Tapping sustainable agricultural potential in the Senegal River Valley: famine risk reduction in Senegal

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Abstract

Imminent threats of climate change, limited freshwater supply, and insufficient local harvests are all drivers of livelihood challenges for communities along the Senegal River Valley (SRV). Studies have assessed and reviewed the productivity of agricultural practices along the SRV, with findings reporting low efficiency and yield of crops in this area – particularly rice. Additionally, the Senegal River Basin (SRB), a transboundary basin, sustains both energy and food production needs for neighboring countries – Mauritania, Mali, and Guinea. The challenges faced within the SRV's agricultural operations could lead to food insecurity for vulnerable communities within Senegal and in neighboring countries. Stakeholders of SRV have opposing perspectives on dam management and have yet to implement a sustainable and viable solution for these operations. Agricultural strategies between double cropping and monocropping have complicated productivity for smallholder farmers. Levels of salinization affecting arable land in the SRV have placed agricultural constraints, pressuring smallholders and governments to carry out desalinization strategies in the area. Given the complexity of SRB, better governance and multi-lateral collaboration could optimize its potential for economic growth for Senegal and partner nations and promote sustainable livelihoods and improve the quality of life for local communities. This paper examines data and findings from secondary sources including peer-reviewed research and journals to highlight the challenges faced by the riparian communities on the Senegalese side of the SRV. Our findings indicate evidence of water security in the SRV regions as well as its impact on agricultural productivity, earnings, and food security for local people. Addressing the risks hampering the SRV's agricultural potential requires a disaster-risk analysis, this paper assesses the system dynamics through the DPSIR framework with a vulnerability assessment. This paper has indicated the urgent need for an integrated response to both social and environmental vulnerabilities to improve the development potential of the SRV, with policy recommendations provided.

1. Introduction

Since the late 1960s, drought-induced food insecurity has been an imminent challenge in the Sahelian region (Falkenmark & Rockstrom, 2004), which is characterized by erratic rainfall and poor soil conditions. As one of the nations falling into the Sahel belt, Senegal's food production has also been threatened by climate-related disaster risks, including dry spells, frequent droughts, and declining rainfall (Agence Nationale de l'Aviation Civile et de la Météorologie [ANACIM] & World Food Programme [WFP], 2012). Given that rice is one of the country's main staples, the Senegalese government has proactively set out to become rice self-sufficient, reducing the reliance on food imports with high price volatility. However, this agricultural investment in rice-crops has several challenges for smallholder farmers, creating a divide in agricultural planning. The Senegal River Basin (SRB), which is shared by four nations – Guinea, Mali, Mauritania, and Senegal – in West Africa, drains an area of 337,000 km^2 (Tilmant et al., 2020). Facing agricultural crises, famine, and conflicts caused by meteorological droughts (Diop et al., 2021; Sakho et al., 2017), the Senegalese government had a pressing need to harness the water resource effectively and secure food production in the SRV. The authority and infrastructure development project does not only serve for water demands of food production in downstream countries (Mauritania and Senegal) but also energy needs of the upstream countries (Guinea and Mali). An early form of Integrated Water Resource Management (IWRM), hence, evolved in the transboundary context. However, inadequate water resource management and climate stress threatens water and food security in in this region.

The findings of this paper will support policy recommendations for SDG 6, by addressing the goal to ensure that water is a non-excludable good for the vulnerable parties of the SRV communities. Through targets 6.4 and 6.A, we will assess different factors – management of water systems (SDG 9) and impacts of climate variability (SDG 13) – affecting water availability for agriculture (SDG 2) and determine strategies for sustainable agricultural practice and improved freshwater supply. After this brief introduction, this paper is organized as follows: Section 2 provides an overview of the contextual information of SRV, including water resources, demands, climate conditions, blue infrastructure, and governance; Section 3 identifies the challenges faced by the SRV communities in improving agricultural productivity; Section 4 analyzes the challenges through the use of a DPSIR framework to identify the associated disaster risks on the water and food systems; Section 5 summarizes the findings and presents the recommendations.

2. Background

Scope of the study

The Senegal River Basin (SRB) has a complex make-up; it is a transboundary basin with several climatic zones such as rainfall variability, droughts, and floods (Sakho et al., 2017). The headwaters originate from Guinea flowing through Mali, subsequently forming the border between Mauritania and Senegal, before reaching its estuary on the Atlantic Ocean (International Union for Conservation of Nature [IUCN], 2003; Tilmant et al., 2020). The basin is generally classified into three distinct regions: the upper basin, valley (lower basin), and delta (Varis & Lahtela, 2002; Uhlir, 2003). The study scope of this paper focusese on the Senegal River Valley (SRV), which is located within the Senegal border, from the town of Bakel to Dagana – see Figure 1.

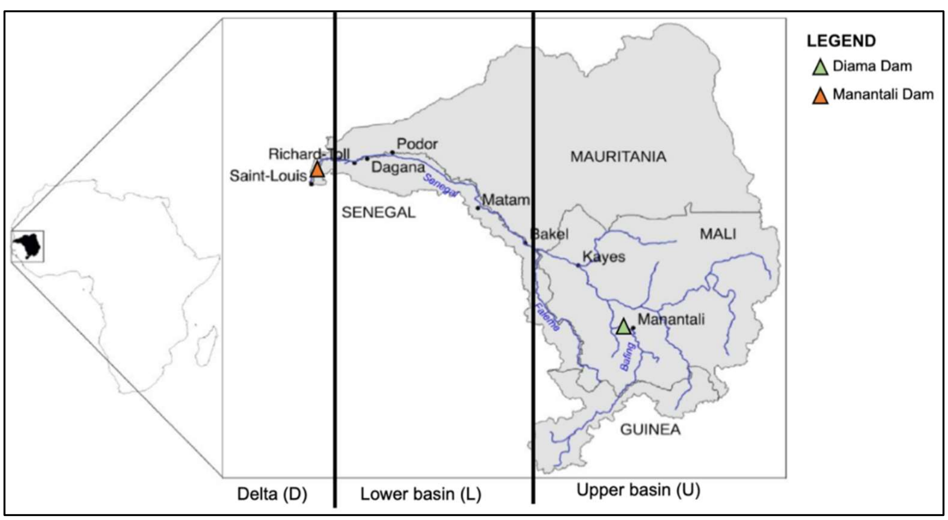


Figure 1: The basin is classified into three distinct regions: the upper basin, valley (lower basin), and delta, adapted from (Tilmant et al., 2020)

Climate conditions

The riparian communities in the SRV lie within the Sahel region, in which the climate is arid (receiving 300-350mm of rain per year) and extremely prone to drought (Asselin & Poulsen, 2015; Wuehler & Wane, 2011). The area has three seasons: a cool-dry season in November-February, a hot-dry season in March-June, and a rainy season July-October (Sall et al., 2020; ANACIM & WFP, 2012) also demonstrated that the annual mean precipitation drops from 1,000 to 200 mm/year, from south to north in Senegal – see Figure 2. In addition, the rainfall distribution during the rainy season is more irregular in the north-western parts of the country – see Figure 3. The SRV, as part of the Sahelian strip and northern Senegal, is no stranger to rainfall variability – with climate change transitions ranging from wet periods to droughts, during the 50s-60s and 70s-80s, respectively (Diop et al., 2021; Sakho et al., 2017). Climate change is believed to be the primary result of this variability; however, dam construction has also led to changes in streamflow responses and inter-annual variability of rainfall within the last two decades (Diop et al., 2021; Sakho et al., 2017).

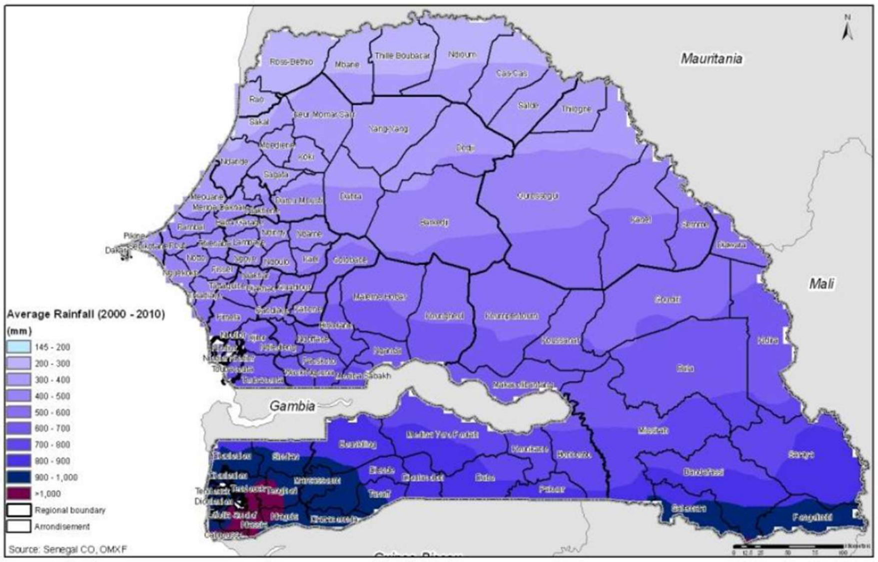


Figure 2: Average annual distribution of rainfall across Senegal between 1999 and 2012, reprinted from (ANACIM & WFP, 2012)

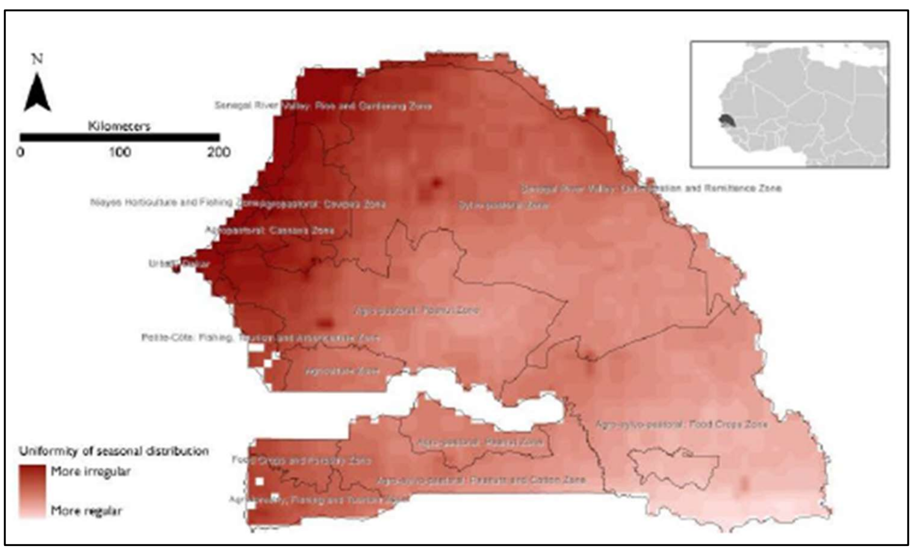


Figure 3: Uniformity of rainfall in Senegal, average from 1999 to 2011, reprinted from (ANACIM & WFP, 2012)

Water resources and needs

The available water from the SRB is around 15,000 to 17,000 Mm^3/year, shared among Mauritania, Mali, and Senegal. Currently, Senegal withdraws approximately 1,766 Mm^3/year from the SRB, with over 95% of it used in agriculture – see Appendix

A (WBG, 2022). Current freshwater resources, including surface and groundwater, is still abundant in SRB, which is 24.5 times greater than the national water consumption, around 1,591 million m^3 in 2000 (Faye et al., 2021). However, studies pointed out that the volume of renewable water falls below 1,700 m^3/capita/day, implying a high probability of freshwater depletion in the long run – see Figure 4 (Faye et al., 2021; WBG, 2022). Shifting from the traditional farming – rain-fed and flood-recession agriculture – to drought-proof irrigated farming, the water demand on surface water resources significantly increased, and multiple benefits of flood recession were lost – see Appendix B (IUCN, 2003).

Figure 1: Yearly available renewable water resources per capita.

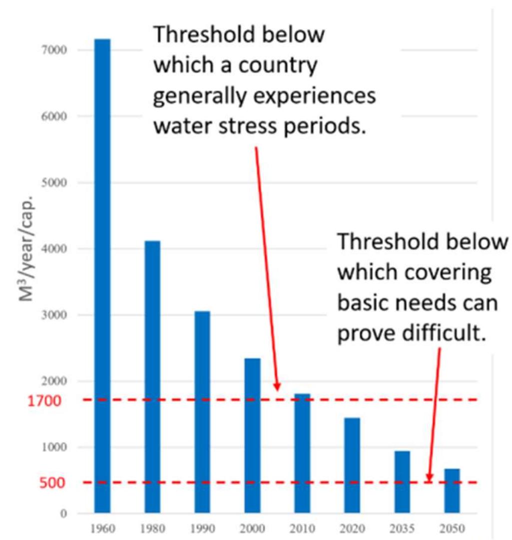


Figure 4: Volume of renewable water resources per year per capita, reprinted from (WBG, 2022)

Hydraulic infrastructure

There are two major hydraulic infrastructures built with reservoirs, which are the Manantali dam in the upper basin at Mali and the Diama dam near the River Mouth in Senegal (Tilmant et al., 2020). The role of the Manantali dam is to control the flow of water from Guinea and reduce flooding downstream while the Diama dam aims to prevent saltwater intrusion for the sake of agricultural production in Senegal and Mauritania along the SRV (Tilmant et al., 2020). The Manantali dam and artificial flood release were designed to optimize the flooding for 50,000 hectares of floodplain cultivation while other floodplain areas were transformed into irrigated agriculture (IUCN, 2003). Added to the dams, there are two hydropower stations at Manantali and Félou in Mali for the riparian countries – see Figure 5. The operation of the Manantali Dam has been prioritized to generate hydroelectric power, of which 33% was anticipated to benefit Senegal – see Appendix C (Varis et al., 2008; Niasse, n.d.). The increasing rainfall variability and dam operation induce changes in flood intensity, frequency, streamflow response, and water availability, impeding the development of flood-recession and irrigation agriculture (Sakho et al., 2017; Sall et al., 2020). Traditional flood-recession farming is encouraged to be replaced by irrigation agriculture, reallocating land resources from crops like millet and sorghum towards rice and a lesser extent to onions in the SRV (Moss et al., 2018; Tanaka et al., 2015).

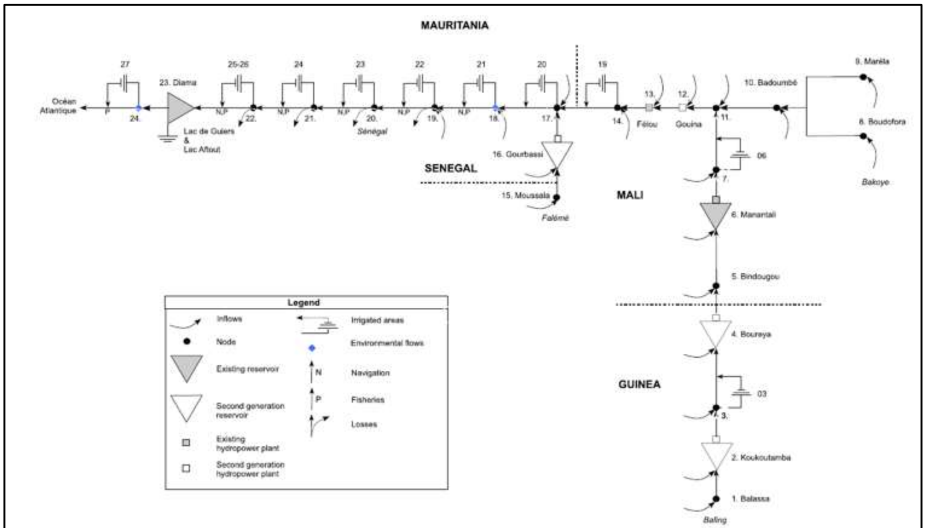


Fig. 2. Schematization of the Senegal River basin.

Figure 5: Schematization of Senegal River Basin, reprinted from (Tilmant et al., 2020)

Governance

SRV is part of a transboundary river, making up territory for parts of Mali, Guinea, Senegal, and Mauritania; and with mixed political interests and water demands (Tilmant et al., 2020), the region is at risk of potential conflicts due to the different countries' preferences for diversified water resource use (Sakho et al., 2017). At the transboundary, national, sub-national levels, there are several key actors and stakeholders to the Senegal River Valley – see Table 1. The Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS), composed of three of the riparian countries – Mali, Mauritania, and Senegal, was established to address the considerable inter-annual variability in rainfall and water flow of the Senegal River in 1972 (Sakho et al., 2017; Uhlir, 2003). The OMVS recognizes the importance of cross-border coordination to optimize the social, economic, and environmental benefits for member states (Uhlir, 2003). The IWRM plans of the OMVS included three elements: irrigation, navigation, energy (Varis et al., 2008). Existing efforts have not achieved the goals and tasks of managing the SRV due to both insufficient capacity and lack of shared knowledge and data, in optimizing hydraulic conditions of SRV (Sakho et al., 2017; Uhlir, 2003). Additionally, increasing irrigable land and area for crop productivity has been further aggravated since adequate capital and knowledge are required to physically transform the land use for irrigated agricultural production (Diouf et al., 2015). The SRV region has economic potential, with 70% of local people relying on agriculture as their main source of income; however, until these challenges are addressed the population could face displacement, migration, and food insecurity (Sall et al., 2020). Since the implementation of an IWRM for the SRV, the National Society of Senegal River Valley and Delta Development (SAED), have faced budget shortfalls and with little funding support from governments, the irrigation infrastructure is at risk (Harris et al., 2021). The concern with budget constraints, planning, coordination, and implementation challenges all affects water availability in the SRV. With a high number of actors and stakeholders, comes several challenges that pose a threat to water and food security to communities reliant on the SRV. Although an IWRM plan has been prepared for the SRV region, the actual implementation of this plan has been slow due to unclear roles and responsibilities for each actor, in addition to insufficient funding (USAID-Sustainable Water Partnership, 2021). The Senegal government's funding for the water sector is limited, and most of the funding is covered by external agencies such as the World Food Programme, World Bank, USAID, European Union (USAID-SWP, 2021). The reinforcement of both transboundary and national responsibilities is key to improving agricultural operations for the SRV region.

Level	Actor	Roles/Responsibilities
Transboundary	• The Organization for the Enhancement of the Senegal River (OMVS)	• OMVS is responsible for management of transboundary initiatives, oversees collaboration and resource use for hydropower, as well as supporting conflict resolution
National	• The Ministry of Water and Sanitation (MEA) • The Directorate of Management and Planning of Water Resources (DGPRE) • The Ministry of Agriculture and Rural Equipment (MAER) • The Ministry of the Environment and Sustainable Development (MEDD)	• MEA is responsible for water resource management, drinking water supply and sanitation, and agricultural water allocation • DGPRE manages water abstraction and discharge permits, monitors water availability and quality, and oversees Senegal's IWRM plan • MAER manages retention basins and artificial lakes and development of the Senegal River Basin through the National Society of Senegal River Valley and Delta Development (SAED) • MEDD oversees the Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS), responsible for conservation of water, forests, hunting, and soil
Sub-National	• Management and Planning Units (UGP) • Management and Planning Sub-units (SUGP) • Local Water Committees (CLE)	• UGP which are 5 units managed by the DGPRE and responsible for the regional management plan (SDAGE) • SUGP a total of 28 sub-units responsible for preparing localized IWRM water management plans • CLE who coordinates and manage local water resources across all actors, including the state, local authorities, and the private sector, as well as identify local water management problems and needs, assess local demand and environmental impacts, develop Community IWRM Plans (PCGIRE)

Table 1: Role and responsibilities of key actors managing the Senegal River Valley, adapted from (USAID-SWP, 2021)

3. Challenges in ensuring food security

Water-related challenges: Demand-side

The challenges of water demand in Senegal present a difficult case for water security and agricultural productivity in the SRV region. According to the European Commission (2007), water scarcity means the available water resources are insufficient to meet the long-term average needs. In other words, it occurs under long-term water imbalances, where the water demand exceeds the renewable water reserves, coming from natural recharge. The annual renewable water resources in Senegal are 38.87 km3, with 25.8 km3 sourced within the country and the annual precipitation is around 686 mm (FAO, 2016; Faye et al., 2021). As mentioned in Section 2, the seemingly abundant freshwater from SRB, shown by the estimates, hides the true state of water scarcity in Senegal. Currently, Senegal's renewable water availability falls below the threshold of 1700 m3/capita/day, classified as a water-stressed country by FAO, and water withdrawal is expected to rise by 30 to 60 percent by 2035 – see Figure 4 (WBG, 2022). It has been challenging to meet the growing water demand for irrigation in the SRB, particularly during the dry seasons, and surface water alone cannot meet these demands (Faye et al., 2021; WBG, 2022). Due to the deterioration of water and significant spatial-temporal variability associated with the transboundary nature of SRB and climate change, actual available water may be overestimated and may not be sufficient to meet the rapidly growing demand (WBG, 2022).

The burden on surface water resources of irrigated farming systems is much greater than the traditional ones. Currently, more than 95% of water withdrawal from the SRB is used for irrigation in Senegal – see Appendix A. As part of the IWRM, there have been several government-led initiatives in converting floodplains to irrigatable land (IUCN, 2003). These initiatives include dam construction projects, to reduce the vulnerability of food production to climatic variability and rainfall deficits, allowing farmers to be less dependent on the rainfall (IUCN, 2003). Transforming floodplains or rain-fed cropland into irrigation, which is a common way to drought-proof the crop system, can reduce the chance of crop failure under meteorological droughts and dry spells, achieving a higher yield than traditional farming (Falkenmark & Rockstrom, 2004). Because rice is such a water-intensive crop, switching from drought-tolerant millet and sorghum to drought-sensitive maize and rice resulted in a higher vapor shift and increased irrigation water demand. (FAO, 2000; Falkenmark & Rockstrom, 2004).

Although it has been challenging to farm in SRV regions, added to irrigated agriculture, there are other water management opportunities for agriculture in the SRV region. Firstly, rather than solely relying on irrigation water from the SRB, the government can implement rainwater catchment projects to maximize the use of available rainwater and introduce supplemental irrigation from groundwater in the SRV (Falkenmark & Rockstrom, 2004). Additionally, better green water management, including enhancing soil infiltration and reducing soil surface evaporation, can reduce the demand for irrigation water and the effects of dry spells on traditional farming (Falkenmark & Rockstrom, 2004). Ample research also suggested that floodplains should be maintained as much as possible although the crop productivity is lower than irrigation. Multiple benefits, including the lower inputs of capital and labor, as well as the nutrient-rich soil provided for crops, could be enjoyed through recession agriculture – see Appendix B (IUCN, 2003; Sall et al., 2020). To determine an optimized proportion of floodplains and irrigatable lands, the government could perform a cost-and-benefit analysis by taking environmental constraints and economic factors into consideration.

Water-related challenges: Supply-side

The construction of the dams in the SRV is to sustain the agricultural, energy, and navigation purposes of all countries along the river. Conflicting interests, limited data, and restricted capacities have all played a role in the complexity of dam operations in SRV. Actors upstream of SRV have maximized the Manantali Dam to generate hydroelectric power, however, this decision has impacted communities downstream of the river, who are dependent on the river and dams for agricultural production (Tilmant et al., 2020; Sakho et al., 2017). Although Senegal may share a portion of the benefit generated from hydropower generation, the gain from the irrigated and recession agriculture has not been optimized in the existing management of the dam (Tilmant et al., 2020). The current hydraulic conditions are not favorable for flood-recession cultivation, making the SRV communities that rely on recession agriculture the most vulnerable among different parties in SRV (Tilmant et al., 2020). Climate events like floods have conflicting perceptions on the benefits and challenges of these events among SRV communities. For example, downstream cities like Saint-Louis have struggled with severe flooding (Uhlir, 2003), whereas other communities sustained livelihoods through flood-recession cropping (Uhlir, 2003).

Before the construction of the Manantali Dam, flood-recession cropping made farming operations possible in parts of the Senegal River Valley, particularly in regions below Bakel (Uhlir, 2003). One of the two dams, the Manatali Dam, works as a reservoir for floods and supports the regulation of river flows for agricultural irrigation and hydropower (Sakho et al., 2017). Although the OMVS member states agreed to arrange artificial flooding to sustain flood-recession agriculture, the details of actual implementation such as the intensity, frequency, and period, have been contested. With conflicting interests and perspectives, comes the opportunity to implement a multi-objective dam management model (Tilmant et al., 2020). A model like this would work to optimize dam management to improve water allocation policies, as well as fulfill the needs and maximize the utility of all sectors. Suggestions have also been made to implement the *Geospatial Stream Flow Model (GeoSFM)* established by the Famine Early Warning System Network (FEWS NET) program (Uhlir, 2003). This model could help provide timely information about flooding in the SRV region. For flood events, this model provides an opportunity to enhance institutional knowledge and capacity in dam operation management; the tool can support the prediction of timing, spatial extent, and volumes levels (Uhlir, 2003).

Conflicting objectives in Agricultural production between government and farmers

Agricultural production in the SRV region has also been challenged by conflicting objectives between governments and smallholder farmers. The objective of government agricultural policy is to achieve rice self-sufficiency through crop intensification and maximizing rice area. However, the objective of smallholders is more holistic, by maximizing the area of rice, operating to profit farms, and optimizing the use of fertilizers. The focus of smallholder farmers is to achieve self-sufficiency and maximize profitability under environmental constraints. As rice production is an important and prioritized crop, the high cost and physical risks of rice production should not be ignored. Rice is a drought-sensitive crop and cannot grow well in water stress regions (Falkenmark & Rockstrom, 2004). This challenge then requires a transformation of agricultural operations to fit these requirements by improving irrigation systems, capital to invest in pumping equipment, and supporting the operating costs of seeds, and fertilizers, compared to rainfed crops like sorghum and cowpea (Comas et al., 2012). In the SRV, the main drivers of rice production and crop intensification were incentivized by both credits and subsidies provided by the government (Brosseau et al., 2021). For small-holder farmers, rice production was beneficial for self-consumption, however, a large portion of the return on rice production was used to cover cultivation costs and household expenses – see Figure 6 (ANACIM & WFP, 2012). In these cases, farmers are confronted with the challenge of earning a low income, making it difficult to meet basic needs, like covering their household expenses. This financial instability has also resulted in farmers relying on a credit system to purchase production inputs and soil preparation costs (ANACIM & WFP, 2012). However, farmers have shared how vegetable production was beneficial to increasing their income and fulfilling both household needs and food security (ANACIM & WFP, 2012). This shows the opportunity and potential of vegetable production. As part of these conflicting agricultural objectives, the government encouraged monocropping (rice-rice production) to increase rice yield per hectare in the year (Brosseau et al., 2021).

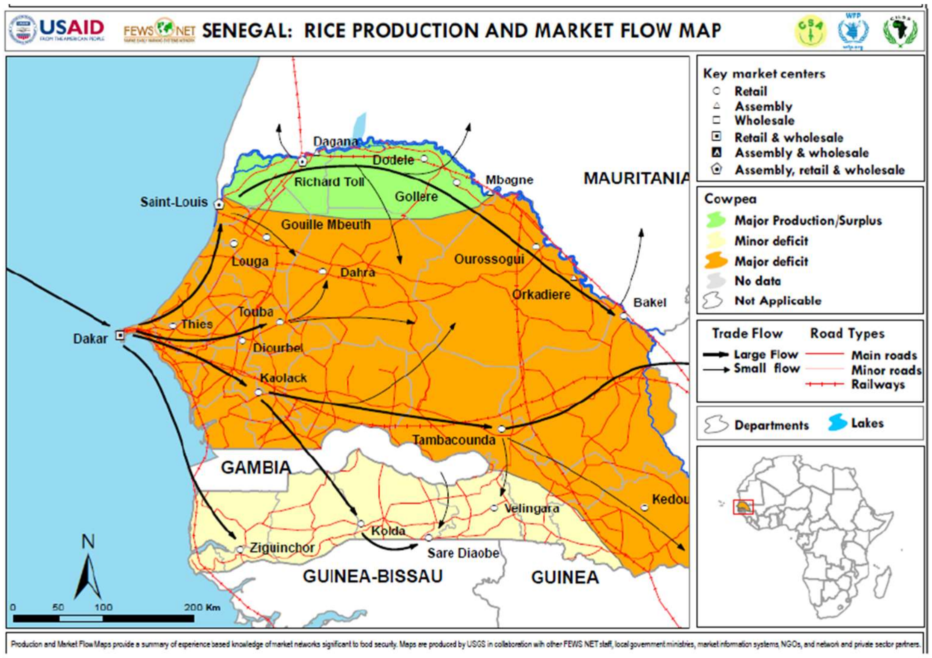


Figure 6: Rice production and flow map, reprinted from (ANACIM & WFP, 2012)

Although the government encouraged and subsidized this practice, local farmers face difficulties when cultivating rice in the wet season because vegetables are more profitable (Brosseau et al., 2021). In addition to the financial benefits for farmers, vegetable production has a lower physical risk compared to rice production (Brosseau et al., 2021). Vegetable crops are less vulnerable to diseases and do well in humid environments. Hence, the SRV provides suitable conditions for vegetables to grow, except for soil with high salinity caused by saltwater intrusion. (Brosseau et al., 2021; Tilmant et al., 2020). To improve agricultural practices in SRV regions, the perspectives and decisions of smallholder farmers are critical, as they are most knowledgeable on local agricultural efficiencies. Farmers shared their preference for short-duration rice variety crops, as it gives them an opportunity to reduce biophysical risks and the impacts of delayed sowing (Brosseau et al., 2021). Additionally, farmers were also found to transition the cultivation of rice from wet season to hot dry season and rely on irrigation systems for water, since rice produced a higher yield and margin in hot dry seasons, compared to wet seasons (Brosseau et al., 2021). This creates a greater opportunity cost if farmers transition from double cropping (e.g., rice-vegetation) to monocropping (e.g., rice-rice production), given the climate constraints of SRV that affect yield and operational costs. Despite the opportunities with vegetable production in SRV, the operational capacities are still limited as there are evident gaps in financial resources and technical support needed (Brosseau et al., 2021). Governments must assess these agricultural trade-offs from a policy perspective, and provide the necessary resources for optimal production, such as improving nutrient management, water management, soil quality, transportation, infrastructure, and knowledge on operation and markers (Brosseau et al., 2021).

There is also an opportunity for Senegal's government to promote double cropping, to allow the farmers to optimize the crop productivity, which is highly dependent on favorable climate conditions (Brosseau et al., 2021). The optimal crop rotation practice for rice-vegetable production is rice in the hot dry season, while vegetables in the cold wet season. The government is currently boosting the annual rice production per hectare and encouraging monocropping – rice is grown in two seasons for all croplands to achieve a higher annual rice production – despite climate constraints (Brosseau et al., 2021). Policy-based and technological intervention (i.e., agronomic research and technical assistance) in crop intensification should focus on the crop yield performance in every harvest instead of by year (i.e., policies could aim at promoting rice varieties best adapted to the hot dry season and farming practices aiming at increasing rice yields in this season (hot-dry season). Additionally, farmers of the SRV region can adopt a more sustainable farming system to increase plant water availability, which improves the food system's resilience to climate risks (Brosseau et al., 2021; Falkenmark & Rockstrom, 2004; Jägermeyr et al., 2016). An example of this would be by adopting intercropping, water harvesting, and soil moisture conservation; all of which are techniques that could maximize soil infiltration, minimize soil evaporation, and improve the irrigation system (Brosseau et al., 2021; Falkenmark & Rockstrom, 2004; Jägermeyr et al., 2016).

Land-related challenges

The Land Tenure Security Activity (LTSA) is responsible for the creation of land occupancy and use inventory, inclusive process for allocating land, formalized land rights, and trained local officials to administer land rights in the Senegal River Basin (Harris et al., 2021). LTSA focuses on the reinforcement of the capacity of local governments to fulfill their legal obligations as land managers, allowing for future opportunities to nudge land governance in Senegal toward transparency and decentralized efforts (Elbow et al., 2015). In parts of the SRB, land use and cropping intensity is at 78% (below the target of 150%); lack of funding and logistics have prevented further intensification (Harris et al., 2021). Changes in settlement patterns in the area have also impacted agricultural productivity; the SAED played a role in increasing migrant workers to support irrigated agricultural production in the SRV (Diouf & Elbow, 2013). However, there have also been incidents of out-migration in parts of the SRV where young workers search for employment opportunities in urbanized parts of West Africa, as well as Europe (Diouf & Elbow, 2013). This can be a result of increased famine and poverty in the area, and where resources are limited for agriculture productivity, as well as the impacts of rainfall variability.

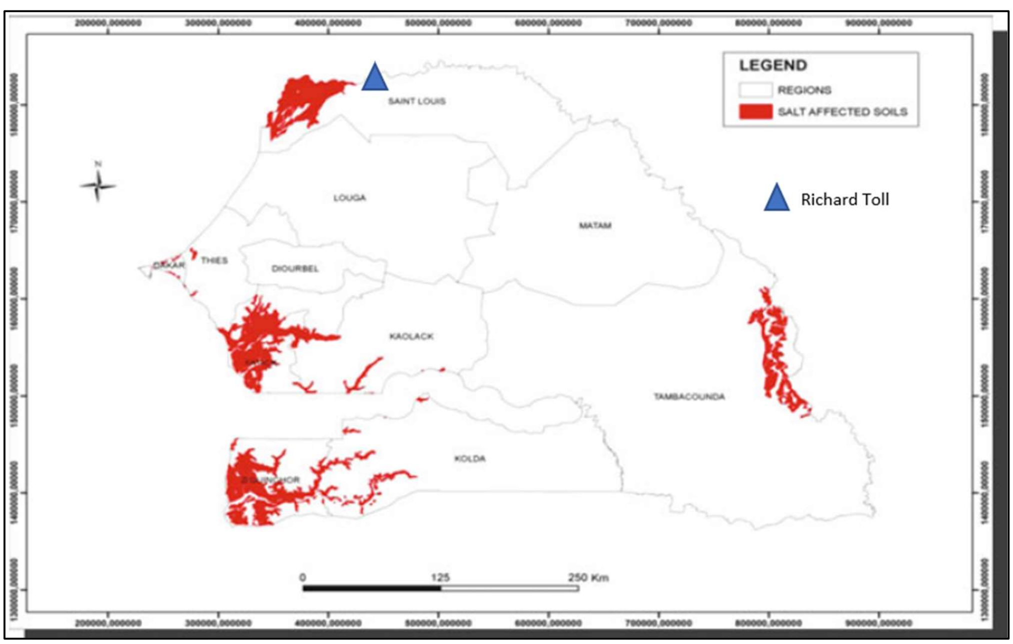


Figure 7: Distribution of the affected zones by salination processes, adapted from (Diack et al., 2015)

Another land-related challenge in agricultural production in the SRV is the levels of salinization. During the dry season, the salinity of the water of the river mouth increases due to saltwater intrusions, with the impact reaching the SRV at Richard Toll – see Figure 7 (Tilmant et al., 2020). The salinity in the SRB is a concern, particularly for parts of the Delta, however, this impacts the entire river (USAID-SWP, 2021). High levels of salinity have impacted fisheries, increased evaporation, and saltwater intrusion – and poor draining capacities have further complicated this (USAID-SWP, 2021). As a response to this, desalination techniques and tools are necessary to meet both water and land demands for agriculture in the SRV. Desalinization techniques were able to restore degraded soils for crops and improve land tenure for agricultural operations (Diack et al., 2015). With effective desalination techniques, farmers can increase arable land and improve soil quality, improving crop and agricultural capacities (Diack et al., 2015).

4. DPSIR framework and vulnerability to famine risks

Due to the complexity of the problem, in which economic, social, and environmental stressors are interlinked at the nexus of water, land, and food, a DPSIR (Drivers-Pressures-State-Impacts-Responses) framework (Kristensen et al., 2004) – see Appendix D – is introduced to assess the socio-ecological challenges to food security faced by the SRV communities under the government-led policy in boosting rice productivity. Using the framework, potential famine risks exposed to the current food system can be better understood, which will help to communicate the four key elements: exposure, hazards, risk, and vulnerability for policy recommendations.

Based on the literature review and analysis in Sections 2 and 3, the drivers, pressures, states of the environment, impacts, and responses, are identified in the following to illustrate the current context and challenges in SRV's food system – see Figure 8.

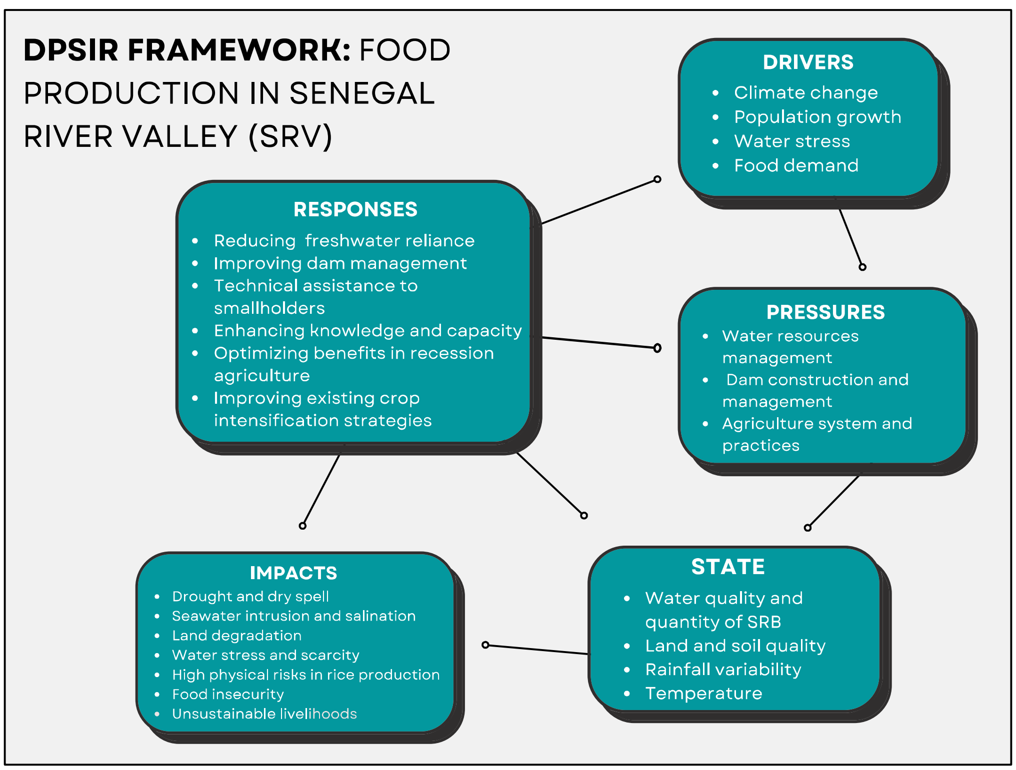


Figure 8: DPSIR Framework for food production in SRV

Drivers

Climate change, population growth, water stress, and domestic food demand are the four major driving forces behind the food system's fragility. Climate change has impacted the weather patterns in SRV, which is the most vulnerable region in Senegal with the lowest annual average rainfalls. Furthermore, the population tripled between 1975 and 2015, reaching 14.58 million in 2015, and is expected to reach 19.06 million by 2050 (Grid Arendal, 2020). With the increasing population, the demand for water and food has been growing. Besides, the renewable water resource in the Senegal River is not necessarily able to satisfy the growing water needs for agriculture because water availability is susceptible to climate change and deterioration of water quality. As for food demand and production, Senegal has been heavily reliant on food imports, with only a small share of domestic agricultural outputs.

Pressures

To limit their dependency on the global food market, the government has strived to promote rice self-sufficiency to ensure national food security. However, added to the semi-arid climate conditions in SRV, as part of the Sahelian belt, agricultural production has also been threatened by climate change, including prolonged dry seasons, more frequent droughts, and more unpredictable rainfalls. Hence, traditional agriculture – rainfed and flooding-recession farming – has been vulnerable to unreliable rainfalls and the high evaporation rate, shifting the agriculture system to the drought-proof one, irrigated farming. The transboundary water authority, OMVS, was then established to manage and construct the Manantali Dam to meet the water demand for irrigation in Senegal and Mauritania, as well as other purposes such as power generation and navigation. Based on the integrated plans agreed upon by the member states, the dam was designed to create artificial floods in support of 50,000 hectares of floodplains in SRV. However, the Manantali Dam's operation has been prioritized in producing hydroelectric power, at the expense of agriculture development and other water purposes in SRV. Apart from that, the Senegalese government also has promoted a monocropping system to intensify rice production and devoted efforts to maximizing the area of rice cropland.

State

With current development practices over water management and food production, loss of the floodplains' ecosystem services and overuse of fertilizers in irrigated agriculture have deteriorated the water quality of the Senegal River. In addition, replacing floodplains with irrigated land has imposed a heavy burden on the freshwater resources of SRB. Apart from that, the land and soil quality of SRV are highly vulnerable to erosion and salinization because of climate change and the region's semi-arid climate. Although irrigation is a way to drought-proof the crop system, the problems of increasing soil evaporation and reducing soil infiltration remained unsolved and exacerbated by rainfall variability and temperature rise.

Impact

The rising annual average temperature and increasing inter-annual precipitation variability contributed to a higher occurrence and intensity of droughts and dry spells in the SRV. The sea-level rise contributed to saltwater intrusion, which salinized and degraded the cropland at the lower end of the SRV. The systemic shift from recession agriculture to irrigated agriculture led to the imminent withdrawal of SRB's freshwater. The accelerated rate of freshwater depletion placed the SRV and agricultural system under intolerable pressure in the long run. Added to that, current political goals about rice self-sufficiency are at odds with the farmers' food production objectives. The policymakers of Senegal solely focused on the annual rice production per hectare of cropland and failed to recognize the considerable opportunity costs of the undesirable rice yield in a particular season, which posed physical risks to the smallholders' production. Due to the high cost of rice production in SRV, even with government subsidies, local farmers are unable to achieve full self-sufficiency, and a large portion of the harvest is sold to other provinces to help with household expenses. Thus, aligning with government-led initiatives in monocropping would jeopardize the SRV farmers' livelihoods.

Vulnerability and responses

The earlier discussions described the occurrence of potential hazards (impacts) to which food production in SRV communities is exposed. The vulnerability of agricultural production, defined as the characteristics of the system that make it more susceptible to the adverse effects of hazards, can be divided into two categories: environmental vulnerability and social vulnerability. The environmental vulnerability includes unsustainable freshwater withdrawal for irrigation, irregular river inflow to SRV for irrigation agriculture, insufficient artificial flooding for flood-recession agriculture, and inadequate drainage for desalinization, threatening the crop productivity in SRV. On the other hand, the social vulnerability, which mainly focuses on political and institutional issues in this paper, covers the unequal benefits from the basin resources shared with other sectors and other OMVS member states, little recognition of the socio-ecological benefits of recession agriculture, and ambitious rice production targets regardless of climate and water constraints.

To reduce the likelihood of famine or food insecurity, the Senegalese government needs to take an integrated approach to strengthen the food production system in SRV. Coping with environmental vulnerability, sustainable farming strategies to reduce reliance on freshwater resources, improved dam operation coordination among OMVS member states, and increased provision of technical assistance to smallholders make SRV communities less vulnerable to harvest loss and climate-related risks. In terms of social vulnerability, responses must enhance the institutional knowledge of water, soil, and land resource management, optimize the benefits of low-cost flood-recession agriculture, and improve the existing crop intensification strategies.

5. Conclusion and recommendations

In this section, we present our findings and recommendations for addressing the identified challenges and vulnerabilities in the SRV food production system, as illustrated in **Table 2**. The recommendations mainly highlight the role of the Senegalese government in building resilience to the existing SRV's food production.

Type of vulnerability	Descriptions	Responses
Environmental vulnerability	Unsustainable freshwater withdrawal for irrigation	- Reduce reliance on freshwater resources from the irrigation system in farming - Implement water catchment projects to strengthen rainwater harvesting and adopt supplemental irrigation from groundwater - Explore farming techniques to improve green water management such as intercropping, water harvesting, and soil moisture conservation
	Irregular river inflow and insufficient artificial flooding	- Adopt GeoSFM to enhance institutional knowledge and capacity in dam operation management - Adjust dam operation based on more reliable prediction in river flow in time, volume, and spatial extent
	Inadequate drainage for desalinization	- Develop and improve the drainage system, along with the irrigation development, especially for regions threatened by high soil salinity.
Social Vulnerability	Unequal sharing of the benefits from the basin resources	- Enhance the institutional knowledge of water, soil, and land resource management - Map all stakeholders and deepen the understanding of different water usage along the SRB - Strengthen coordination with Mauritania and Mali
	Underappreciated socio-ecological benefits of recession agriculture	- Optimize the benefits of low-cost flood-recession agriculture and irrigation agriculture - Improve watershed management and irrigation planning
	Insufficient institutional capacities in agricultural policy design and implementation	- Support agronomic research to gain a better understanding of the environmental constraints on crop performance, including requirements on climate conditions, soil quality, water, and land - Improve the existing crop intensification strategies

Table 2: Environmental and social vulnerability of SRV's food production and the corresponding responses for risk reduction

As for Environmental vulnerability, one of the major threats is the huge demand and withdrawal of freshwater from SRB for irrigation. Adopting irrigation cropping helps boost crop yield by eliminating climate-related risks like droughts and rainfall variability. However, the shift in the cropping system transfers the water burden from rainwater to freshwater from SRB, which is highly vulnerable if the demand for irrigation water keeps growing indefinitely. Hence, the government of Senegal could devise strategies to reduce the reliance on freshwater resources, extracted through irrigation, in the cropping system by promoting water efficiency and conservation in irrigation, strengthening rainwater harvesting, adopting supplemental irrigation from groundwater, and improving farming techniques to increase plant water availability. These could be done by implementing water catchment projects as well as promoting intercropping, water harvesting, and soil moisture conservation.

Another environmental-related threat is the irregular river inflow and insufficient artificial flooding, mainly driven by dam management and operation. As one of the OMVS members, the Senegalese government could negotiate and co-manage the dam operation with Mauritania and Mali. By establishing a shared database and adopting GeoSFM, the institutional knowledge can be enhanced to optimize the operation based on more reliable predictions in hydrological conditions of SRB. Aside from that, some of the regions located at the west end of SRV have been susceptible to land degradation caused by saltwater intrusion. Inadequate drainage is crucial for both irrigation and desalinization of soil. Hence, the national government should work with the local government to provide technical assistance in improving the existing drainage system.

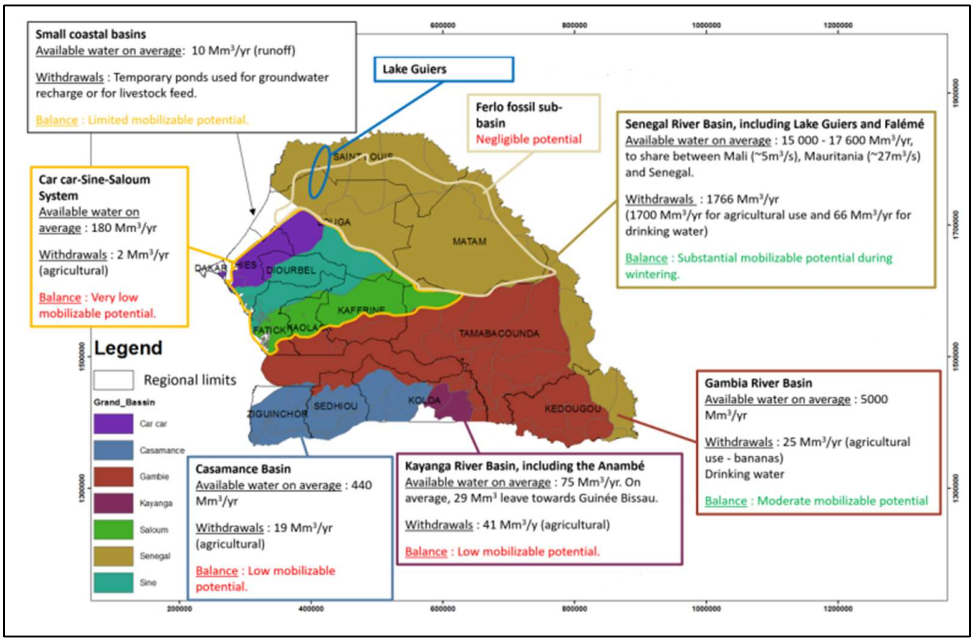
In terms of social vulnerability, benefits from the SRB water resources are distributed unequally among actors from various sectors, nations, and geographic locations, which are primarily controlled by the Manantali Dam. To ensure food security and agricultural productivity for Senegal, the government needs to enhance the institutional knowledge about the current state of water, land, and soil for agriculture. Mapping relevant SRV stakeholders and deepening the understanding of different water usage is highly recommended to avoid conflict and optimize resource allocation. Subsequently, multi-lateral coordination with other OMVS member states is critical to reducing risks of crop failure and ensuring the availability of irrigation water and flooding.

Lack of considering environmental constraints, beyond the amount of arable land, is another institutional factor that led to the loss of flood plains, together with its socio-ecological benefits – see Appendix B. The government-led initiatives focus on irrigated cropping while recession agriculture is often underappreciated. Although recession agriculture produces less crop per hectare of land, it is less capital- and labor-intensive as well as maintains nutrient-rich soil from flooding. Thus, the government should improve the watershed management and irrigation planning, based on the cost-benefit analysis of different cropping systems along the SRV.

Currently, there is a significant gap between crop productivity and the ambitious rice production targets. This implied the government lacked the capacity to design and implement agricultural policies that are compatible with the goals of smallholders' food production. The government has promoted the farmers to have rice cropping in both the hot-dry season and wet-cold season to intensify the rice production in the same amount of land. Although the annual rice production per hectare increased, the crop productivity for the unfavorable season (wet-cold in this case) is poor. Following the current crop intensification initiatives would lead to unsustainable livelihood because of the low farm profitability and food insecurity. Hence, policymakers and decision-makers should implement policy and technological interventions based on agronomic research, through the investigation of crop performance under various environmental limitations. The country can benefit from improving crop intensification strategies by considering climate conditions, soil quality, water, and land resources. As mentioned in Section 3, moving toward vegetable cropping in the wet-cold season could be a way to secure food production.

APPENDIX A

Overview of the hydraulic potential of surface water, reprinted from (WBG, 2022)



APPENDIX B

Recession and Irrigation Agriculture Comparison, reprinted from (IUCN, 2003)

Box 6. Recession agriculture versus irrigated agriculture

Recession agriculture

- Low labour costs
- Low capital costs
- Low yield per area farmed
- Seasonal, allowing rural inhabitants to diversify income by generating income in urban areas in the dry-season
- Traditional division of labour
- Diverse resources maintained
- Risk in food and income production spread over several options
- A varied floodplain landscape maintained
- Flooding and grazing livestock fertilise floodplains

Irrigated agriculture

- High labour costs
- High capital costs
- High yield per area farmed
- Non-seasonal, requiring labour year round
- Migration of males to urban areas to finance capital costs of irrigation schemes
- Increased workload in rural areas for woman, children and elderly persons
- Resources homogenized to maximise production
- Floodplain changed to a uniform landscape
- Artificial fertilizers needed

APPENDIX C

Benefit-sharing arrangement between OMVS member states, reprinted from (Niasse, n.d.)

	Irrigation	**Energy Production**	**Navigation**	**ALL**
Mali	11,00	52,00	82,00	35,30
Mauritania	31,00	15,00	12,00	22,60
Senegal	58,00	33,00	6,00	42,10
Total	**100,00**	**100,00**	**100,00**	**100,00**

APPENDIX D

Definition of DPSIR Framework elements, adapted from (Sanon et al., 2020)

Definitions of DPSIR	
Drivers	Agents or processes dominate the system's dynamics in such a way that they are unavoidable factors of change to ecosystems or human activities, including social, demographic, and economic development. As such, they profoundly influence nature and society.
Pressure	Direct results of the drivers. They can be human actions in response to the driver that affect aquatic ecosystems or effects of the driver in the case of natural drivers.
State	Quantitative or qualitative indicators that describe a component of the ecosystem of interest.
Impact	The effects of changes in the state on the ecosystem components.
Responses	The measures that are taken to improve the state of water bodies and to ensure the provision of ecosystem services. They can be also policies to prevent, mitigate, or adapt to the impacts triggered by the alterations of environmental states.

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