors such as the agro-ecological zone, geomorphology, land cover, and land use in the catchment areas.

3.4.2. Sediment Deposition in Small Reservoirs

More studies on West Africa have indicated high rates of sediment deposition in SRs. In the UER of Ghana, for example, the annual siltation rates of four reservoirs were quantified as ranging from 19 to 157 t ha^{-1} yr^{-1}, using a bathymetric survey and reservoir soil sampling methods [75,76]. The results are compared with similar studies in Table 9, which documents the storage capacity losses of nine SRs ranging from 4 to 35% per year.

These high siltation rates have consequences for the storage capacity of SRs. In the four reservoir studies by Adwubi et al. [75], the dead storage, designed to store sediment over the design lives, had been fully exhausted. The values were also relatively high for the Dua (23%) and Kumpalgogo (33%) reservoirs, possibly due to the modification of the natural vegetation and the relatively small catchments areas of the two reservoirs (35 and 40 ha respectively) compared to the others, which ranged from 70–216 ha [75,77]. The projected capacity loss at 25 years shows that the reservoirs' storage capacities will be reduced by 91 and 58%, respectively. Meanwhile, the Bongo reservoir has lost 10% of its capacity due to continuous siltation over the past 55 years since its construction, while the 35% loss of the Afaka reservoir storage capacity happened over 26 years [78]. In Nigeria, the Akufo small reservoir was estimated to have lost 4–7% of its storage capacity since its construction in 2008, due to active agricultural activities upstream [79].

Table 9. Sediment deposition and storage capacity loss of reservoirs in West Africa.

Reservoir	Study	SC (10^3 m^3)	SSY (t ha^{-1} yr^{-1})	Current Capacity Lost (%)	Projected Capacity Lost * (%)	Reference
Doba	Upper East, Ghana	180	19	4	11	[75]
Dua		99	103	23	58	
Zebilla		452	27	5	15	[76]
Kumpalgogo		n/a	157	33	91	
Bongo	Upper East, Ghana	430	n/a	10	n/a	[44]
Fafo	Upper Volta Basin, Burkina Faso	480	n/a	15	n/a	[71]
Wahable		480	n/a	10	n/a	
Afaka	Kaduna, Nigeria	16.5	n/a	35	n/a	[78]
Akufo	Nigeria	110	41–82	4–7	n/a	[79]

SC = storage capacity; SSY= specific sediment yield; * reservoir design life is 25 years.

3.4.3. Nutrient Load in Small Reservoirs

SR sediments are reportedly high in nutrients [76,77,80]. The results of catchment soil and reservoir sediment sampling tests carried out in the Sudan savanna zone in the UER of Ghana are reported in Table 10 [76]. The catchment areas range from 35 to 216 ha and are fairly bare and vulnerable to erosion. The previously reported high rate of sedimentation is an indication of the upslope catchment effect on downstream reservoirs [76,77]. Enrichment ratios greater than one have been recorded, indicating that sediment deposits are rich in nutrients, clay and silt compared to the catchment topsoil [76,77]. The results also show relatively high nutrient export rates from the catchment. The export of organic carbon is higher than other nutrients, with an average of 0.76 kg ha^{-1} yr^{-1} [76].

Table 10. Enrichment ratios (ER) and rate of nutrient export (NE) and particles in reservoir sediments [76,77].

Reservoir	ER/NE	OC	N	P	K	Ca	Mg	Sand	Silt	Clay
Dua	ER	1.08	0.73	1.73	1.25	2.22	3.67	0.31	4.48	8.21
	NE (kg ha^{-1} yr^{-1})	0.61	0.06	0.00	0.03	0.22	0.05	-	-	-
Doba	ER	1.45	1.16	1.52	0.87	1.98	6.29	0.81	1.60	3.86
	NE (kg ha^{-1} yr^{-1})	0.27	0.02	0.00	0.01	0.03	0.01	-	-	-
Zebilla	ER	1.53	4.58	1.24	6.44	5.94	5.82	0.34	5.3	12.61
	NE (kg ha^{-1} yr^{-1})	0.37	0.07	0.00	0.01	0.11	0.02	-	-	-
Kumpalgogo	ER	2.96	2.13	1.96	0.31	1.31	1.98	0.34	4.54	4.32
	NE (kg ha^{-1} yr^{-1})	2.24	0.35	0.00	0.03	0.17	0.05	-	-	-
Bugri	ER	1.94	1.83	0.63	0.12	1.62	1.96	0.28	2.96	5.27
	NE (kg ha^{-1} yr^{-1})	0.29	0.03	0.00	0.00	0.03	0.01	-	-	-
Average	ER	1.79	2.09	1.42	1.80	2.61	3.94	0.42	3.85	6.85
	NE (kg ha^{-1} yr^{-1})	0.76	0.10	0.00	0.02	0.11	0.03	-	-	-
	CV of NE (%)	42.90	29.00	20.30	30.20	18.30	41.70	-	-	-

OC—organic carbon; N—total nitrogen; P—available phosphorus; K—potassium; Ca—calcium; Mg—magnesium; CV—coefficient of variation.

3.5. Water Quality and Health Impacts of Small Reservoirs

3.5.1. Water Quality of Small Reservoirs

There are only a few scattered case studies of water quality status in small reservoirs. Most irrigation water in northern Ghana, including in SRs, was found suitable for use and within the acceptable FAO threshold for irrigation water [81]. The concentrations of nitrates, phosphates and fecal content were below the FAO threshold (Table 11). Although the E. coli counts were generally low, a few sampling points had high contamination [81]. The Doma and Aiba reservoirs in Nigeria showed acceptable water quality with most of the physicochemical parameters within the desirable limits for aquatic organisms and fish production [60,82]. The results for the Oyun reservoir in Offa, Nigeria, were also acceptable in 2002–2003, except for high levels of nitrate and phosphate [61,83]. More recently, this reservoir has been found to pose health concerns with the presence of heavy metals such as nickel, lead, and mercury above the WHO limits [84].

The water quality of the Kubanni reservoir also showed high fecal coliform (between 2.0×10^1 and 1.6×10^6 MPN/100 mL), making the water unsuitable for domestic and irrigation purposes [85]. These are potentially linked to anthropogenic disturbances around the reservoir, mainly from the runoff of fertilizers, sewage transport, and perhaps the discharge of industrial effluent. In Burkina Faso, SR water quality was affected by the demography, land-use and land-cover changes over a period of time [32]. The study analyzed the concentration of suspended particulate matter (SPM) in SRs as a proxy for water quality, finding a significant correlation between SPM, population densities, and the expansion in croplands at the watershed scale. Diversified land use in watersheds reduced the fluxes of nutrients and contaminants compared to crop-specialized landscapes [32].

Invasive weeds such as *Ceratophyllum submersum* have been reported by Cecchi et al. to degrade SR water quality [86]. Agricultural practices, mainly the use of agrochemicals in the intensified agriculture system around the Boura reservoir in Burkina Faso, are responsible for the poor water quality. This has been widely noticed in the region. In a similar study at the Bama reservoir in Burkina Faso, the toxicity of two herbicides, diuron and atrazine, on macroinvertebrates, *Crenitis* sp (*Coleoptera*, *Hydrophylidae*) was documented, implying a toxic effect of these herbicides on water quality, particularly when they are combined [87].

Table 11. Mean values of water quality parameters of the selected reservoirs [60,81–83,85].

Parameters	Doma SR, Nigeria (Wet Season)	Aiba SR, Nigeria (Dry Season Wet Season)	Oyun (Large) Reservoir, Nigeria (Dry Season Wet Season)	Kubanni Reservoir, Nigeria (Dry Season Wet Season)	Irrigation Water, Ghana (Dry Season Wet Season)
Water temperature (°C)	28.15	29.25 ± 0.15 29.28 ± 0.43	23.1 ± 0.5 29.6 ± 0.1	22.52 [b] ± 1.86 28.04 [a] ± 0.56	n/a n/a
pH	7.09	8.32 ± 0.12 7.44 ± 0.19	8.2 ± 0.2 6.8 ± 0.01	6.54 [b] ± 0.04 6.70 [a] ± 0.04	6.0–8.0
Dissolved oxygen (mg O_2/L)	7.45	7.40 ± 0.24 6.95 ± 0.35	8.2 ± 0.31 4.8 ± 0.25	n/a n/a	n/a n/a
Total hardness (mg/L)	80.08	46.03 ± 1.30 43.71 ± 1.07	68 ± 1.4 32 ± 0.5	n/a n/a	n/a n/a
Turbidity (FTU/NTU)	30.53	49.79 ± 5.55 29.43 ± 2.93	n/a n/a	77.24 [b] ± 24.57 181.3 [a] ± 35.54	n/a n/a
EC (µS/cm)	n/a n/a	n/a n/a	n/a n/a	155.98 [a] ± 23.03 149.62 [a] ± 14.94	56.2–641
TDS (mg/L)	n/a n/a	n/a n/a	119.8 ± 2.0 53.9 ± 0.8	20.63 [a] ± 4.33 24.17 [a] ± 2.94	n/a n/a
Chloride (mg/L)	n/a n/a	n/a n/a	n/a n/a	27.73 [a] ± 4.75 24.74 [a] ± 2.46	6.0± 0.0 13.9± 0.0
$PO4^-P$ (mg/L)	n/a n/a	n/a n/a	2.2 ± 0.2 0.7 ± 0.0	0.15 [a] ± 0.03 0.17 [a] ± 0.02	0.07 ± 0.13 6.64 ± 5.45
$NO3^-N$ (mg/L)	n/a n/a	n/a n/a	6.4 ± 0.3 1.4 ± 0.1	1.67 [a] ± 0.22 1.75 [a] ± 0.15	0.50 ± 0.24 2.79 ± 1.62
FCC (MPN/100 mL)	n/a n/a	n/a n/a	n/a n/a	5.6×10^3 [a] $\pm 2.6 \times 10^3$ 1.4×10^3 [a] $\pm 7.3 \times 10^2$	2.0 ± 0.0 * 453.5 ± 472.0

FCC—fecal coliform counts; WT—water temperature; EC—electrical conductivity; NTU—nephelometric turbidity units; TDS—total dissolved solid; TSS—total suspended solids; $PO4^-P$—phosphate–phosphorus; $NO3^-N$—nitrate–nitrogen; ([a,b]) means are significantly different ($p < 0.05$), using Student's *t*-test.

3.5.2. Small Reservoirs and Human Health Concerns

Several water-related diseases are associated with SRs, including diarrhea, schistosomiasis, onchocerciasis and malaria [88]. The spread of malaria due to SR development has been reported by previous studies, for example, in the Yatenga reservoir, Burkina Faso, where a household survey around the reservoir reported a high percentage (80%) of malaria cases compared to other diseases [5]. A recent study carried out on both large and small dams in four African river basins, including the Volta, concluded that the malaria impact of dams is far greater than previously reported; while both small and large dams represent hotspots of transmission, small dams represent a higher risk than large dams due to lower water depth being conducive sites for mosquito breeding [89].

A compilation of the prevalence rate of schistosomiasis (bilharzia) in SRs and other irrigation schemes in the early 2000s is presented in Table 12. In the UER of Ghana, the construction of SRs increased the spread of the disease from 20% to 45% of the population, while in Mali the prevalence increased from 13% to 67% [90]. Elsewhere, the development of the Kuo Valley irrigation scheme in Burkina Faso in 1968 resulted in increased *S. haematobium* prevalence from 14% to 80% [90], while in the Valley of Sourou irrigation scheme, urinary and intestinal schistosomiasis increased from 5–10% to 60–80% of the population after the scheme development [91,92]. The distribution of the prevalence of urinary schistosomiasis in Burkina Faso indicates that villages with SRs have a high prevalence of the disease compared to those without [5]. Prevalence generally varies across different climatic zones, with the Sahelian zone (annual rainfall $\leq$ 500 mm yr^{-1}) recording a very high prevalence due to its high dependence on the few available SRs [5].

Table 12. Prevalence of schistosomiasis around SRs and irrigation schemes.

Study Area	Type of Infection	Prevalence (%)		Description	Reference
		Before Scheme	After Scheme		
Kou valley, Burkina Faso	*S. haematobium*	14	80	Before and after start of irrigation in 1968	[90]
SRs, Mali	*S. haematobium*	13	67	Based on national data, on small dams	[90]
Lagdo reservoir, Cameroon	*S. haematobium* *S. mansoni*	13 3	26 15	Prevalence before and after dam construction	[90]
Lagdo reservoir, northern Cameroon	*S. haematobium* *S. mansoni*	15	43 16	For the irrigation scheme, irrigated area 1000 ha	[92]
Lake Volta, Ghana	*S. haematobium*	1	70	Prevalence before and after the construction of Akosombo dam	[90]
Upper East, Ghana	*S. haematobium*	20	45	Based on number of districts with and without SRs	[90]
Valley of Sourou, Burkina Faso	urinary and intestinal schistosomiasis	5–10	60–80	Based on irrigation schemes of villages	[91,92]

The risk of schistosomiasis from SRs has also been studied in Nigeria. At the Opa reservoir, the risk of urinary schistosomiasis with four potential host species of snails was found, and the B. globosus type was identified with the human schistosoma cercariae [93]. Another study showed that the construction of SRs contributes to disease transmission: snail intermediate hosts of schistosomiasis were found in 20 reservoirs out of 47 surveyed. Of the 11 reservoirs investigated for human infection, 10 were positive, highlighting human health risk [94]. Urinary schistosomiasis infections around the Oyan reservoir in Nigeria continued from 1988 to at least 2008 [95]. The examination of the urine samples of 536 participants from five communities revealed that 45% of the participants tested positive for haematuria, while the presence of parasite eggs was found in 55% (293) of people. All the communities showed schistosome infection with a prevalence rate ranging from 20% to 84% [95]. In a later study of one community around the Oyan reservoir, the presence of both S. haematobium and S. intercalatum was confirmed in 79 of the 150 urine samples, and the overall prevalence was 52% [96].

The presence of *V. cholerae*, a cholera pathogen, is reported in SR in Burkina Faso, as shown in Table 13, with *V. cholerae* (non-O1/non-O139) present in 14 out of the 39 sites visited. The *V. cholerae* serogroups found (non-O1/non-O139) are known to be the causative agent for endemic cholera, and thus represent a health threat for the country [97]. Their levels are above the WHO drinking water limit of zero; hence, some treatment would be required for safe human consumption. Factors such as shallow depth, turbidity, and elevated phytoplankton biomass appear to be positively associated with the presence of the pathogens in water masses.

Table 13. The results of the measured parameters of some selected sites sampled between April and June 2014 [97].

Site/SR	Situation	Volume of SR (M m^3)	SPM (mg/L)	*V. cholera* (MPN/L)	*V. cholera* Positive Strains	TTC/100 mL
Loumbila	Rural	42.2	11.9	0	-	5.5
Bam	Urban	31.0	38.1	0.36	+	0
Tibin	Rural	0.0	167.6	0	+	100
Yantenga	urban	0.6	319.0	460	+	1000
Saaka reservoir	Rural	5.4	333.0	24	+	500
Boura	Rural	4.2	11.9	0	+	500

SPM—suspended particulate matter; *V. cholerae* positive strains—presence of identified strains; TTC—thermotolerant coliforms.

3.6. Small Reservoir Management

Small reservoirs are built and financed by different agencies and at different periods. Governments and financial institutions, including the International Fund for Agricultural Development (IFAD) and World Bank, have contributed to developing many SRs across West Africa [6]. Unlike large dams, which are often prioritized by governments, SRs lack regulation and legislation to ensure the safety of their use and longevity [98]. Once they are built, SRs are left to the local community, who, through local water committees or water user associations (WUAs), operate and maintain them [6,99,100]. These groups play a critical role in maintaining SRs; however, Andreini et al. [101] found that the partnerships between funding agencies, governments, and the local community groups who operate and manage small reservoirs needs to be improved.

Reservoir management affects performance and sustainability. The local committees or WUAs are solely responsible for the management of reservoirs after their establishment, but they are often ineffective and plagued with various challenges [2,102]. In Burkina Faso, for instance, local water committees have struggled with resolving conflicts over livestock water use and other issues [99]. It is widely accepted that local communities lack the financial and human resources to manage reservoirs; indeed, their presence or absence may have no significant impact on reservoir operations [3,101]. Improving WUAs' technical knowledge and providing sufficient funds are essential measures to promote the sustainability of reservoirs [102]. Emerging initiatives in the region may also consider co-investing in SR programs, such as the "One Million Cisterns for the Sahel" and the "Great Green Wall Initiative".

As Saruchera and Lautze [2] also conclude, to achieve higher performance and long-term sustainability, it is critically important for governments to implement long-term support programs. Furthermore, a legislative framework for managing SRs is required, just as other water sources are managed under the Integrated Water Resources Management (IWRM) policy and decentralization, with forceful and effective local level representatives [3,99]. An effective well-supported participatory management approach will increase the willingness, capacity, and ability of local members to operate and maintain such water sources [103].

4. Discussion

This review adds to the body of literature addressing sustainable agricultural and water management in rural development from the multiple perspectives of livelihood opportunities, water and food security, and environmental impacts. Other reviews have addressed rainwater harvesting and agricultural water management at field/plot scale [104–106], and other types of storage structures such as sand dams [107]. This review demonstrates that

SRs can provide multiple benefits in dry areas, with a marginal impact on basin hydrology under current and potential future climate conditions.

This conclusion is especially important because many arid and semi-arid regions with seasonal dry periods face multiple challenges: poverty, food and water insecurity, and few options for sustainable livelihoods. These conditions are being exacerbated by a combination of climate change, population growth and, all too often, degrading natural resources.

The findings show that SRs in the dry areas of West Africa provide multiple types of benefits to address water security, especially through improving food security during the dry season [16,17]. The studies have reported a positive impact of SRs on rural livelihoods and economies, making them vital water resources in high demand by local communities [41,48]. SRs also play a vital role for climate risk management in arid and semi-arid regions [12,15]. The inevitable threat to rainfed agriculture posed by climate and rainfall variability has again shifted the focus onto SR development as a climate-smart adaptation, especially in Mali, Burkina Faso and Ghana [18,108].

Small reservoirs remain a great asset to users, but they can be more efficiently utilized for irrigation [18,41] and for other uses, such as livestock production and aquaculture. This review suggests there is considerable scope to significantly improve economic returns, as well as water productivity, up to 100% in some cases (Table 3). These findings may be highly subjective, given that different groups value performance differently; notably, irrigation is only one aspect of SR performance. For example, local users often put more emphasis on multiple uses of SRs than extension officers [3] and, indeed, considering the value of multiple uses significantly improves the economic returns of SR investments [53]. Therefore, their performance must be assessed from multiple dimensions, taking into consideration different users and uses and the benefits derived from them. This may include indirect benefits which are difficult to quantify, e.g., social and environmental services. It is important to pursue integrated approaches to planning and management to enhance SR performance and long-term sustainability [41,99]; knowledge of their hydrological characteristics is also crucial [28,64].

Notwithstanding these benefits, the development of SRs may also come with unexpected long-term consequences. Their construction creates new ecosystems and results in the modification of the local environment, such as increased population density around the water system and increased risk of water-related diseases [5,89,109]. The prevalence of diseases such as malaria and schistosomiasis is high, though more recent data suggest reservoir management practices and effective health support have improved since the 1970s–1980s.

SRs may also cause hydrological changes such as a reduction in flow, higher evaporation, and increased siltation [28,110]. However, the evidence supporting this is weak, with most studies lacking real-time monitoring over a long period. For example, there is limited empirical data on the effect of siltation on the storage capacities and lifespan of SRs, suggesting that the scale of the problem needs to be comprehensively assessed [75,111]. Anthropogenic activities around SRs, primarily high nutrient pollution and pesticides from agrochemicals used in agriculture, can affect their efficiency and water quality [81,112]. Land-cover and land-use changes around SRs can impact reservoir water quality. Urgent actions are needed to protect these water resources, including educating users and engaging stakeholders to reduce the problem. Shifting the focus of SR development from the reservoir alone to the broader landscape can lead to more comprehensive interventions to manage watersheds and reduce anthropogenic pollution.

Whilst there is no evidence of the impacts of SR development on groundwater recharge, we hypothesize its effects are mildly positive, considering the results of Garg et al. [113] who, in a study in a dry area of India, monitored rainwater harvesting structures' effects on shallow aquifer recharge and observed increased water availability and crop production in recurring dry years. This is another gap in the current research.

Finally, local communities play an important role in SR performance, but their poor management limits reservoir productivity [3]. A participatory approach to resource management where all stakeholders are extensively involved in the planning and implementation of SR development can achieve sustainable SR use [3,102]. The role of traditional leaders, district assemblies, and existing local institutions in promoting SR operation and management is also important [102], and governments should implement longer-term support programs.

To realize the maximum benefit of SRs, their technical development needs to be combined with better governance and management strategies to address current and future challenges, including equity in benefits, upstream land management, and water quality and quantity monitoring, which are currently not in place.

5. Conclusions

This review has gathered evidence on how SRs impact both water quantity and quality at landscape and basin levels, and local communities and farmers. The benefits, such as income generation, food security, and improved livelihoods, provide strong support for scaling-up SR investments. Their impact on streamflow seems minimal compared to other large-scale water infrastructure developments. We found no literature on SRs' impacts on the recharge of groundwater, which is an important resource for dry season rural livelihood resilience.

Investments in SRs could help address the growing pressures on livelihoods due to climate change, rainfall variability, population growth, and high abstraction demands, which are undermining sustainable development efforts in many developing countries. The study has shown the important role of SRs in irrigated agriculture, livestock, and fisheries, improving livelihoods, and contributing to the national economy. Their multiple benefits highlight their contribution to reducing hunger and poverty.

Whilst the findings of this study provide useful insights, data limitations make it difficult to draw generic region-wide conclusions. The data analyzed are highly localized and have many gaps, for example, on the role of SRs in groundwater recharge. Most flow partitioning was performed based on modeling, with often limited calibration and validation of data for large streams. There is a great need for long-term monitoring of the long-term performance of small reservoirs. Overall, this review highlights the following for the utilization of SRs in the study region:

- Empirical data on SR performance are limited, and more studies are necessary to address the gaps in the evidence, particularly on the impact of SR development on groundwater recharge and the effect of siltation on the storage capacity and lifespan of the water infrastructure, among others;
- Real-time monitoring of SR water quality and quantity over a long period is needed, as well as rudimentary water treatment for human consumption. This is also necessary to support local community management and water allocation;
- The careful consideration of the technical needs of SRs, combined with better governance and management strategies, would maximize the benefits drawn from the development of these water infrastructures;
- Based on these findings, SRs, as distributed water infrastructures for rural development, have high potential to deliver multiple SDGs, compared to large water infrastructure investments;
- We propose that SRs can serve as effective nature-based solutions under climate adaptation, if designed and managed under evidence-based approaches, for the conditions of semi-arid and sub-humid West Africa.

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