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Tracing the inclusion of health as a component of the food-energy-water nexus in dam management in the Senegal River Basin

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ABSTRACT

Dam development improves water, food, and energy security but often with negative impacts on human health. The transmission of dam-related diseases persists in many dammed catchments despite treatment campaigns. On the Senegal River Basin, the transmission of *Schistosoma spp*. parasites has been elevated since the construction of dams in the late 1980's. We use narrative analysis and qualitative content analysis of archival documents from this setting to examine health as a component of the food-energy-water (FEW) nexus and understand priorities and trade-offs between sectors across the policy-to-practice continuum. We find that health is recognized as an important component of river basin development, but that priorities articulated at the policy level are not translated into management practices. Incorporating health as a management objective is possible without imposing substantial trade-offs to FEW resources. Coordinated research and surveillance across transboundary jurisdictions will be necessary to inform decision-making on how to operate dams in ways that mitigate their negative health impacts.

1. Introduction

Health impacts of large dam projects are long-recognized but poorly addressed in river basin development (Lerer and Scudder, 1999). Assessments of past projects suggest that measures of public health and livelihoods are not sufficiently included in dam management and operations (Lautze and Kirshen, 2007) and that negative health impacts diminish the intended benefits of dams (Ersado, 2005). Dams create conditions that facilitate disease transmission and increase the burden of dam-related diseases (Jobin, 1999). Accounting for these health impacts involves trade-offs and opportunities within the tightly linked food, energy, and water (FEW) sectors.

Abbreviations: EIA, environmental impact assessment; ESIA, environmental and social impact assessment; FEW, food energy water; FEW+H, food energy water and health; GEF, Global Environment Facility; HIA, health impact assessment; LMIC, low- and middle-income countries; OMVS, Senegal River Basin Development Organization; PASIE, Environmental Impact Mitigation and Planning Program; PGIRE, Integrated Management of Senegal River Basin Water Resources and of Multi-Use Development; QCA, qualitative content analysis; SDGs, Sustainable Development Goals; SDAGE, Master Plan for Water Development and Management; SRB, Senegal River Basin; SOE, Environmental Observatory; WHO, World Health Organization.

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Of the 3700 large hydropower projects planned or under construction, most are located in low- and middle-income countries (LMICs) (Zarfl et al., 2015) and overlap with much of the global burden of dam-related diseases (Jobin, 1999). The most common dam-related diseases (e.g., schistosomiasis and malaria) are treatable, but transmission often persist when environmental conditions promote reinfection after treatment (Garchitorena et al., 2017). The World Health Organization (WHO) formally recognizes the need to complement treatment or drug-based interventions for these diseases with additional measures to control vector populations and reduce the risk of repeat infection (WHO, 2021; World Health Assembly, 2012). Reducing this risk in dammed landscapes is essential for achieving sustainable and equitable disease control. The current pace of hydropower development in LMICs suggests that the need to manage the health impacts of dam development will continue to grow.

Given continued dam development, dam-related disease prevalence, and the history of transboundary basin management, the Senegal River Basin is an illustrative case of the need to manage dam-related diseases more effectively to reduce health burdens associated with dam development in LMICs. Since the 1970 s, the *Organisation pour la mise en valeur du fleuve Sénégal* (OMVS; in English, Senegal River Basin Development Organization), its member states (Senegal, Mali, Mauritania, and more recently, Guinea) and funding organizations pursued development on the Senegal River. Dams intended to improve food and energy security and promote economic development across the transboundary basin resulted in outbreaks of schistosomiasis and other dam-related diseases (Sow et al., 2002). Recognition of these impacts is documented in the administrative documents of OMVS and its funders, which are publicly available in an online archive (OMVS, 2017). We analyzed documents from this archive to investigate how trade-offs between food, energy, water, and health (FEW+H) sectors are framed, addressed, and put into practice in the Senegal River Basin (SRB).

Given the well-documented health impacts of dam development in the SRB, we analyze administrative documents from the OMVS archive to investigate why the burden of a dam-related disease, namely schistosomiasis, persists. Specifically, we examine trade-offs described in policy, assessment, and operations documents to understand how health is framed in basin management regimes and where opportunities exist for proactively addressing health through management of FEW resources. By comparing content in these three document types, we explore how ideals articulated in policy documents are accounted for in impact assessments and in turn reflected in operational guidelines. We also identify the extent to which inconsistencies exist between policy and practice in achieving balance between FEW+H priorities.

In Section 2, we develop an analytical framework that integrates health into the FEW literature and across dam development stages. In Section 3, we summarize the SRB context. In Section 4, we describe our methods, including the curation and coding of archival documents. In Section 5, we describe the role of health in OMVS programs since the 1990 s, and in Section 6, we analyze the FEW+H nexus in policy, environmental impact assessment (EIA), and operational documents from 1996 to 2016. In Sections 7 and 8, we discuss the contributions of our findings to scholarship and river basin management, concluding with areas for future work.

2. A framework for internalizing health in the FEW nexus in the Senegal River Basin

Incorporating health into the FEW nexus framework highlights opportunities for synergy between various human and environmental needs (Hopkins et al., 2020). The FEW nexus is a systems-based framework that emphasizes how outcomes in multiple sectors might be improved by identifying underlying cross-sector dependencies and enhancing cross-sector policy cohesion to reduce trade-offs and enhance synergies (Albrecht et al., 2018; Bazilian et al., 2014; Hoff, 2011; Pahl-Wostl, 2019). However, scholars argue that other sectors beyond FEW may be equally important to consider for sustainable development in the Anthropocene (Howells et al., 2013; International Water Management Institute, 2015a, 2015b; Karabulut et al., 2016; Lal et al., 2017). It may be practically challenging to incorporate new dimensions into already complex FEW systems, but worthwhile as relationships among FEW resources and health, the environment, poverty, education, social equality, and effective governance are a central emphasis of the Sustainable Development Goals (SDGs) (Rosa, 2017).

In addition to resource scarcity, poor or ineffective governance impedes resource security and sustainability (UNESCO World Water Assessment Program, 2003). Such governance challenges prompt the need for a "people-centric approach" to resource management (International Water Management Institute, 2015a, 2015b) that emphasizes resource access and utilization. Such processes are mediated by social, governance, and political dimensions of resource management (Jepson et al., 2017; Pritchard et al., 2013). To address these concerns, Biggs et al. (2015) link environmental security represented by the FEW nexus with sustainable *livelihoods*, or the "capabilities, assets… and activities required for a means of living" (Chambers and Conway, 1992, p. 6). Central to sustainable livelihoods is a strong asset base that includes natural, economic, physical, social, and human capital (DFID, 1999). Health is a key component of human capital (International Water Management Institute, 2015a, 2015b), with linkages to other capital assets. Healthy people have more capacity to contribute to economic productivity (Bleakley, 2010) and access and use resources than unhealthy people (Sen, 2010). In this framing, health becomes an internal component of the FEW system with linkages and dependencies with resource production and use (Biggs, 2015). As a component of livelihoods, health has two-way trade-offs with food and water sectors—(i) water supplies are necessary for clean drinking water, and crop irrigation; and (ii) health supports the ability to effectively utilize resources and maintain productive agricultural activities (Fig. 1) (Hawkes and Ruel, 2006).

Despite clear links between health and access to clean water, electricity, sanitation, and food – aspects mediated by multi-purpose hydroelectric dams – few studies have explicitly addressed health via a FEW nexus framework. Ding et al. (2019) consider health outcomes (e.g., malnutrition, diarrhea-related illness, and deaths attributable to air pollution) as the result of FEW resource availability. Mabhaudhi et al. (2016) assess water, agriculture, and health interactions through a nutritional water productivity index. Dam-related diseases have not yet been investigated as part of the FEW nexus framework, despite widespread evidence that their transmission is exacerbated by the conditions that dams create (Jobin, 1999; Kibret et al., 2021; Steinmann et al., 2006).

Global guidance for sustainable hydropower development has long identified public health as a key component of impact assessment and sustainable design, but health continues to be a side point, rather than a focal point, in the FEW nexus (Harris et al., 2015; International Hydropower Association, 2018; World Commission on Dams, 2000). Environmental impact assessments (EIA), environmental and social impact assessments (ESIA), and health impact assessments (HIA) are the primary assessment mechanisms for identifying cross-sectoral impacts, implementing project requirements set out by donors, and translating the SDGs into practice (Ahmed and Sánchez-Triana, 2008). While subject to decades of critique (Singh et al., 2020), impact assessments remain an important tool for understanding "the connection between the environment and livelihoods." (Li, 2008, p. 19). Health is often incorporated under the broader umbrella of EIAs. HIAs are increasingly applied to projects in sub-Saharan Africa but less frequently to holistically assess policies, programs, or strategies (Winkler et al., 2020). Despite critiques, impact assessments remain a critical decision-making tool by which to assess basin development tradeoffs. The range of impact assessments illustrates the relative weighting of development priorities, including health.

The World Commission on Dams (2000) suggested that dam

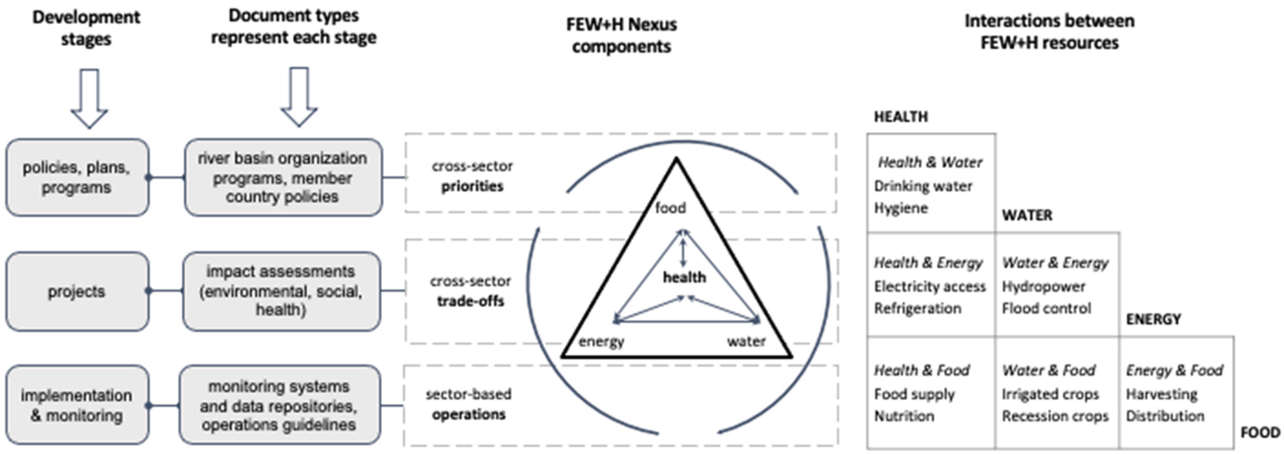

Fig. 1. Conceptual diagram. Links between stages of river basin development, an integrated food energy-water-health (FEW+H) nexus, and the interaction between FEW+H resources (adapted from Rossouw et al., 2000 and Biggs et al., 2015)

operations should reflect social and environmental issues, not solely resource production. Since the early 1990 s, studies of the SRB identified that dam operations could help control dam-related disease transmission. In addition to managing diseases post-hoc through treatment, rapid water fluctuations and reservoir draw-down can reduce transmission and prevent repeated reinfection with pathgoens such as schistosomes (Ofoezie and Asaolu, 1997). More recent modeling of dams in Ethiopia, Zambia, and Zimbabwe, suggests that management strategies can accommodate malaria control with minimal trade-offs for irrigation and hydropower production (Bianchi and Gianelli, 2017; Kibret et al., 2018; Reis et al., 2016). Shortcomings in vector-borne disease control programs (McMillan and Meltzer, 1996) suggest a role for sustainable river basin planning and dam operations in mitigating the health impacts of dam-related diseases.

We propose a FEW+H nexus that positions health as a livelihoods asset that is integral to FEW management, rather than health as an externality to be mitigated post-hoc. We use a FEW+H nexus framing that maps stages in river basin development to policy priorities, resource trade-offs identified in assessments, and operational guidelines that influence the ongoing management of health in the FEW nexus (Fig. 1). By examining stages of development iteratively and over time, we identify priorities across stages, develop cross-stage comparisons and build an understanding of how stated river basin management goals are translated into management practices.

3. Case: managing environmental and human health impacts in the Senegal River Basin

The Senegal River begins in northern Guinea and flows through western Mali before forming the border between Senegal and Mauritania in the West African Sahel. The Senegal River Basin is the second largest in West Africa, draining 300,000 square kilometers and serving a population of 3.5 million people (UNESCO World Water Assessment Program, 2003). In 1972, the governments of Senegal, Mali, and Mauritania formed OMVS to manage the river's resources, and Guinea joined in 2006.

Initial dam development took place in the 1980 s in response to prolonged drought in the region. The Diama and Manantali dams were intended to function as a pair: Diama as a saltwater barrier supporting agriculture in the lower valley and Manantali – upstream in western Mali – generating electricity for the capital cities of OMVS member states (Jobin, 1999). In addition to electricity generation, flow regulation at Manantali was intended to support irrigated agriculture and navigation for large tonnage vessels (African Development Bank, 1994). Since dam construction, electricity generation and intensification of agriculture have come at a substantial social and environmental cost.

Today, hydro-agricultural interventions make the SRB one of the most modified basins in the Sahel (Gajjar, 2007). Flow regulation at Manantali reduced the annual flood and flood recession agricultural practices (Saarnak, 2003; Varis and Fraboulet-Jussila, 2002), provoking ecological changes that facilitated the spread of invasive aquatic vegetation and dam-related disease (Gajjar, 2007). Within two years of construction, researchers documented increases in schistosomiasis transmission at Diama (Talla et al., 1990). Despite pre-development assessments anticipating the impacts of these dams on schistosome transmission (Gannett Fleming Corddry, 1981), its prevalence remains high today (Lund et al., 2021; Wood et al., 2019). Management policies and practices evolved in the SRB to reflect changes in strategies, integration of safeguards, and policies for integrated management, but dam-related diseases persist.

The hydropower component of Manantali was completed in the late 1990 s - years after the initial dam construction (Boinet, 2013; Merzoug, 2005). The hydropower project provided opportunities for the integration of international safeguard regimes into the project and generated new assessments. Even so, hydropower development at Manantali was criticized due to limited public participation in dam planning and implementation, lack of transparency regarding the artificial flood, and out-migration of the local population (Bosshard, 1999; DeGeorges and Reilly, 2006). Historical data on discharges suggest that there have been no artificial floods to support recession agriculture since 2003 (Raso et al., 2020). Together, these external assessments demonstrate a pattern of uneven development, with electricity generation prioritized at the expense of rural health and livelihoods.

4. Methods: document curation and analysis

To understand how health is framed in the management of the Senegal River Basin, we used a narrative analysis of the basin's institutional development and qualitative content analysis (QCA) of documents representing the three stages of river basin development in the SRB (Fig. 1). Program details (funders, dates) and priorities were identified and cataloged (Table 1) to provide a narrative context to support QCA. The narrative analysis was conducted iteratively as new programs were discussed in reports or in the documents used for QCA (Fig. 2) and ultimately used 19 documents (Table A1).

Building on similar analyses of health in EIAs (Riley et al., 2020) and FEW policy (Venghaus and Hake, 2018), our QCA examined FEW+H sectors in policy, EIA, and operational documents from SRB management programs (Fig. 2). Documents selected for QCA (n = 15) addressed environmental and health issues across the entire transboundary basin (rather than sub-basins or in single member states) from 1996 to 2016. This represents the period after hydropower electricity production

Table 1
OMVS programs developed to manage impacts of dam development in the Senegal River Basin.

Program[a]	Years	Purpose	Funder[b]	Ref[c]
PASIE	1998–2004	To monitor and mitigate environmental impacts from energy development and distribution from Manantali.	AFD, WBAfDB, CIDA	13, 16, 22
SRB Water & Environmental Management project	2003–2008	To build capacity for environmental management at regional, national, and local levels; data management in member countries; environmental analysis and strategic action planning; community and local land and water conservation; and public participation in water resources management.	GEF, WB, UNDP, GoN	20, 24
MWRD	2006–2013	Adaptable loan program focused on fisheries, irrigation, health, and water resource management in Guinea, Mali, Mauritania, and Senegal with OMVS.	WB	25
PGIRE Phase 1	2007–2013	Three components: (1) development of water resources at regional level, (2) integrated development of water resources at local level, (3) development of an integrated and multisectoral regional plan.	WB, AFD, EU	23
SDAGE Phase 1	2009	Developed as a part of PGIRE Phase 1 to help chart how OMVS will achieve the Millennium Development Goals by 2025.	WB	31
SDAGE Phase 2	2010	Developed regional sectoral plans.	WB	
SDAGE Phase 3	2011	Developed a master plan for the basin through 2025.	WB	34
PGIRE Phase 2	2014–2021	Aims to jointly increase productive uses of water, enable macroeconomic growth, and safeguard the health and livelihoods of vulnerable communities.	WB, GoN	35

[a] Program name abbreviations: PASIE = Environmental Impact Mitigation and Planning Program; MWRD = Senegal River Basin Multi-Purpose Water Resources Development Project; PGIRE = Integrated Management of Senegal River Basin Water Resources and of Multi-Use Development; SDAGE = Master Plan for Water Development and Management

[b] Funding agency abbreviations: AFD = French Development Agency, AfDB = African Development Bank, CIDA = Canadian International Development Agency, EU = European Union, GEF = Global Environment Facility, GoN = Government of the Netherlands, UNDP = United Nations Development Program, WB = World Bank

[c] Reference numbers correspond to documents listed in Table A1.

started at Manantali, when the negative impacts of Diama and Manantali began to be addressed and planning started for second-generation dams in the upper basin. We reviewed the tables of contents of QCA documents to identify sections addressing recommendations, trade-offs, or priorities. The resulting 959 paragraph-length excerpts for QCA were collated in a shared spreadsheet with the document type (policy, EIA, operations) and other metadata.

Documents for narrative analysis and QCA were obtained from the OMVS archive (OMVS, 2017) and supplemented with documents from funding and consulting agencies and peer-reviewed literature (Fig. 2; Table A1). All documents are listed chronologically in Table A1 with bibliographic and classification details. In Sections 5 and 6, we support findings in both analyses with reference to document numbers outlined in Table A1.

We developed a coding scheme deductively based on the concepts we expected to encounter in documents but revised this scheme iteratively (MacQueen et al., 1998). Coding categories focused on trade-offs, links between FEW+H sectors, strategies used by different actors, and the laws or regulations governing basin activities (Table B1). Excerpts were divided among five members of the team for coding (Appendix C). Interviews were conducted with environmental health and hydrologic engineering staff (n = 3) at the Manantali dam in July 2019 and were used to validate and contextualize findings from both arms of analysis but did not comprise our primary source of data nor form the core of our analysis. (Fig. 2; Appendix D). Interviews were transcribed, translated (from French to English), and reviewed based on the coding categories used in the QCA. We identified evidence from interviews to help us better characterize trade-offs in FEW+H (see Section 6.1). The interview study received approval from the Institutional Review Board of Stanford University (Protocol #34158).

Our analysis addressed three questions across the policy-to-practice continuum (Fig. 2). First, how are FEW+H trade-offs framed in SRB documents? We used institutional background documents and QCA excerpts that expressed goals to examine the framing of cross-sector priorities. This analysis focused on policy documents in comparison to EIA and operations documents to understand whether priorities remain consistent across stages of development. We hypothesized that health impacts would be framed as externalities of FEW resource development. Second, to what degree are health outcomes addressed? We examined coded excerpts across document types that conveyed health as a goal or priority, and whether health was discussed in the context of other FEW resources or separately. We hypothesized that discourse on health outcomes would be broad in scope in policy and impact assessments, with minimal discussion in operational documents. Third, what strategies are referenced to operationalize FEW+H considerations in practice? We used excerpts discussing strategies to understand how FEW+H resources are operationalized. We hypothesized that discussions of operations would focus primarily on energy-water and water-food trade-offs, neglecting health outcomes.

Transboundary water resource management and nexus approaches have been criticized for being overly technical, with emphasis on efficiency and economic outcomes and insufficient attention to the political underpinnings and power relationships among riparian nations that influence decision-making and implementation of basin-wide efforts (Allouche et al., 2015; Zeitoun and Mirumachi, 2008). We recognize that while we documented institutional development and coded for institutional change and capacity in the QCA, our analysis is limited by how accurately our texts reflect such institutional dimensions or account for significant political and institutional barriers critical of any FEW+H approach. We were careful and deliberate with document and excerpt selection, but our analysis is limited by the documents we were able to access for our narrative and content analyses. We also assumed that these documents reflected institutional priorities and thereby allow us to draw meaningful conclusions based on language included in documents. Finally, we operated under the assumption that the three document categories (policy, impact assessment and operational) we used to

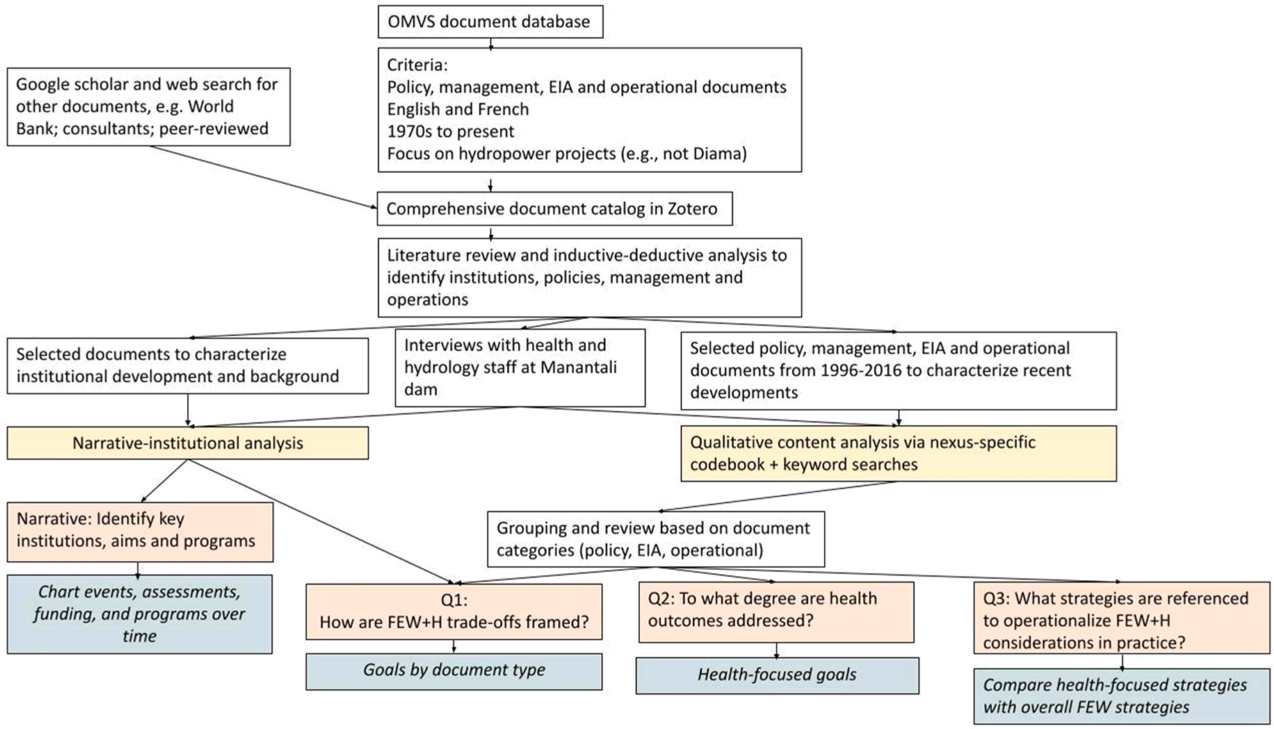

Fig. 2. Methods flowchart. Processes used to identify, select and analyze documents from the OMVS archive and other key sources (based on discourse analysis framework from Chaudhary et al., 2015).

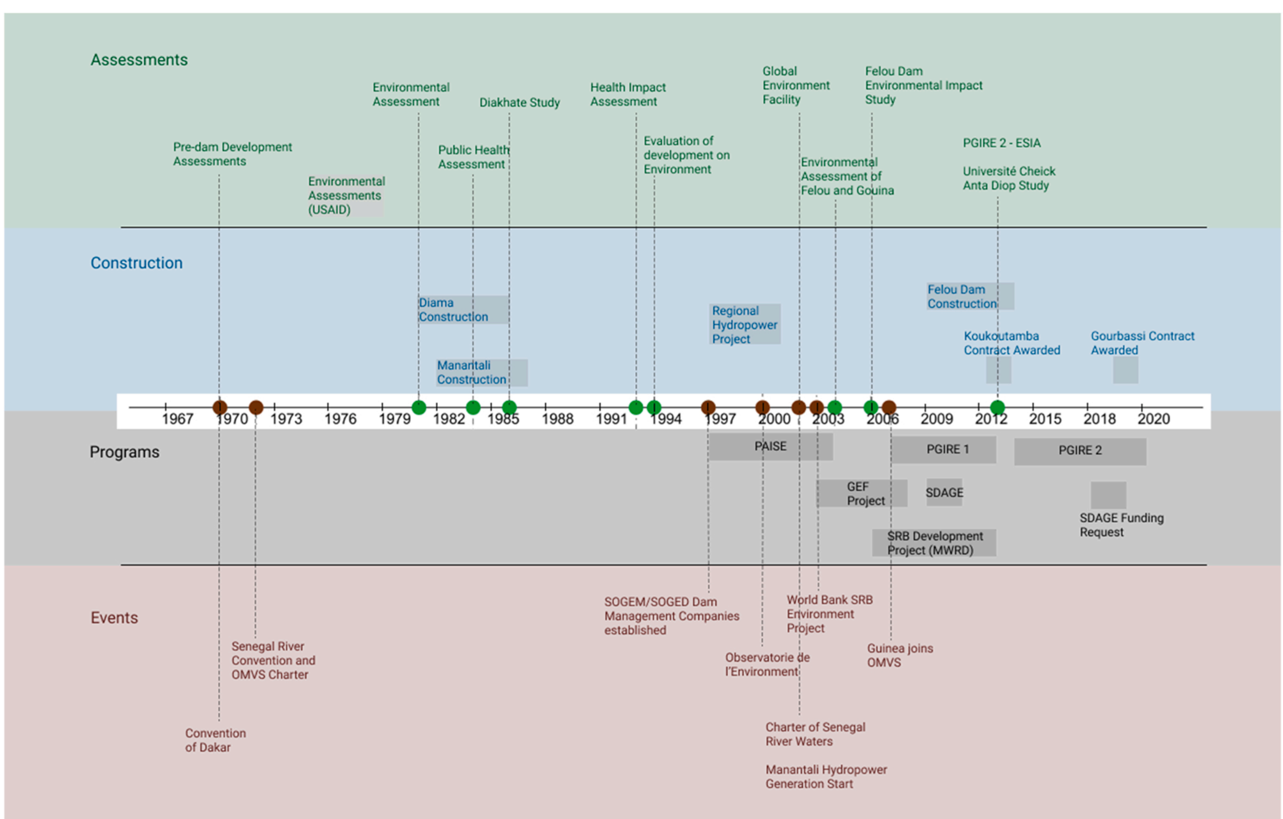

Fig. 3. Timeline of development on the Senegal River. Illustration of the overlap between environmental management programs (gray), construction activities (blue) as well as key assessments (green) and events of interest (red) in the governance of the Senegal River Basin.

organize our analysis accurately reflect the policy-to-practice continuum in the SRB.

5. Narrative analysis: tracing environmental management programs in the Senegal River Basin

Changes in environmental management programs in the SRB over the course of OMVS' history demonstrate a growing effort at the basin-level to understand and manage the environmental impacts of Diama, Manantali, and future dam development (Fig. 3). The emphasis on large-scale, rather than smallholder, agriculture was recognized as a failure of early integrated water resource planning efforts. Poor accounting for human factors (e.g., livelihoods, culture) led to uneven distribution of costs and benefits (Table A1, document 18). The negative health, social, and environmental impacts reflect the significant costs of development, and, if properly accounted for, likely would have reduced the financial attractiveness of the investment (Table A1, document 28). As a result, evaluating impacts became central to contemporary management programs (Table 1). Crucial to this evaluation was the capacity of local and national actors to cooperate in the implementation of basin-wide monitoring activities.

Environmental management programs in the basin started in the 1990 s, but assessment activities preceded dam construction at Diama and Manantali (Fig. 3). As early as 1970, a WHO assessment outlined pre-dam conditions, including baseline prevalence of several diseases (Table A1, document 1). Pre-construction EIAs funded by USAID attempted to balance economic development with environmental protection (Table A1, document 2). However, early assessments did little to shift basin development plans despite documenting anticipated health impacts. Construction at Diama and Manantali proceeded under the rationale that economic development would outweigh the anticipated, and later realized, health impacts (Table A1, document 6).

EIAs conducted in the 1980 s included health dimensions, but it was not until the early 1990 s that health assessments began to focus on the link between dam development and increases in dam-related diseases. Health impacts in EIAs were often studied independently of environmental concerns (Fig. 3). A 1993 health assessment highlighted health outcomes linked to the construction and operation of Manantali and the opportunity for OMVS "to adapt operational methods for control of insects and snails to local conditions" (Table A1, document 3, p. 2). While there was the flexibility to enact such measures in the early years of electricity generation, recent studies suggest these opportunities were overlooked (Table A1, document 32).

As deviations from pre-dam flow regimes increased, management plans did not incorporate the suggested means of controlling disease vectors through flow maintenance in irrigation canals and fluctuations of reservoir water levels (Table A1 document 3). Programs were designed to facilitate integrated mitigation of health and environmental impacts, but they ultimately failed to consider the longstanding recommendations of integrating health into river basin operations and management. Assessments of the health impacts of Diama and Manantali were available before construction but did not change the development trajectory (Fig. 3).

Health impacts were recognized by OMVS in the late-1980 s and prompted formal efforts to enhance OMVS' capacity to monitor and mitigate health impacts, which were initiated a decade later. The *Programme d'Atténuation et Suivi des Impacts sur l'Environnement* (PASIE) began with hydropower development at Manantali in 1998 (Table A1, document 13). PASIE's hydropower-focused activities aligned with new World Bank investment in the basin, as the World Bank had previously withdrawn support due to disagreements over the rationale and the anticipated impact of the first-generation dams. PASIE marked the start of a concerted effort to address impacts in the SRB (Table 1). At this point, the World Bank's Independent Evaluation Group recognized the complexity of the transboundary project and prioritized regional rather than project-based EIAs, including coordinated monitoring and evaluation across OMVS member states (Table A1, document 16, p. xii). Capacity and coordination were central to evaluating the scope of the health problems and outlining measures to address them.

Since PASIE in the 1990 s, OMVS developed a series of monitoring and mitigation programs with support from a range of international donors. These programs developed strategic frameworks in the early 2000 s (see GEF, Table 1; Table A1, document 20) and emphasized trade-offs across sectors (see MWRD, Table 1). After hydropower development at Manantali, OMVS balanced "critical power and telecommunications capabilities… [that] also interrupted the annual cycle of river flooding depriving many farmers of access to water necessary to grow crops" (Table A1, document 25). These trade-offs between FEW resources remain part of OMVS' programs, planning, and management, but programs from the mid-2000 s incorporated health and regional economic development priorities as well. The inclusion of health and economic development as priorities in these later programs suggests a recognition within OMVS and international organizations that basin development programs needed to support ecological and human health (Table 1).

The influence of PASIE on OMVS' commitments to address human and environmental health impacts was apparent in the planning for second-generation dams at Félou and Gouina. These second-generation dams continued to focus on electricity generation but benefitted from more coordinated efforts to assess and plan for development impacts. In part, development at Félou and Gouina included ESIAs and management plans, as required by the World Bank Safeguard Policies that were put into place in 2006 (Table A1, documents 14 and 15). A third generation of dams is now underway, with contracts awarded for Koukoutamba (2019) and Gourbassi (2020). Continued development is anticipated to heighten conflicts between hydropower and traditional agricultural water use (Table A1, document 32). Additional programs - namely the *Projet de Gestion Intégrée des Ressources en Eau* (PGIRE) and *Schéma Directeur d'Aménagement et de Gestion des Eaux* (SDAGE) - built on the work that began with PASIE and focused on the integrated management and planning of water resources across the transboundary basin. Trade-offs between hydropower and agriculture remain central to regional development, but now with more resources and capacity to assess impacts.

6. Qualitative content analysis of policy, assessment, and operations documents

6.1. Framing of FEW+H trade-offs

Our content analysis explored the goals and priorities described across policy, EIA, and operations documents from the SRB starting in the 1990 s. This period followed the concerted effort of PASIE to include health and economic development alongside agriculture and hydropower priorities in the basin. Despite a growing number of programs in the SRB that focused on integration across sectors (e.g., PGIRE and SDAGE; Table 1; Fig. 3), we found that some goals identified in documents aligned closely with sectoral targets (e.g., "produce energy", "expand/maintain agriculture", "improve health"), while others crossed sectors (e.g., "fill knowledge gaps", "restore/protect environment") (Fig. 4). The distribution of goals and responsibilities reflected a siloed approach to basin management, overlooking clear opportunities to achieve integrated water management (via PGIRE) and long-term basin planning (via SDAGE).

Excerpts cited goals related to FEW resources more frequently than socio-economic, environmental, or health indicators. In practice (e.g., in operational documents), trade-offs across FEW sectors were more common than in other stages of development (e.g., policy or assessment documents) (Fig. 4). Operational documents emphasized water management as a means of achieving agricultural and electricity production targets. Hydroelectric management was described in terms of maximizing energy production while also providing for irrigation needs and

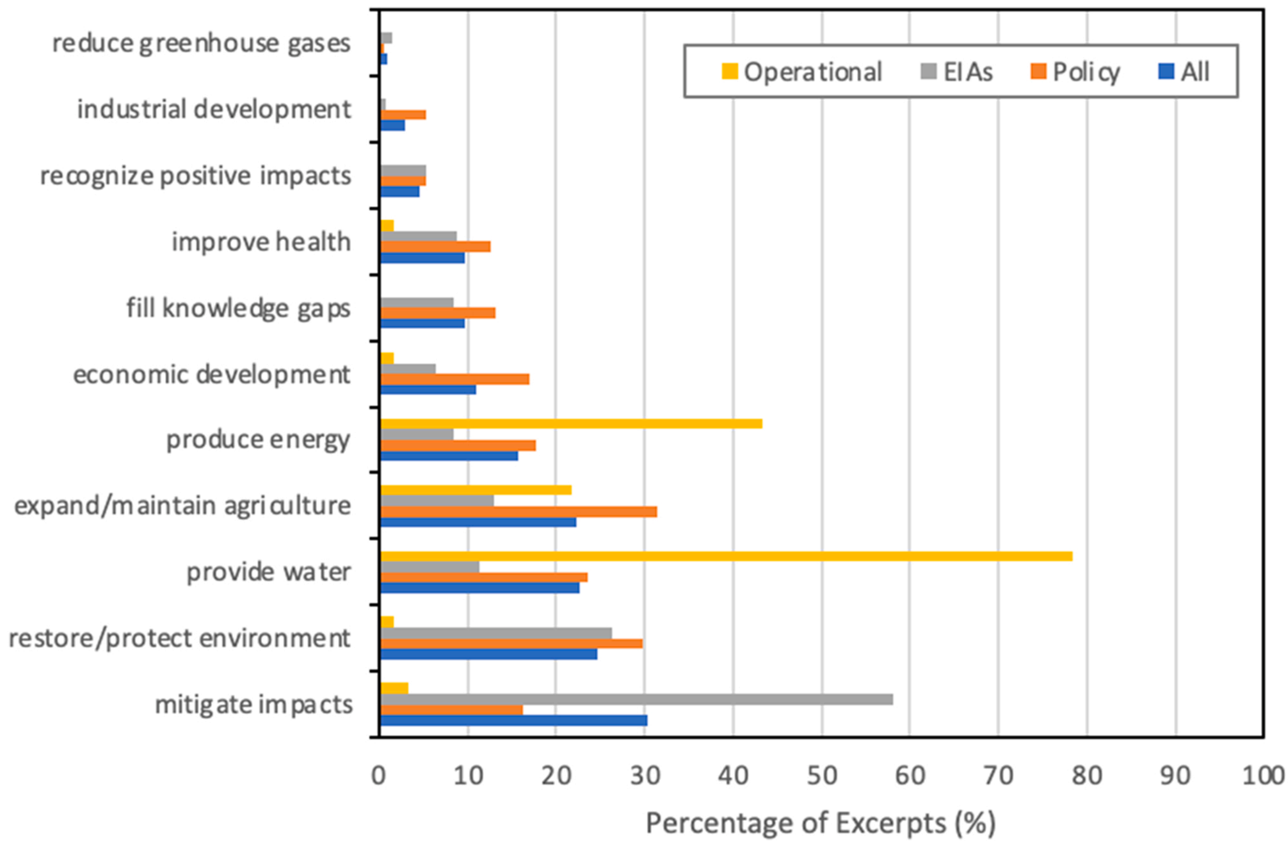

Fig. 4. Coded goals by document type. Percentages of non-null coded excerpts assigned to operational (yellow), EIA (gray), policy (orange), and all (blue) documents. Excerpts may be coded with multiple goals; category totals may exceed 100%.

navigation. Stakeholder interviews also suggested that trade-offs favored energy more than food or water, with a hydrologic engineer at Manantali initially stating, "irrigation is the priority," but later emphasizing "everything depends on hydroelectricity." Together, our data point to the primacy of hydroelectric and agricultural goals in practice, despite the recognized importance of mitigating health at the project and policy levels.

The goals articulated at the policy level were more varied than other stages of development, but emphasized agriculture, environmental protection, and water provision (Fig. 4). Policy documents accounted for broader influences on basin activities, such as the 1970 s drought and the ecological changes that followed construction at Diama and Manantali (Table A1, document 12). Aligned with longer-term basin planning efforts (e.g., SDAGE), policy documents identified environmental protection, economic development, regional and cross-boundary challenges as high-level priorities, and suggested modes of assessing decisions and investments via indicators, use scenarios, and references to modeling efforts (e.g., economic simulations).

The SRB environmental programs (e.g., PASIE, PGIRE and SDAGE) evolved to emphasize the management of health and environmental outcomes within economic development goals related to energy and agriculture, but not all trade-offs were weighted equally. Few health-related excerpts discuss mitigation strategies, a sign that health considerations were outside of the scope of policy, assessment, and operations of the interconnected FEW systems in the SRB. At the policy level, food sector goals associated with agriculture and irrigation were articulated more often than energy, water, or health, although general environmental protection goals were a close second (Fig. 4). Operational documents emphasized co-management of energy and water in management practices, while project specific EIAs expressed a broad range of goals across FEW+H sectors and were more evenly distributed than for policy or practice.

Even for programs that explicitly intended to mitigate health impacts, OMVS policies and programs enacted since the 1990 s continued to focus on piecemeal components of the FEW+H nexus. Stakeholder interviews supported this finding, where OMVS was described as responsible for "environmental impact mitigation," including treating affected communities for dam-related diseases like schistosomiasis. OMVS recognized the interconnectedness of FEW+H resources, but in practice, management and operations remain siloed, with some stakeholders focused on dam operations and others focused on impact mitigation.

Health is included in SRB policies, but not linked to Manantali operations. The negative health impacts of dam development were acknowledged in policy documents for all three basin-level programs (e.g., PASIE, PGIRE and SDAGE), but these documents seldom discussed the need to mitigate the transmission of dam-related diseases. The health impacts of dams were described in one SDAGE document as a "major obstacle to human and socioeconomic development" (Table A1, document 23, p. 9), with efforts to mitigate the spread of disease centered on drug distribution and the provision of water and sanitation infrastructure (rather than a change in ecological conditions related to transmission). In policy documents, support from OMVS was "essential for [the] implementation" (Table A1, document 25, p. 14) of efforts to mitigate local health impacts. OMVS brought national health services under its authority by "reinvigorating the national schistosomiasis control programs, via the basin level program" (Table A1, document 25, p. 18). In doing so, OMVS aimed to reduce the prevalence of heavy infections through treatment and education (Table A1, document 25, p. 34), measures that are necessary but often not sufficient to interrupt transmission without complementaryy interventions that address the source of infection in the environment.

Epidemiological surveillance was also portrayed as crucial to mitigating the health impacts of dam development. In the late 1990 s, rapid assessments completed as part of the PASIE program included health as a part of the economic value of artificial floods (Table A1, document 7, p. 14). Health was also incorporated into baseline surveys for PGIRE, with plans to continue regular and long-term monitoring and evaluation (Table A1, document 26, p. 25). An SDAGE policy document highlighted the role of GEF funding (see Table 1) in continued financing of the Environmental Observatory (*Observatoire de l'Environnement,* abbreviated SOE), a data observatory established as a part of PASIE in 2000 to monitor environmental change in the basin and support evidence-based decision-making to mitigate the negative impacts of dam development. The same GEF funding also supported efforts to address aquatic invasive plants, land degradation, water-borne diseases, and drinking water (Table A1, document 20, p. 21). Efforts to build and coordinate basin-wide data collection on environmental and health impacts provide a basis for evidence-based health, environmental, and social impact assessments, an effort that emerged decades after construction at Diama and Manantali.

Health was not frequently referenced in practice-focused operational documents and in policy documents, the health focus centered on the impact mitigation efforts in the PGIRE program (Fig. 4). PGIRE was the

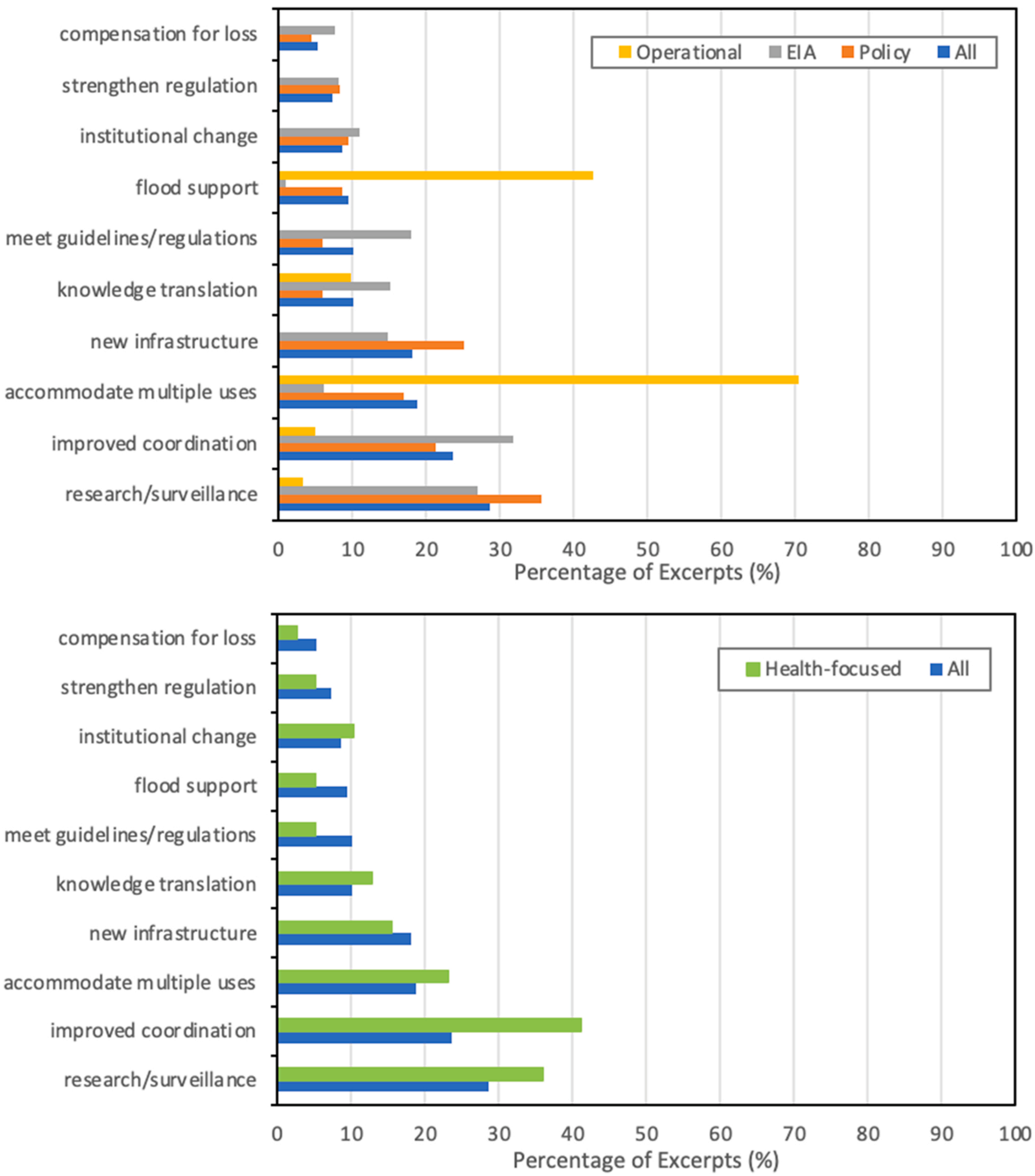

Fig. 5. Strategies referenced in qualitative content analysis. Strategies discussed by document type (top) and in excerpts that focus on improving public health (bottom). Values are percentages of non-null coded excerpts. Excerpts may be coded with multiple strategies; category totals may exceed 100%.

only program of the three with EIA documents that discussed health as a priority, but the EIAs for PGIRE emphasized the short-term rather than long-term health impacts of construction projects. For example, site-specific plans included mitigation plans for the respiratory impacts of air pollution and increases in sexually transmitted infections from demographic changes (Table A1, document 26). While short-term construction impacts are important, including only these health priorities overlooks the longer-term impacts of environmental change caused by dam development that, for decades, has been associated with the transmission of dam-related diseases like schistosomiasis. From this analysis, we demonstrate that policy discussions include health but do not result in coordinated collection and synthesis of data to support decision-making that translates policy, in particular health-related policy goals, into practice.

6.2. Operationalizing FEW+H priorities through sectoral and cross-sectoral management

References to research and surveillance activities reflect the nature of planning, construction, and operation of river basin infrastructure projects. "Research/surveillance" and "improved coordination" were the most frequently coded strategies (Fig. 5). Scientific studies, reconnaissance studies, feasibility studies, and environmental and social impact assessments are conducted to inform project design and planning. Monitoring and surveillance activities include environmental and epidemiological monitoring to collect baseline data, document change over time, or evaluate impacts. Other types of research that directly inform resource management in the SRB included scenario analysis, cost-benefit analysis, optimizing dam operations, and maximizing water and energy provision. The data generated from such studies form the basis for decision-making across FEW sectors related to health, environmental, and social impacts.

"Improved coordination" referred to efforts to improve cohesion among policymaking, program administration, and project implementation across programs, projects, and governance levels (e.g., local to national, national to basin). Coordination efforts included integrating national activities into regional programs (Table A1, document 12), integrating community monitoring programs into EIA projects (Table A1, document 15), and leveraging institutional capacity across levels to coordinate broad epidemiological monitoring (Table A1, document 26). Improved coordination - both vertically (e.g., across local, national, and basin-wide levels) and horizontally (e.g., among programs or sectors) - was recognized in policy priorities and project goals (Fig. 5).

By promoting vertical coordination, OMVS' basin-level capacity bolstered insufficient institutional capacity at local and national levels. In 2013, PGIRE promoted "a basin wide institutional framework including both top-down and bottom-up planning and control instruments" (Table A1, document 25, p. 6) and coordination among regional, national, and community level institutions (Table A1, document 25, p. 13). PGIRE recommended that regional staff at OMVS supervise contractors because national capacity (e.g., funding, staffing) to do this was insufficient (Table A1, document 25, p. 9).

In addition to coordinating vertically between governance levels, programs aimed to improve cohesion of OMVS' goals and programs. In particular, there was a strong need to harmonize data collection methods to better facilitate horizontal data sharing across member states or divisions within OMVS (Table A1, documents 12, 23 and 26). In the early 2000 s, the SOE aided in coordinating data for monitoring and decision-making across governmental and non-governmental organizations across the basin (Table A1, document 27). Horizontal coordination with an emphasis on data sharing demonstrates the complexity of supporting other critical components of basin-wide research and surveillance activities central to basin management and project-specific assessments.

The emphasis on research, surveillance, and coordination across policy, project-level EIA assessments, and operations documents demonstrates the importance of these strategies to strategic discourse on basin management but identifies a gap in linking these areas to the practice of dam operations. In Fig. 5 (top), the emphasis of research/surveillance and coordination in EIAs and policy documents is indicated by higher counts, while there are far fewer references to these areas in operations documents. In addition to research/surveillance and coordination, policy documents also emphasized the construction of new infrastructure (e.g., canals, diversions, access roads) and addressing multiple uses of water. Project-specific EIAs emphasized additional strategies, including compliance with guidelines and regulations, which reflects the role of assessments in project planning and evaluation. In contrast, practice-oriented operational documents focused almost exclusively on technical aspects of FEW+H management, underscoring the need to accommodate multiple uses of water through dam operations – balancing hydropower production with flood support and protection. Notably, the strategies that were commonly articulated in EIA and policy documents were seldom mentioned in operational documents, demonstrating a disconnect between the discourse occurring at the policy, program, and project levels of development and how priorities are then operationalized in practice.

Focusing only on coded excerpts that mention health as a goal (7%, or 67/959 excerpts), research/surveillance and improved coordination were, again, commonly identified strategies (Fig. 5, bottom). This pattern suggested a need for coordinated and coherent data to document the ecological and social mechanisms that lead to increases in dam-related disease burdens. Mechanistic approaches that emphasize understanding ecological processes to determine how or why a disease is occurring can facilitate the translation of integrated assessments into action through resource management and dam operations. We noted a tendency for documents to emphasize management and governance rather than infrastructure design or modification. In the 1990 s, with the start of PASIE, OMVS recognized the need for an integrated, region-wide plan to address dam-related diseases through improved diagnosis and treatment. Along with this need for coordinated planning was a need for a central repository to harmonize and store regional environmental and health data. The SOE was an important demonstration of OMVS' effort to support coordination in monitoring and evaluation activities as a means to proactively address the health impacts within the FEW nexus.

Starting with PASIE, programs continued to recommend basin-wide coordination on scientific studies to ensure cohesive results (e.g., using the same modeling software to promote sharing of results), joint development of Health Action Programs, and harmonization of national health program goals and strategies to better support basin-wide outcomes. Following PASIE (see Table 1), the MWRD Project was a flagship project that "integrate[d] waterborne disease management into water resources management projects" (Table A1, document 25, p. 7), yet the need for improved monitoring of dam-related diseases persists. With the PGIRE program in the mid-2000 s, basin-wide coordination helped expand and strengthen weak national health programs in member states and enabled cost-savings through the regional distribution of medication and bed nets.

7. Discussion

Based on our narrative and qualitative content analysis of environmental programs in the SRB, we find mixed evidence for our hypotheses. First, while dam development has long been recognized as a source of increased disease transmission, it is unevenly accounted for across stages of development, with emphasis on health in high-level policy priorities but limited translation of health priorities into the management of FEW resources. So, while our evidence supports health as a growing priority in the SRB, it continued to be treated as an effect to be mitigated externally to the FEW system. Second, health-focused excerpts were a small proportion of the coded data, and operational documents – representing the link to implementation and practice – seldom referenced health. Third, strategies that operationalize the FEW+H nexus focused on knowledge production and governance, necessary precursors to effectively managing infrastructure and/or modifying operations to equitably maximize the benefits of dam development. This ongoing emphasis on knowledge production and governance suggests that transboundary management of the SRB is still building the needed intuitional capacity (vertically and horizontally) to support stronger integration of health into FEW management. Our findings underscore that integrating health into FEW management can facilitate progress across multiple SDGs simultaneously. The SRB, as a case of dam development and management across LMICs, demonstrates the ongoing burden of dam-related disease that threatens sustainable development and identifies the critical need to consider managing disease transmission as an integral component of more established FEW management.

7.1. Addressing health proactively through FEW+H coherence

The environmental conditions created by dams ensure prolonged and elevated exposure to dam-related diseases. Health sector interventions mitigate these impacts but often focus on treatment rather than prevention of infection. Such interventions treat health outcomes as external to FEW resource management and limit the implementation of sustainable and practical solutions. Operating dams for disease control can potentially suppress vector populations, reducing transmission and the risk of repeat infection. Modeled fluctuations of reservoir levels suggest opportunities to meet health goals without imposing significant trade-offs with hydroelectric generation (Reis et al., 2016, 2011). Monitoring and surveillance of environmental and health impacts could inform the development of new guidelines that internalize health in dam management. Such guidelines could lead to quantifiable benefits in reduced disease transmission for riparian populations. Prior scholarship calls for nexus approaches in transboundary contexts that promote new strategies and alter the status quo (Keskinen et al., 2016). The integration of health into dam operations represents an opportunity to alter status quo practices in the SRB as well as other dammed rivers in LMICs.

A nexus approach can help achieve multiple SDGs simultaneously by minimizing trade-offs and cross-sectoral impacts (Hoff, 2011), but realizing these broader impacts requires including sectors outside the traditional nexus boundaries (Pittock et al., 2013). Our findings suggest that FEW nexus scholarship can further promote approaches to SDG targets that challenge the status-quo by integrating FEW+H management. Including health in stages from policy to operations can proactively improve health (SDG 3) while securing resource-dependent livelihoods and economic development (SDG 8) and providing food (SDG 2), clean water (SDG 6) and energy (SDG 7) (Rosa, 2017).

We find that existing practices in the SRB operate with commonly constructed sectoral boundaries, and even programs that strive to integrate across goals have yet to fully bridge these boundaries. Narrowly focused health interventions rely on treating existing infections without widespread measures to prevent new infections and encourage behavior that may not be feasible for local populations. Integrating health into basin management practices, such as through dam reoperation can reduce the risk of acquiring infections from the environment between treatments. Dam reoperation has been successful in restoring environmental flows and achieving positive environmental outcomes across multiple contexts (The Nature Conservancy, 2021). A recent assessment indicates the potential for dam reoperation across nine river basins in schistosomiasis-endemic regions of the African continent (Thomas and DiFrancesco, 2009). Past efforts to reoperate dams have been motivated by ecological restoration and the benefits of alternative operations to traditional agricultural practices. Our analysis suggests that reductions in dam-related disease may yield additional benefits to dam reoperation. This is a substantial opportunity to integrate health as a component of the FEW systems and sustainably reduce the risk of re-infection while improving the outcomes of treatment campaign for the hundreds of millions at risk of dam-related diseases like schistosomiasis (Sokolow et al., 2017; Steinmann et al., 2006). Doing so will require bolstering coordinated monitoring and evaluation efforts across sectors.

7.2. Linking policy to practice

The importance of improved coordination and research/surveillance activities in our findings reinforce a need for better scientific understanding and improved governance of health linked to other priorities in the SRB. Concerted efforts to address this in the SRB through the Environmental Observatory (SOE) recognize the importance of coordinated data collection and management. More recent dam development, such as the second-generation dams of Félou and Gouina, benefited from the institutional capacity built since the 1990 s (Table 1; Fig. 3), but gaps in implementation persist. Research and data gaps identified in our analysis of the SRB are supported by similar findings that inadequate scientific knowledge can limit effective governance in transboundary basins (Milman et al., 2020; OECD, 2011).

Beyond data and research gaps, the operational rules for Manantali fail to realize the aspiration of sustainable development articulated in policy documents. We find that dam operations focus more on water for agriculture and hydropower than on goals and strategies that address the dams' impacts on health and livelihoods. Integrating livelihoods is central to a nexus approach (Biggs et al., 2015), but our findings suggest that the gap between policy and practice may reduce the benefits of integrating new dimensions (such as livelihoods) into the FEW nexus.

In the SRB, we find that the siloed nature of establishing priorities and developing management strategies hinders knowledge transfer and solutions across sectors and stages of development. Implementing FEW+H nexus governance requires enhanced institutional capacity and coordination among governance levels; this coordination is particularly challenging in transboundary contexts (Howells and Rogner, 2014). The effectiveness of river basin organizations, like OMVS, is related to existing institutional capacity and knowledge exchange (Schmeier, 2015). Changes to existing institutional arrangements may be slow (Leck et al., 2015), and require political will, adequate funds and, often, new tools and strategies (Leck et al., 2015; Pittock et al., 2013). OMVS is a longstanding and leading transboundary organization, but our analysis demonstrates that coordination challenges may be particularly acute in LMIC settings that face weaker governance regimes and higher prevalence of dam-related diseases.

7.3. Crossing disciplines, crossing sectors

Programs and policies in the SRB recognize the multifaceted impacts of dam development on human and environmental conditions, but activities and related solutions continue to remain siloed. We find that multi-sector problems, such as FEW+H systems, require multi-sector solutions. OMVS acts as other international river basin organizations do: to promote and enhance scientific decision-making in river basins (Milman and Gerlak, 2020). However, we find a weak or missing link between the scientific and decision-making arms of OMVS and its operational arm. Therefore, our findings suggest that we must go beyond promoting and enhancing and focus on capacity for scientific decision-making at the implementation levels in FEW+H sectors. Building links across basin decision-making requires understanding the implementation practices of each sector, not just the high-level priorities.

Our findings suggest transboundary river basin organizations contending with a high burden of dam-related diseases must promote cross-sector collaboration across member states and organizational divisions. We found that the programs in the SRB developed to respond to the health and ecological impacts of dam development and those focused on long-term planning target multiple (and different) audiences. Recognizing opportunities for cohesion across programs requires complementary expertise within OMVS, just as analyzing health in dam management and operations required familiarity with multiple and interconnected disciplines (watershed governance and planning, SRB history, economics, hydrological modeling of dam management and operations, and the epidemiology and ecology of vector-borne disease). The emphasis on interdisciplinary and complementary expertise has yet to reach the operations-level activities in the Senegal River Basin. Participatory, transdisciplinary approaches—involving a broad range of participants from decision-makers, scholars, and practitioners across sectors—will support the development of solutions that extend beyond sectoral silos to address various stakeholder concerns (Albrecht et al., 2018; Howarth and Monasterolo, 2017). Our findings suggest a need to continue to deploy such participatory and transdisciplinary approaches in a manner that builds greater coherence across stages of development – from policies to programs to projects to ongoing implementation and monitoring. In the SRB, there is a gap between hydropower and irrigated agriculture goals and the lived experiences of those facing persistent risk of infection due to the altered ecological and livelihood impacts of dam development.

8. Conclusion

This paper was motivated by a seemingly simple question: is health integral to river basin development goals? We found that health is recognized as an important component of river basin development in high-level policy discourse, but that health is minimally considered in how dams are operated in practice. Instead, traditional objectives of dam operations - namely hydropower and irrigated agriculture - are emphasized and prioritized. Of these two priorities, hydropower often takes precedence. In this respect, it is obvious why health is not an objective for optimizing dam operations; dams like Manantali are motivated by electricity goals. Yet, given the widespread and long-recognized impacts of dam development on the transmission of dam-related diseases, opportunities to address health outcomes through dam management are critical for contextualizing energy and food production among other SDGs. Further, opportunities to address health outcomes are especially worth pursuing in light of evidence that they may not require substantial trade-offs with the traditional objectives of dam operations.

In our historical analysis, we used archival documents from the Senegal River Basin to identify where in the planning cycle health is overlooked. We find this occurs between dam and reservoir operations and key areas of decision-making, such as impact assessments and basin-wide programs. In our narrative and qualitative content analyses, we build an understanding of how river basin institutions deal with the health impacts of dams: they are aware of them but fall short of managing them. We identify key barriers to achieving integrated and sustainable development, namely the need to generate and synthesize knowledge across sectors and the subsequent use of that knowledge as a basis for decision-making and implementation.

Our analysis shows how the history of early basin development decisions created tension between the anticipated (and later realized) health impacts and the drive for economic development. We traced the influence of international financing and donors on efforts to better understand the impacts of dam development in the years following construction at Diama and Manantali. We found these efforts to be confined to sectoral siloes which hinder the integration of health (or other livelihood-related objectives) into current FEW nexus approaches.

Additional research is needed to understand how financial safeguards and international standards can support programs and policy development to address health and environmental impacts in tandem with electricity production and economic development. Our FEW+H nexus framing helps identify how to address tradeoffs among these multiple priorities. Population-level data on the prevalence of dam-related diseases remains limited for the SRB, especially across jurisdictions. Further support is needed for measuring and monitoring the impacts of dam development to support interdisciplinary approaches that extend from high-level goal setting to implementation and operational practices. Efforts to coordinate across member states and build new mechanisms to integrate multiple goals across policy, assessment, and operations will only grow in importance as hydropower development continues in LMICs.

CRediT authorship contribution statement

Andrea J. Lund: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – review & editing. **Elise Harrington**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Tamee R. Albrecht**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Tejasvi Hora**: Conceptualization, Data curation, Funding acquisition, Investigation, Visualization, Writing – review & editing. **Rebecca E. Wall**: Conceptualization, Data curation, Funding acquisition, Investigation, Writing – review & editing. **Tihitina Andarge**: Data curation, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2022.03.005.

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