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Irrigation development under uncertainty: A call for adaptive investment pathways

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ABSTRACT

There is an urgent need in sub-Saharan Africa (SSA) to enhance irrigation access to meet the challenges of growing population and climate risk. To achieve this, big investments are currently planned in large irrigation infrastructure. We believe there is danger in following this conventional approach, which requires big lumpsum investments, locking large capital into projects that do not adapt to deep uncertainties from climatic or socio-political factors. Instead, in this Perspective article, we propose an alternate "adaptive investment pathways" (AdIP) approach for planning step-wise investments towards desired objectives, implemented progressively depending on how the future unfolds, in order to gain flexibility. AdIP extends the adaptation pathways concept, which refers to a sequence of actions to be taken in response to a changing reality, and applies it to the context of development under uncertainty. Monitoring and learning is at the heart of this approach, which ensures that the plan adapts as new knowledge becomes available. Thus, AdIP internalizes risk and reduces chances of failures. For financial institutions backing development projects, following a pathway of smaller de-centralized investments lowers risk and incorporates a learning approach that allows re-thinking and adapting along the path. We illustrate the AdIP approach using the case of ephemeral sand river based small-scale irrigation in the drylands of SSA. We conclude that in face of deep uncertainties, the path to successful irrigation development in SSA requires a shift from making few large upfront investments in large-scale projects to making large numbers of smaller investments that assure flexibility.

1. Introduction: current approaches to irrigation development are not adaptive

In 2050, Africa is estimated to have nearly 1 billion more people than in 2020 (UN, 2017). Africa will need to produce more food, feed, fibre and (bio-) fuel to satisfy the needs of all its inhabitants. Rainfall is the major source of water for food production in Sub-Saharan Africa (SSA), where at least 20% of all arable land is semi-arid to arid (300–600 mm/y). Despite the uncertainty about the future climate, most experts agree that in 2050 rainfall will be more erratic: rainfall events will be more intensive and dry spells during the rainy season are likely to be longer and more frequent (Conway et al., 2015). The large variability of rainfall directly impacts agricultural yields, which are low and have remained nearly stagnant for the last 30 years (Mueller et al., 2012). Combining population growth, climate change, and current agricultural production numbers, paints a challenging future. However, there is a vast potential to increase crop yields by enhancing access to water storage during dry spells and dry seasons. Most countries in Africa have a large scope for irrigation expansion. You et al. (2011) estimated that the irrigated area in Africa can profitably expand to 37 million hectares (177% increase from 2011) with most of it being in SSA. Harnessing this opportunity requires different types of investments as per the resource characteristics.

The opportunity of increased irrigation is widely recognized, also in the African Water Vision 2025 and various national development plans. However, to achieve this, the focus remains on large investments for big infrastructure projects (Harrison, 2018). For example, Kenya has set a goal to add 1.2 million ha to its irrigated area by 2030 (Republic of

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Kenya, 2013) primarily through new construction, rehabilitation or extension of dams and weirs. Large funds are channelled to enable this[1] in the form of big upfront investments. Such large-scale projects take many years to plan and implement, and have dubious returns even in the best-case scenario (Kikuchi et al., 2021; Lebdi, 2016; Merrey, 2020). They do not have the ability to adapt to changes, including in the social and political environments. The centralized management of such structures takes the power away from local communities, and often cannot adequately address the variegated developments on the ground. Given these known challenges of large irrigation projects, combined with growing challenges from future uncertainties due to changing climate or socio-political environments, we see a danger in the conventional approach to irrigation planning. In this Perspective paper, we draw upon our (action) research experience on investments in small-holder irrigation development (Duker et al., 2020a, 2022; Karimba et al., 2022) to instead call for alternative ways of investments, which can adapt to a rapidly changing uncertain world, minimize adverse impacts to society and environment, and empower communities.

2. Alternatives: what to invest in

Alternative ways of irrigation development in SSA focus on small- and micro-scale irrigation, both formal and informal, as well as farmer-led initiatives. Studies on economies of scale for irrigation projects in SSA (Fujiie et al., 2011; Inocencio et al., 2007) recommend investments in large projects that support many small-scale irrigation systems. That this idea is reaching a critical mass can be seen by the fact that the World Bank now embraces farmer-led irrigation development (FLID) in SSA. In their FLID guide (Izzi et al., 2021), the World Bank states that small-scale irrigation has greater potential for economically viable expansion, including in SSA, and makes a strong case for intervention support to multiple small-scale systems instead of large-scale irrigation schemes. It would therefore be a missed opportunity if the planning continued to follow the traditional mode of making large lumpsum investments that lock-in the plan to a specific future without taking future uncertainty into account. Conventional irrigation plans typically do not anticipate changes in biophysical system parameters (e.g. changes over time in precipitation, evapotranspiration, crop yields etc.) due to climate impact. They also ignore the dynamics of human response to changes in the climate and socio-political systems. Cropping pattern, irrigation practice, operation and management through well defined water users' associations – all of these are assumed to be static and known. Projects are evaluated ex-ante through a theoretical IRR (internal rate of return) computation based on a static, assumed scenario, and not on the actual development impact of the project. The World Bank approach to FLID recognizes the variability in stakeholder behaviour but it does not consider farmers' increasing risk due to the impact from climate and other factors. In contrast, we propose an adaptive approach to planning investments for irrigation development in a way that internalizes risk as part of the process. This is done by reversing the existing pattern of making few large upfront investments in large-scale projects to making large numbers of smaller investments in irrigation in a way that builds local capacity to monitor, learn and adapt.

3. Adaptive investment pathways (AdIP): how to invest

Adaptation pathways (Haasnoot et al., 2013; Werners et al., 2021b; Wise et al., 2014) refer to planning a sequence of actions towards a desired objective, to be implemented progressively depending on how the future unfolds, in order to gain flexibility and to prevent lock-in. It entails prioritizing no-regret actions and postponing or breaking down bigger investments. Monitoring and learning is at the heart of this approach, which ensures that the plan adapts to new knowledge as it becomes available in order to be future-ready.

There is a growing body of literature on developing the adaptation pathways concept for different objectives and contexts (Werners et al., 2021b). This is characterized by Bosomworth et al. (2015) using the Thompson and Tuden framework, which we reproduce in Fig. 1, by adding some cases as reported in the literature. The first axis in the framework captures the extent of availability of scientific data and tools to model uncertainties and their impact on the system – where these exist, pathways construction tends to be a largely computational and modeling task. The second axis captures the extent of agreement in stakeholder goals and roles. Where there is high divergence in stakeholder goals, building pathways requires greater stakeholder participation and negotiations. The most well-developed approaches for adaptation pathways occur in the bottom left quadrant, i.e. highly data-rich contexts with high stakeholder agreement on the goal of the pathways. They are designed for limited large national scale projects with the goal of preserving existing system from climate risks such as floods, droughts and sea-level rise (Lawrence and Haasnoot, 2017; Werners et al., 2021b). They rely on extensive analytics and modeling but are limited in their consideration of socio-economic uncertainties. They are also conservative in nature, aiming to preserve the status-quo and not specifically designed to seize opportunities.

Our extension of the pathways approach to the development context, specifically for development of irrigation in SSA, takes us to the least-explored top-right quadrant. Here, the goal of the pathways is to plan transformative interventions that exploit opportunities for development, as identified by stakeholders. In this context, scientific data and models are insufficient for an analytical approach to planning as it requires considering uncertainties not only from climate change but also from variable socio-political-economic environment. Moreover, there is high divergence amongst stakeholders on the pathway goals, as resources are scarce and there are competing demands. This requires the approach to explicitly address concerns of possible maladaptation and questions of equity and justice.

Our proposed "adaptive investment pathways" (AdIP) is an approach for planning small, step-wise investments to meet development goals under uncertainty. The nature of investments may vary depending upon stakeholder needs. For irrigation development, investments may support new infrastructure (water storage, roads to access market, post-harvest storage etc.), service provisioning (knowledge extension, irrigation equipment supply, access to capital etc.) and institutional capacity

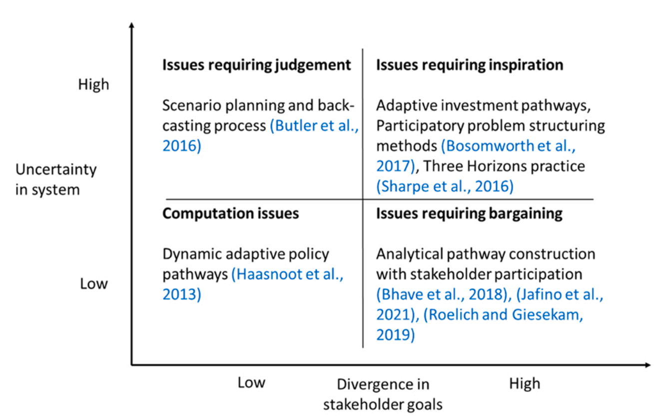

Fig. 1. Thompson and Tuden framework for classifying the use of adaptation pathways approach in literature (Bhave et al., 2018; Bosomworth et al., 2017; Butler et al., 2016; Jafino et al., 2021; Roelich and Giesekam, 2019; Sharpe et al., 2016).
Adapted from Bosomworth et al. (2015).

[1] For example, the average unit cost in SSA for new projects with construction is estimated at US$ 14,500/ha and for rehabilitation projects at US$ 8200/ha (Kikuchi et al., 2021). 50% new construction and 37% rehabilitation projects have been found to be failures in terms of their returns on investment.

building (e.g. monitoring systems). The infrastructure may be public (e.g. sand dam) or privately owned (e.g. solar pumps).

4. The AdIP planning approach reduces risk: who invests

The conventional approach to irrigation planning requires large lumpsum investment with very little co-investments from farmers (Fig. 2). The owner of the infrastructure and the borrower of funds is generally a government body or a large farmers' collective. The schemes have a long gestation period, and the farmer revenue stream from the irrigation activity starts after significant delay from the time of investment. The scheme life span is planned to be about 30 years during design but in most cases it is unable to meet the changing stakeholder demands and starts to run into operation and maintenance (O&M) problems. As a result, frequently, and often sooner than later, a fresh plan for scheme modernisation and rehabilitation is needed to revive the scheme (Kikuchi et al., 2021).

In contrast, an adaptive investment pathways approach to irrigation development entails a large number of small-scale investments that supplement farmers' own investments. Fujiie et al. (2011) show that each dollar of external investment in small- and micro-scale irrigation schemes induces 0.1–0.7 dollars of additional local investment, for example, through farmers' own labour contribution. Farmers take a larger role in shaping and in investing in their irrigation practice, whereas the role of the implementing agencies increases in providing safety nets for the farmers and facilitating loans, for example through credit guarantee arrangements (Izzi et al., 2021). Funds may be administered to farmers through local financing institutions such as microfinance institutions, farmer groups, savings groups, co-operative banks etc. (Karlan et al., 2017) or a large private entity in the agricultural value chain. To the farmers, this may be made available in the form of loans, subsidies or models such as pay-as-you-go or uber-for-irrigation (Merrey and Lefore, 2018). Farmers may start to see the benefit as early as within a season or two. Monitoring and learning is an important aspect for the farmers as well as investors. Farmers' revenues rise with increased learning and as bottlenecks are identified, new targeted investments are planned to address them. Constraints to successful irrigation can be identified and lessons learnt can be integrated into the plan at any stage to ensure that objectives are met. If an unforeseen uncertainty or crisis were to impact the development, it is possible to pause future investments or adapt with limited consequences. A large number of such small-scale investments planned as an adaptive investment pathway has the potential to be more successful and impactful than the existing approach of big upfront investments that get locked into large inflexible projects.

The AdIP internalizes risk, and thus reduces chances of failures, thereby addressing one of the most challenging aspects of development projects, i.e. securing funding for what is generally considered high-risk. For financial institutions backing development projects, following a pathway of smaller de-centralized investments administered through intermediate institutions may lower risk of investment and incorporates a learning approach that allows re-thinking and adapting along the path as new information becomes available. This has been documented in other domains as well. For example, in rural electrification, the idea of a flexible adaptive microgrid has been proposed in order to attain modularity, keep initial costs low, avoid lock-ins and expand gradually to suit an uncertain, changing demand (Ehnberg et al., 2020). Also, in Morocco, in response to a state subsidy scheme, local adaptation and innovation called "bricolage" led to rapid small-holder investments in drip irrigation systems. Farmers often started out with simple drip systems stripped of the costly components and made progressive improvements until they had developed complete systems themselves (Benouniche et al., 2014). These support the potential of AdIP in the irrigation sector to address the current problems.

5. Monitoring and learning is central to AdIP

The objective of monitoring is not to simply measure the extent of infrastructure developed (or area brought under irrigation) and assume this will lead to development outcomes. Instead, it is to measure the development outcomes and system states that may constrain achievement of goals (e.g. water availability, crop production, incomes etc.). Each investment action in an adaptive investment pathway has a corresponding saturation point,[2] that is, the point after which the investment no longer helps in meeting the development objective. As this point is approached, additional investments are required to make further progress towards the goal. The saturation point is a function not only of the biophysical system, but also of the social, economic and political environment and the risks therein. The AdIP therefore requires a portfolio of future investment options (e.g. water storage, extension, market infrastructure etc.) that may collectively meet inter-related sub-goals. Monitoring of the system is key to identifying saturation points and to inform the prioritization of the next incremental investment in the portfolio. The actual investment pathway which gets implemented evolves over time as the future unfolds and new information becomes available, possibly creating new investment options and/or closing others. As a result, investments may be re-sequenced, or new investment options may be added.

6. Design and implementation of AdIP

An adaptive investment pathways approach for irrigation development is embedded in the specific landscape (Sayer et al., 2013). Landscapes support diverse livelihoods, of which irrigated agriculture may only be one (Rietdijk et al., 2019). There are thus multiple and competing stakeholder demands for shared natural resources. The natural landscape and the socio-political landscapes are interconnected across scales through feedbacks. Achieving sustainable development through AdIP requires engagement not only with irrigators but also with diverse stakeholders to explicitly discuss and negotiate investment choices for accommodating different objectives (Bosomworth and Gaillard, 2019), addressing concerns of equity and justice, and avoiding maladaption (Juhola et al., 2016). Fig. 3 suggests a possible framework to develop the AdIP within a landscape.

7. Example: The case of sand river based irrigation

We now illustrate the potential of AdIP using the example of sand-river supported small-scale irrigation development, which is based on our past and ongoing research, including lessons from our action research activities (Duker et al., 2020a, 2022; Karimba et al., 2022).

Ephemeral sand rivers are a significant water resource in arid and semi-arid lands of sub-Saharan Africa. On the surface, these rivers appear to be dry for most of the year but their sandy river bed forms a shallow alluvial aquifer which has the potential to store significant volumes of water that is recharged from each occasional flood event. Upto one-third of the sand river bed volume is made up of water, of which a large part can be accessed at a very low cost, through scoop holes or hand-dug wells. Due to its transient, small-scale characteristic, sand river based irrigation is rarely recognized or supported through planned investments, which is, in our view, a missed opportunity. In this context, a large investment in creating water storage may not meet objectives and may even result in unintended consequences, such as large evaporation losses. The sand river itself makes a renewable nature-based water storage that is readily available for irrigation and other livelihood needs. Here we explore how by following the AdIP approach in Fig. 3, it is possible to develop a low risk irrigation development plan.

Step 1. Defining focal natural and social landscape: An integral part of

[2] Analogous to the "tipping point" in the adaptation pathways literature

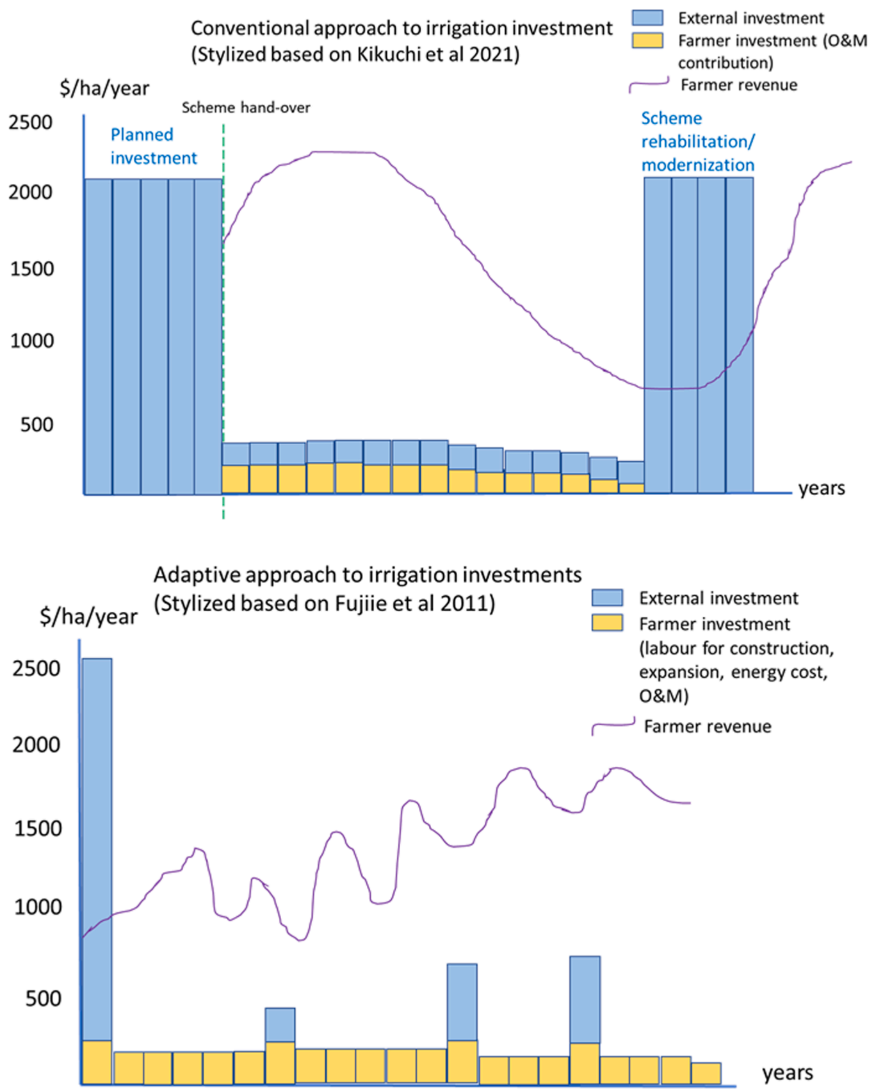

Fig. 2. Approaches to irrigation investments: Conventional vs. Adaptive. The investment for new and rehabilitated scheme in the graphs is informed by Unit Project Costs provided in Kikuchi et al. (2021) and Fujiie et al. (2011) for large schemes of size 1000 – 10,000 ha area and small schemes of less than 10 ha. O&M costs for large and small scale schemes are informed by Fujiie et al. (2011). For the adaptive investment pathway approach, the incremental investments are indicative and will vary depending upon the specific investment made. The ratio of O&M investment by farmer to external investments is an assumption informed by authors' experiences. The farmer revenue values are estimates in line with de Fraiture and Giordano (2014).

this step is to define the spatial scale in a way that it aligns with the physical and social landscapes under consideration. The sand river supports diverse needs of the communities around it, such as: drinking water, domestic and livestock needs, small-scale irrigation as well as sand-harvesting. The sand river also supports the riparian forest and related ecology. Hence, there are multiple, interconnected stakeholder demands from the natural resource. A participatory stakeholder discussion brings forth diverse stakeholder goals, common concerns and trade-offs.

Step 2. Identify opportunities and risks: The big opportunity, in most cases, is that the level of water use is currently far below what appears feasible. Hence, there is the potential to expand diverse water uses, including irrigated farming to reduce the impact of long dry spells and droughts. The sand river can support a significant number of small-scale farmers along its river banks.[3] However, the system faces many risks. Some possible risks that may be identified by stakeholders are not only climate related, in the form of severe drought and occasional floods, but also others such as market uncertainties, pest and wild animal attacks, failure of informal contracts, changing policies, remoteness to and access to resources etc. A combination of these risks often results in a start-stop dynamic that characterizes small-scale irrigation (Duker et al., 2020b; Karimba et al., 2022).

Step 3. Determine intervention goals and trade-offs: Stakeholder identified goals may relate to greater farm returns, greater resilience to risks through diversification of agriculture, higher value crops, fodder cultivation for livestock, expansion of irrigated area, expansion of water storage and actions to support complementary livelihoods. The trade-offs associated with the use of land and water resources for irrigation as opposed to other livelihood activities is negotiated amongst stakeholders, and set socio-political limits for each action.

Step 4: Identify external investments: Depending upon the selected goals, no-regret investments may be identified by stakeholders in interventions such as facilitation of extension services, access to market or irrigation equipment. These can be sufficient to jump start small-scale irrigation for cultivation of vegetable and fodder crops. It can initiate an endogenous development process that includes learning to know system boundaries and devising smart strategies, including new investments to expand coverage and/or address constraints.

Step 5. Identify saturation points of investments and parameters to monitor: Each targeted external investment supports the identified goal until a saturation point is reached, which is the point beyond which further progress towards the goal requires additional interventions. The

[3] This is our provisional estimate: Some 15% of Sub-Saharan Africa is criss-crossed by these sand rivers, hosting at least 100 million people in 20 million households. If 5% live close to large enough sand rivers, and would each cultivate 0.5 ha, this amounts to an irrigation potential of at least 0.5 million ha in African drylands

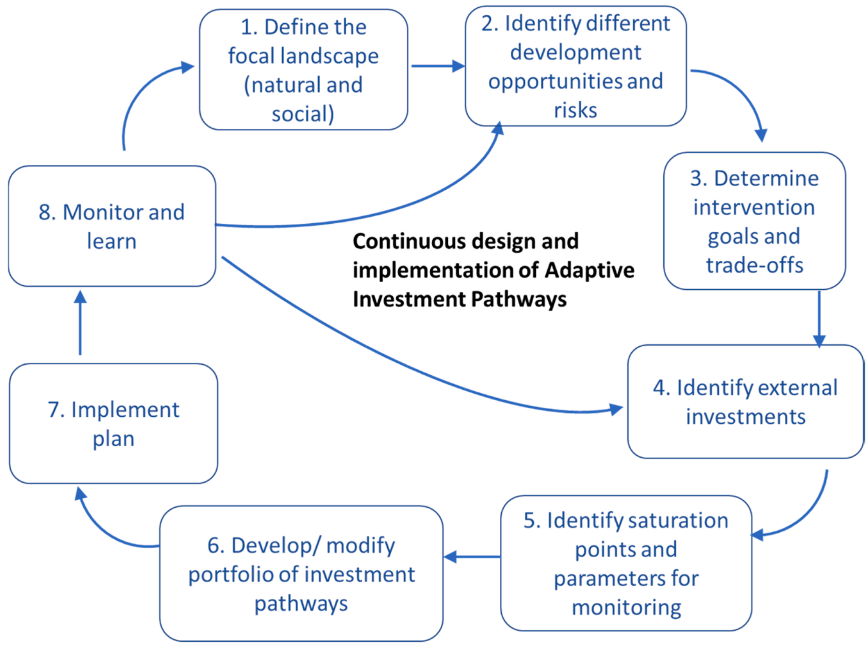

Fig. 3. Possible steps to develop Adaptive Investment Pathways
Modified from (Jeuken et al., 2015).

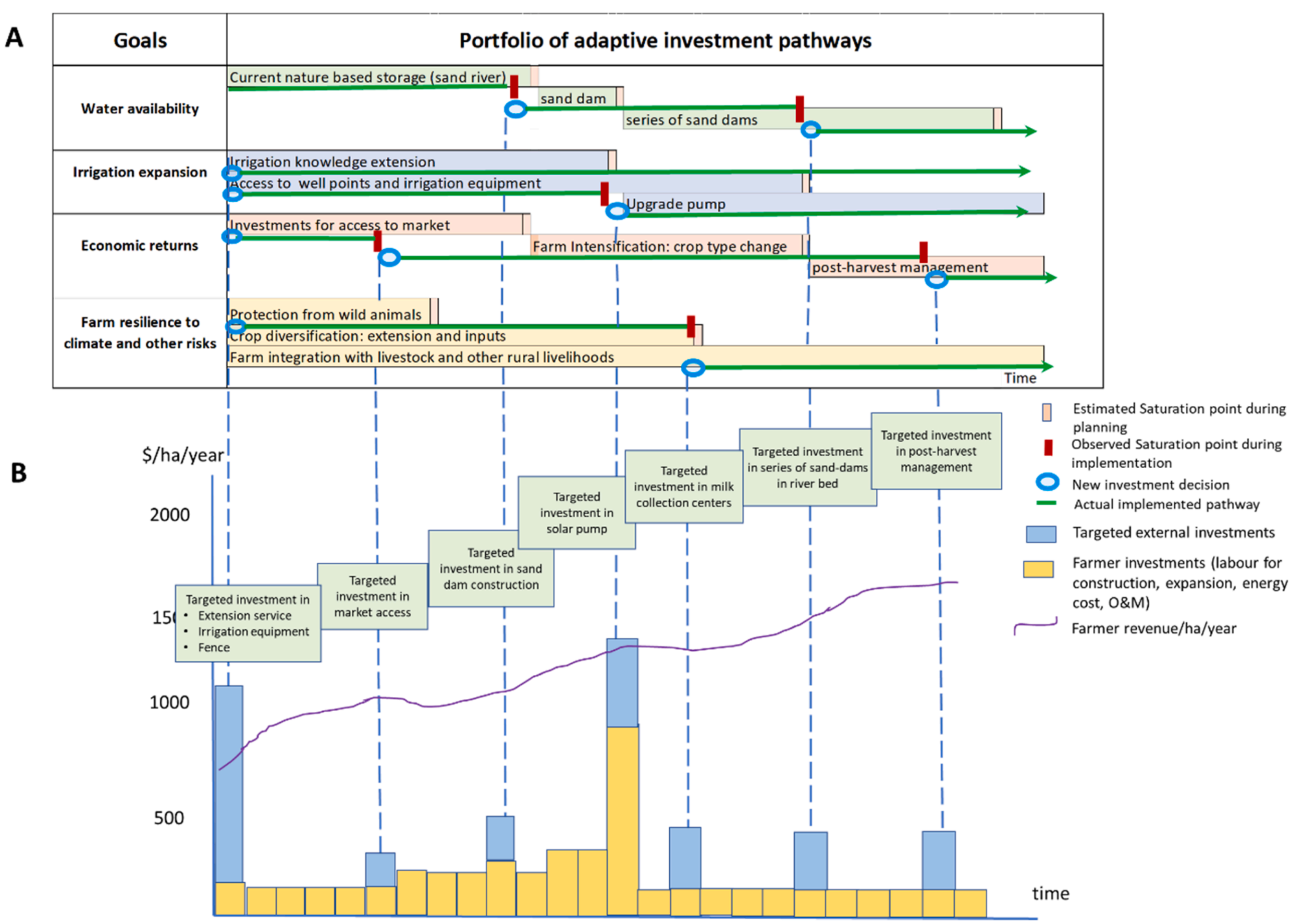

Fig. 4. Possible implementation of Adaptive Investment Pathways for sand river based small-scale irrigation development A. Example of planned portfolio of investments; B. Possible evolution of an actual implemented pathway.

saturation point for each investment may be a function of natural or socio-political limits. For example, an intervention to enhance water storage will reach a saturation point when irrigation and other water-use activities have expanded sufficiently to utilize the available storage. The monitoring process helps to identify the approaching saturation points and the new emerging constraints. A possible parameter for monitoring the saturation point for water availability would be the seasonal depth of water table within the shallow aquifer.

Step 6: Develop a portfolio of adaptive investment pathways: During the planning stage, it is not possible to precisely know when different saturation points will be reached due to various uncertainties. Hence, the idea of a portfolio of pathways is to indicate meaningful sequences of step-wise investments that may be followed to achieve identified goals. Fig. 4A shows a possible portfolio of investment pathways that may be planned for irrigation development. Where there is no dependency between investments (e.g., investment in knowledge extension and access to irrigation equipment) investments may be made in parallel or in any sequence in response to observed constraints.

Step 7 and 8: Implement plan, monitor and learn: The implementation of the investment pathways is done in an adaptive manner guided by new learnings from the monitoring process. As a result, the actual adaptive investment pathway evolves with time as investments are re-prioritized or new ones are added to the plan to address identified constraints. Fig. 4B indicates how implementation of adaptive investments may unfold over a period of time, guided by the planned portfolio of investments and monitoring of the system.

For example, during implementation, small investments in extension services and irrigation equipment may help to start off small-scale irrigation activity. This may be supplemented by farmers' own investment in fencing the farm. As farming expands and there is an increase in marketing surplus, there may be a need for intervention to enhance market access. Further, as farming scales up in the region the naturally available water in the sand river may reach a saturation point. This is flagged by the monitoring process (for example, monitoring of water availability in wells). At this time, a decision is made to invest in sand dam construction to enhance water storage capacity. It is possible that a saturation point on a parallel pathway is reached, for example high energy cost for pumping, and this may pause the overall irrigation growth. In that case the next investment to be prioritized could be solar-pumps. Over time, there may be an opportunity to enhance farmer resilience by integration with livestock management and fodder cultivation activities which may trigger an investment in milk collection centers and value chain development. The monitoring process thus identifies the emerging saturation points as well as opportunities and this learning is incorporated by adapting the investment strategy accordingly. In this way, a series of investments are made in response to the evolving situation.

A strength of AdIP for irrigation development is that it is anchored in the practices of smallholders. Research (de Fraiture and Giordano, 2014; Duker et al., 2022; Karimba et al., 2022) shows that smallholders value flexibility and expand their operations organically by making incremental investments, keeping their risks low at all times, and adapting their plans with changing circumstances. Lumpsum investments in conventional irrigation schemes ignore this and require farmers to conform to farming practices that are pre-planned in the scheme. AdIP proposes to turn this around, by instead asking investment agencies to change their way of operation and align with small-holder practices.

8. The way forward: from adaptation to adaptive investments

There is an urgent need for investment in irrigation development in the SSA, and at the same time there are growing risks due to factors such as climate change and capricious socio-political environment. In light of this, we believe there is danger in following the conventional paths for investment in irrigation development, which tend to be large-scale lumpsum investments that can lock large capital into projects that are unable to adapt to a rapidly changing, uncertain environment. We propose the adaptive investment pathways (AdIP) as an approach for making investments that are incremental, adaptive and sequenced in time depending upon and in response to the learning process. The AdIP approach is embedded in the natural and social landscape. It strengthens the capacity of communities and local institutions to collectively plan and negotiate to transform their livelihoods in face of change. At the same time, it has the potential to reduce risk for financing institutions making it possible for them to invest in small-scale and farmer-led initiatives, which are otherwise considered high risk.

Implementing AdIP requires a transformation in how development projects are currently evaluated, implemented and monitored. The investment pathways are long-term with no specific end, while development projects have defined duration and budgets. Hence, implementing AdIP may require disaggregation of pathways into a series of short-term development actions (Werners et al., 2021a) with continuous monitoring of progress towards the development goals and possible saturation points. This is different from current processes that do not consider uncertainties and instead measure tools of development, i.e. infrastructure developed, and area brought under irrigation, with the assumption that development will follow. Our proposed approach calls for a dramatic shift in how development agencies and government administrations operate, and how they co-design and co-implement projects with local communities and institutions. The use of multi-stakeholder agricultural innovation platforms (Parry et al., 2020) is one of the demonstrated ways to implement this.

Our note is a call to researchers for expanding the ongoing work on adaption pathways to orient it for use in development planning facing deep uncertainties. Equally importantly, it is also a call to government and non-government agents, and financing institutions working on irrigation development to urgently incorporate future risks in their investment planning by following an adaptive investment pathways approach. This is a tall order and we acknowledge that the current financial instruments are not conducive to the adaptive learning that we advocate. There is, therefore, a need to re-think the financing instruments and the way that projects are evaluated, i.e. against the objectives that the projects serve rather than the objects that they build. Ultimately, we believe that in an environment of deep uncertainties, the path to successful irrigation development in SSA requires a shift from a thousand investments of million dollars to a million investments of thousand dollars.

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.

Data Availability

All data sources have been cited in the article.

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