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Review

A Review of Payment for Ecosystem Services (PES) in Agricultural Water: Are PES from the Operation of Agricultural Water Control Structures Ubiquitous?

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Abstract: This paper reviews the consideration of the operation of agricultural water control structures (AWCSs) as sources of bundles of ecosystem services (ESs) and the subsequent design of payment for ecosystem service (PES) programs around these ESs. It is thought that PES schemes for AWCSs can complement irrigation service fees (ISFs) in funding the operation and maintenance of irrigation schemes. Case studies from Japan, the United States of America and Tanzania, representing a variety of socio-economic, geographic and climatic conditions, are discussed. In countries where the PES programs had legal backing, they showed evidence of sustainability and success. The measurement of marginal ESs flows from AWCSs proved to be one of the challenges to PES programs. There is a need to improve the measurement and modelling of hydro-meteorological and water quality parameters to ensure the transparency and success of the programs. In general, there was a realisation that ESs flow from irrigated agriculture, but there was no systematic design of PES programs around these ESs flows. An opportunity is seen to complement ISF through the design of PES programs around ES flows from the operation of AWCSs.

Keywords: agricultural water control structures; ecosystem service; irrigation and drainage scheme; payment for ecosystem service; valuing water

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1. Introduction

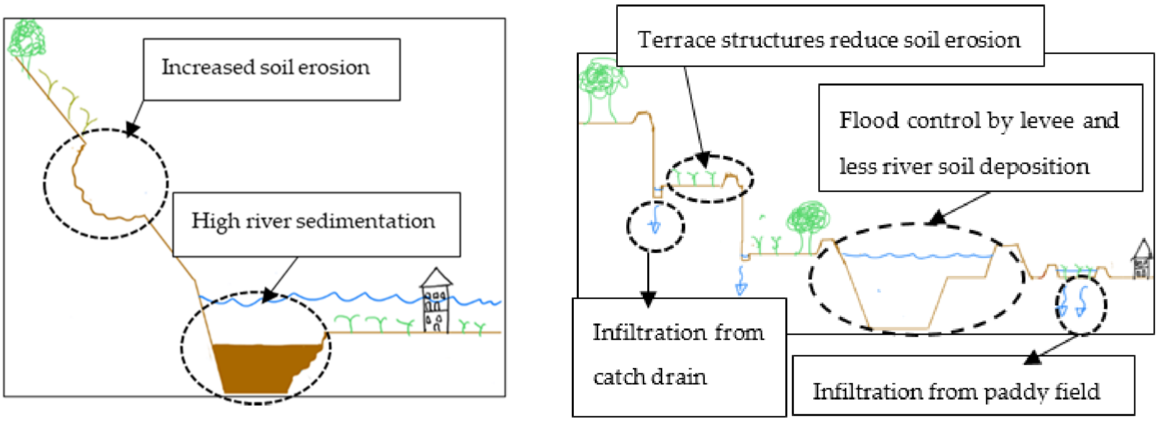
The concept of "Ecosystem Services (ESs)" is a novel front in nature conservation. It emerged in the 1970s, gaining wider recognition in the decades that followed [1]. It seeks an optimum scenario of environmental conservation while simultaneously considering societal needs and economic well-being. Indeed, Villholth and Ross reported that, recently, the dialogue on water and the environment has significantly shifted towards ways in which the environment can not only be conserved but be managed to meet human needs sustainably, focusing on working with nature to produce co-benefits for people and nature [2].

More recently, the Payment for Ecosystem Services (PES) concept was introduced to finance the drives that contribute to the flow of ESs. According to UNDP, in PES, the user or beneficiary of an ES makes a direct or indirect payment to the provider of that service [3]. Here, a program is set up where monetary value is created for ESs stemming from land management practices.

As far back as the 18th century, utility companies in Japan offered grants to upstream forestry workers for their silvicultural activities [4]. PES were first introduced in the mid-1990s and have proven to be an effective tool for ecosystem conservation, with over 550 active PES programs globally and over USD (United States Dollar) 36 billion in annual transactions [5].

The value of water to society is shored up by hydraulic infrastructure, which serves to store or distribute water, thus creating economic, social and cultural benefits [6].

Likewise, in addition to their irrigation and drainage functions, the management and operation of agricultural water control structures (AWCS) has been shown to provide other bundles of ESs [7–10] (Figure 1). AWCSs redistribute the river water to the cultivated field and canal network, allowing more time and opportunity for river water to infiltrate into the ground and increase baseflow and aquifer recharge, as well as purifying water and being a refuge for riparian vegetation and organisms. Pre-Inca civilisations were aware of this and built water control structures to divert water to higher elevation areas so as to secure dry season flow in the Andean areas [8]. Similarly, in its 2003–2006 8th framework program, the French RMC water agency enacted a new canal contract aimed at taking into account their (canal) multi-functionality [9]. Additionally, other bundles of ESs flow from rice paddy growing areas, so-called "multiple functions" of paddy fields [11–13]. A well-maintained paddy field, which is a hydraulic structure, modifies hydrologic processes such as peak discharge reduction (flood reduction) and aquifer recharge, provides grain and fibre and maintains a diverse ecosystem.



(**a**) (**b**)

Figure 1. (**a**) Mode of flow of materials and ESs in the absence of AWCSs. Increased soil erosion due to steep slope and slope cultivation is highlighted; (**b**) Mode of modification of the flow of materials and ESs due to the operation of AWCSs. Increased water infiltration to the ground from catch drains and paddy fields as well as reduced flood spatial extent due to levees and reduced soil deposition in the river are highlighted.

Much as a willingness to pay for such ESs was reported by Vivithkeyoonvong et al. [14], a UN report revealed the valuation of hydraulic infrastructure and other non-consumptive uses of water as being flawed [6]. It is thus remarkable how ESs from AWCSs are not widely considered in agricultural water management strategies.

Globally, ageing infrastructure and the reducing revenues to perform the maintenance and repair of irrigation and drainage infrastructure is a concern [15]. Gany et al. recognised the importance of the timely and effective development and maintenance of infrastructure to the secure functionality and sustainability of irrigation and drainage schemes [16]. This requires financial resources, which are not readily available. More often, farmers are the sole contributors of fees when they pay a water user fee [17], and this is insufficient [18]. This water service fee is normally set below its marginal cost or at its sustainability cost to ensure the profitability of irrigated agriculture for farmers [18]. Gany et al. attributed the limitation in funding sources to policy ambiguity and the social value associated with irrigation water as opposed to its economic value [16]. As a result, in many cases, the burden of major repairs then falls on the central government [18,19], which is sometimes not forthcoming, given budgetary constraints. Because the charged ISF is meagre, many irrigation and drainage projects then become dilapidated or fail to recover the sunk investment [15].

Conversely, rapid urbanisation or the predicted decreasing populations in developed countries lead to the conversion or abandonment of irrigation and drainage infrastructure and areas, respectively [20,21]. The irrigation and drainage infrastructure should therefore be preserved by highlighting and monetising not only their agriculture production benefit but also their economic and social benefits.

Therefore, alternative sources of income must be explored to complement ISF and ensure the sustainability of irrigation and drainage projects. It is proposed that a PES program be built around the multiple ESs flowing from the operation of AWCSs and the various beneficiaries of these ESs. This will allow the sharing of the cost burden of operation, maintenance and repair of irrigation and drainage infrastructure among the various beneficiaries of the ESs. A case in point is that communities around an irrigation and drainage scheme may benefit from reduced flood, and the citizenry will benefit from the reduced cost of food, while the government benefits from having food security and social capital brought about by collaboration and harmony among farmers due to cooperative action through Water User Associations (WUAs).

Our research group developed the idea to consider PES from grey-green infrastructure (irrigation infrastructure) synergy as a potential source of income to boost income for irrigation systems. To confirm the novelty of our thought, this article review looks for evidence of PES schemes built around the ecosystem services that flow from the operation and management of irrigation and drainage schemes. This is useful since finances from PES from AWCSs programs can complement ISF to ensure the sustainability of irrigation and drainage projects in agricultural production and the provision of ESs. Further, we think PES from AWCSs can be successful because there is documented evidence of a willingness to pay for these services. We have explored the existence of such schemes globally, the challenges facing them and good practices from existing schemes and now seek to introduce our idea of PES from the operation of AWCSs if there is no evidence of their existence and strategies to make PES schemes from the operation of AWCSs more ubiquitous.

2. Systematic Review

For the literature search, the study adopted four systematic procedures, i.e., (i) search criteria of the research field, (ii) search and document selection, (iii) software and data extraction and (iv) analysis of results and trends [22].

Step 1: Search criteria for the research field

The study looked at the concept of PES schemes for the operation of irrigation water control infrastructure through a literature review. The search words were "markets for ecosystem services", "payments for ecosystem services", and "payments for environmental services". These terms have been used interchangeably over the years.

Step 2: Search and document selection

Various databases exist for bibliography, e.g., Scopus, WEB of Science, PubMed, ERIC, etc. Herrera-Franco et al. reported that Scopus had a wealth of globally spread metadata records of scientific articles, complete with profiles of authors and institutions [22]. They also mentioned its superior precision and data recovery. For these reasons, Scopus was the bibliographic database of choice. The extraction of necessary articles was carried out in August 2021 using a series of terminologies related to the terminology "payment for ecosystem services".

The initial search aimed at extracting literature related to PES in agricultural water management. An initial search was conducted using the following query string: ((TITLE-ABS-KEY ("Payment for environmental services")) OR (TITLE-ABS-KEY ("Payment for ecosystem services")) OR (TITLE-ABS-KEY ("markets for ecosystem services"))) AND (TITLE-ABS-KEY ("irrigation* "OR "agricultul* "OR "water" OR "agronom*")). It resulted in 567 documents, namely: 431 articles, 53 book chapters, 46 reviews, 20 conference papers, 6 books, 5 notes, 2 editorials and short surveys each and 1 conference review and erratum each.

Later, the search was fine-tuned to focus on PES and the operation of irrigation and drainage infrastructure. The following search was conducted: ((TITLE-ABS-KEY

("Payment for environmental services")) OR (TITLE-ABS-KEY ("Payment for ecosystem services")) OR (TITLE-ABS-KEY ("markets for ecosystem services"))) AND (TITLE-ABS-KEY ("irrigation* infrastructure" OR "agr* infrastructure" OR "irrigation* structures" OR "water infrastructure")). This was done to maximise the number of positive hits on the relevant literature.

No limits were set on the year, type of document or language. Consequently, 3 documents were obtained [23–25]: 2 articles and 1 book chapter (Table 1). On top of the 3 documents sourced from Scopus, more literature from reports of successful case studies in different continents were sourced to tell a more detailed story.

Table 1. Articles extracted from Scopus.

Title	Author(s)	Year	Source	Cited by	Type of Document
Incentives for ecosystem service supply in Australia's Murray-Darling Basin	Banerjee, O., Bark, R.	2013	International Journal of Water Resources Development 29(4), pp. 544–556	12	Article
Can Uplanders and Lowlanders Share Land and Water Services? (A Case Study in Central Java Indonesia)	Andriyani, I., Jourdain, D., Shivakoti, G.P., Lidon, B., Kartiwa, B.	2017	Redefining Diversity and Dynamics of Natural Resources management in Asia. 1, pp. 321–330	2	Book chapter
Protecting Natural Water Infrastructure in Espírito Santo, Brazil	Pagiola, S., Platais, G., Sossai, M.	2019	Water Economics and Policy 5(4), 1850027	2	Article

Step 3: Software and data extraction

The data from Scopus were exported as a Microsoft spreadsheet in (.csv) format for the purpose of further analysis.

Step 4: Analysis of results and trends.

Strictly speaking, the extracted articles were not PES built around the operation of AWCSs. Therefore, case studies of PES related to AWCSs representing various socio-economic and geographic scenarios had to be found.

3. Case Studies for PES from the Operation of Agricultural Water Control Infrastructure

Three case studies were chosen to grasp the state of PES from the management of irrigation infrastructure.

3.1. Japan

Domestic, industrial and agricultural water in Kumamoto City and surrounding municipalities is mainly sourced from ground water aquifers. A third of this ground water is recharged through paddy fields. Recently, paddy fields have been converted to upland crops or built-up areas. Additionally, industrial consumption of the underground water dramatically increased, threatening the yield of the aquifer. To address this problem, in 2003, one of the largest consumers of underground water, Sony Semiconductor Co.'s Kumamoto Technology Center, started a water recharge project in cooperation with farmers, a Non-governmental Organisation (NGO) (Kumamoto Environmental Net-Work) and land improvement districts. The farmers in the middle reaches of the Shira River are paid to flood paddy fields during winter to recharge ground water aquifers so as to offset the ground water consumed by Sony Semiconductor Co.'s Kumamoto Technology Center [26–28]. Through scientific investigation, Ichikawa reported that spring waters in Lake Ezu have recently been on the rise, a sign of the recovery of Kumamoto's ground water aquifer [29]. Further, a water budget investigation of the Shira River Basin attributed most of the recharged water to rice paddy irrigation [29,30].

Success has been recorded since the accumulated amount of water that has been used by the plant as of 2009 (9.8 million tons) has been successfully recharged. Further success of the scheme lies in the fact that the area of winter flooded paddy field has expanded and other small-medium companies that use ground water have joined the scheme. Furthermore, the Kumamoto City Government safeguarded the survivability of the scheme by incorporating it into the municipal water conservation program. In addition, there is a movement to brand the rice grown in these paddies and sell it under a brand name to further support the project [26–28].

The Kumamoto model of aquifer recharge by mid-stream paddy fields can be attributed to leaky soil layers. It can therefore be replicated in areas with a similar soil structure.

The success of the Japanese case studies is attributed to the culture of Participatory Irrigation Water management (PIM). Therefore, among other things, close collaboration and coordination among all stakeholders is necessary for the success of PES schemes.

3.2. The United States of America (USA)

According to Bohlen et al., many farmers and ranchers were willing and able to provide environmental services beyond food and fibre, but they needed incentives to do so [31]. Cognisant of this, in the Northern Everglades, Florida, a 10-year pilot project—the Florida Ranch Lands Environment Services Project (FRESP)—was started in 2003. The idea was to impound storm water on the ranch lands, slowing the flow of runoff off and nutrients into Lake Okeechobee and the estuary. The program also incentivised ranchers not to sell or convert ranches to urbanised areas so that ES flow could be preserved. The ranchers were the sellers of the ESs, while the public, through The South Florida Water Management District, a state agency, were the customers for the ES. Conservation agencies, scientists and researchers were also among the stakeholders [31–33].

From the FRESP program, lessons and challenges to PES program design are identified, e.g., FRESP proved that formerly drained grazing lands can remain in agricultural production and restore a natural drainage flow and that ranchers were willing to reduce livestock production to provide better water quality [31–33].

The uniqueness of the FRESP program lies in the fact that the ESs were quantified. Water retention and water quality parameters were monitored by hydrological and water quality models. In addition, to ensure compliance and improve model accuracy, rainfall and water levels were measured in the target fields.

The success of the pilot FRESPS program is evidenced in the fact that, in 2011, the South Florida Water Management District adopted the Northern Everglades–Payment for Environmental Services (NE–PES) program as a continuation of the FRESPS program [34,35].

3.3. Tanzania

In Tanzania, a PES scheme built on irrigation and drainage infrastructure is a project in the Uluguru mountains, upstream of Tanzania's Ruvu River Basin, in the sub-catchment of the Mfizigo River [36–38]. Prior to the project, a 2007 CARE-WWF (Care International—World Wildlife Fund) study had revealed a decline in the Ruvu River water quality due to increased sediment load and a dramatic fluctuation in the river discharge caused by the slash and burn agricultural practices of the upstream farmers. These environmentally destructive agricultural practices eventually led to increased water treatment costs and to the rationing of water in the downstream areas of the catchment.

A scheme involving downstream buyers (industry (Dar-es-salaam Water Supply and sanitation Authority (DAWASCO) and Coca Cola Kwanza Ltd.)), upstream sellers (265 farmers), NGOs and relevant government agencies was established. Farmers received payment for the adoption of sustainable farming practices targeted at soil and water conservation. Structural, vegetative and agricultural (intercropping of crops with fruit trees, mulching, organic fertiliser) interventions were implemented in an integrated soil and water management strategy. Structural interventions included the construction of bench terraces and *fanya* (traditional terrace with ditches along the contour bunds, commonly observed in East Africa) terraces. The result was enhanced productivity of the land, increased water yield and improved water quality, which reduced water purification costs—a win-win situation for all involved. Payments were allocated according to the area of land that was converted to an identified Sustainable Land Management (SLM) Practice and the type of land use practice adopted.

This PES scheme was less than ideal because there was no monitoring of water quality to determine the effect of land management practice on water quality. Rather, payments were made to farmers based on their adoption of a certain management practice [36]. In addition, there was no evidence in the literature to show the expansion of the program to include other farmers. This scheme should be closely observed to gauge its performance in the long term. Msaghaa et al.'s research on the application of the WEPP (Water Erosion Prediction Project) model in the Wami-Ruvu Basin [39] should be further advanced in tandem with more monitoring and measurement of water quality, erosion and hydrologic parameters.

3.4. To What Extent Are the Case Study Programs Ideal PES?

From all the case studies, there was a willing buyer(s) and seller(s) of ESs. In addition, there existed a neutral intermediary who facilitated the PES program process, as shown in Table 2. In all but the FRESPS case study, payment for the ESs generated was not dependent on actual quantifiable ESs such as the amount of water quality improvement or the amount of water yield increase. Rather, it was established that payment for the flow of ES flows was dependent on the adoption of an agreed land management practice(s). However, there was no evidence of systematic scientific investigations to confirm this link. FRESPS stood out because there was quantification of ESs by hydrological and water quality models.

Table 2. Summary of the selected PES case studies.

PES Program	ES	Seller	Buyer	Evaluation of ES
Groundwater recharge project in Kumamoto	Aquifer recharge through the flooding of mid-catchment paddy fields in off-season	Mid-stream farmers	Sony Semi-conductor Co. Kumamoto Technology Centre	Acreage of flooded paddy field
FRESPS and N-PES	Amount of storm water impounded; the amount of nutrients that can be removed	Cattle ranchers	The South Florida Water Management District	Hydrological and water quality modelling was used to estimate the flow of ESs. Contract compliance and modelling accuracy was ensured by the observation of critical parameters like rainfall and water level on the fields.
PES in Uluguru Mountains	Water quality improvement by reducing river sediment load through SLM by upstream farmers	Upstream farmers	Coca Cola Kwanza Ltd. and DAWASCO	Method of land management adopted; acreage of land converted to PES recommended land management practice

Few examples exist of programs that pay directly for quantified services [31]. The Japan case study showed some scientific evidence of the effect of the management practice by the water level rise of Lake Ezu [29,30], but it cannot be attributed to the PES scheme with certainty. In the Tanzania case study, there was no literature to systematically confirm the effect of the PES scheme in improving water quality, although reports of increased water yield and quality have been made.

On account of the above reasons, the FRESPS case study best approximated the ideal PES scheme. The other two case studies could be classified as "narrow" PES, a terminology introduced by Branca et al. [37]. In an ideal PES program, there ought to be a precisely quantifiable link between the land management practice and the amount of marginal ESs generated. Perrot-Maître doubts that this ideal situation can be achieved [40]. Indeed, hydro-geological relationships and responses are complex, and measurement techniques are not able to achieve accurate linkages between specific land management practices and marginal ESs flows.

3.5. Lessons from the Case Studies

- There are only a few examples of PES schemes from AWCSs worldwide. This is even though AWCSs generate bundles of ESs and there being a willingness to pay for these ESs from the public. It is an opportunity to harness this resource by designing PES to complement ISF to ensure the sustainability of irrigation development projects.
- Apart from the FRESPS case, the PES schemes in the case studies were based on compliance with the agreed management practice. But this is insufficient—there is need for evidence-based evaluation of ecosystem services flow. This includes finding the link between management practices and ESs even before program implementation. When the program is implemented, there is a need for hydrological and water quality monitoring in the valuation of ES flows. Hydrological modelling could complement hydrological monitoring and provide a quick overview of the ES flows. In brief, hydrological monitoring and modelling has an important role in developing capabilities to better estimate the marginal ES flows from the adoption of certain management practices.
- The Kumamoto case study expanded and was incorporated into the municipal water conservation program. Similarly, FRESPS expanded and transitioned to N-PES. This was probably because the case studies were backed by law, strong farmer structures, (e.g., Land Improvement Districts in Japan) and the monitoring of success and compliance. These issues should be seen as critical for the sustainability of a PES scheme.
- For sustainability, there is a need to support PES schemes by legal frameworks. A 2011 report called for the integration of ESs in decision making by the federal government [41]. Further, Kadigi et al. recommended the institution of a regulatory framework in PES schemes to enable their implementation at larger scales [42]. In cases where PES is not incorporated in the agricultural policy, Perrot-Maître proposed the creation of a good and strong enforceable contract law [40].
- Close collaboration and coordination among all stakeholders was necessary for the success of the PES schemes. This has been proven by the success of the Japanese model because of the culture of Participatory Irrigation Management (PIM).
- The PES schemes were mainly a mechanism to secure the flow of ESs and not seen as a complementary finance mechanism for irrigation schemes. It would add more attractiveness to mainstreaming such PES programs if their contribution to finance for irrigation scheme management was also emphasised.
- A willingness to pay for ESs and a willingness to perform land management practices that ensure ESs flow was confirmed.
- Ideal PES is not achievable but only approximated. Indeed, Kroeger argues that true economic optimality in PES is unfeasible and pushes for shifting focus to achieving cost effective PES programs [43].

4. Discussion

4.1. Challenges Facing PES from the Operation of Irrigation and Drainage Infrastructure

Globally, PES schemes from the operation of irrigation and drainage infrastructure are rare. Tapping this potential and building PES programs around these ESs could be a game-changer in financing the sustainable operation and maintenance of irrigation and drainage schemes. The finance from PES can complement Irrigation Service Fee (ISF) as a source of funds for the sustainable management of irrigation schemes. This could be helpful in areas where the cost of production is very high and prohibitive and in areas where finances to repair, maintain and mange irrigation infrastructure are limited.

Perrot-Maître recognises the challenges of PES schemes because of their success depending on the intersection of scientific, societal, economic, political, institutional and power relationships [40]. In areas where this link was strong, such as Japan [27] and the USA [31], the PES schemes were relatively successful, and future sustainability was guaranteed. Conversely, in areas where the link was weak, e.g., the Uluguru Mountains programme [37], with no strong legal backbone to support PES, the long-term success of the scheme was in doubt. In such cases, Perrot-Maître recommended the institution of a strong enforceable contract law.

Many PES schemes are reported to fail after the end of the launch project [37]. This could be attributed to the lack of legal or policy framework backing for PES. This claim was supported by de Groot et al. when they reported that the ES concept had yet to be mainstreamed into management and decision making, e.g., in landscape planning or agricultural policy [44]. Just like previously mentioned by Perrot-Maître, in such cases, a strong enforceable contract law must be written [40].

Numerous PES payments depend on the adoption of suggested management practices and not on the actual measurements of water quality or yield, and it is impossible to determine the contribution of each farm to water quality improvement [28,37,40]. This was the case in all but the FRESPS case study. However, this is not ideal since PES is a trade of ESs. Such ESs must be precisely quantifiable, and it should be possible to attribute a particular environmental management practice to the ES observed. The unique case was the FRESPS case study [31–33], where water quality and yield were quantified by a modelling approach, complemented by site measurement of rainfall and water levels to confirm compliance by the ranchers. Less certain was the case study in Kumamoto, Japan, where a scientific study reported rising Lake Ezu water levels and gave the PES program as a possible reason for this occurrence [27,28].

If setting the price by the valuation of marginal benefits of ESs is impossible, Banerjee and Bark suggested valuation by the opportunity cost to the buyer [23]. However, in the Uluguru Mountains case study [36,37], the opportunity cost to the seller was the basis for the payment. Choosing which opportunity cost to consider could be another point of disagreement, as was seen in the Vittel PES scheme [40]—farmers demanded they be paid based on the opportunity cost to the buyer and the buyer insisted they pay based on the opportunity cost to the farmer. Through negotiation, a middle of the road solution that is agreeable to both parties can be reached.

Aggressive farmers knew the value of their farms and wanted to use opportunity cost to the buyer as the level of compensation [40]. This was different from the Uluguru Mountain case study, where there were no reports of aggressive negotiations with farmers based on their data. In the Uluguru Mountain case study, which must be the case in many areas where subsistence farming is prevalent, farmer illiteracy and low training meant poor record-keeping and book-keeping on-farm activities. This means there is inequality in negotiating PES deals, especially with big corporations. There needs to be a promotion of record and book-keeping, especially among peasant farmers who are mostly illiterate, to secure equality in PES negotiations. In such cases, the role of strong farmer unions in making PES negotiations more equitable should be explored.

4.2. Further Needs for PES for AWCSs

To be able to estimate the marginal flow of bundles of ESs from PES land management programs, the measurement and monitoring of water resources parameters is crucial. The FRESPS program achieved this [31–33]. However, this can significantly increase the cost of PES programs. Therefore, the role of freely available and remotely sensed data and modelling strategies should be explored to fill this gap. These are opportunities for hydrologists to engage in PES schemes. This issue was discussed in previous studies that focused on the challenges and opportunities of hydrological monitoring and modelling (HMM) in the water-related ES assessment of PES schemes [45,46]. The combined role of HMM should be explored, including improving monitoring networks and improving the salience and credibility of water resources models. Considering budgetary constraints, an optimum monitoring-modelling strategy should be adopted, cognisant of the constraints of each individual strategy. This offers new areas of research.

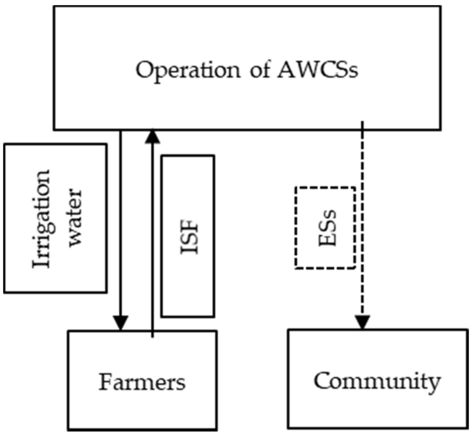
There is a need for further research in understanding the links between adopted management practices and their marginal contribution to the flow of ESs. If such links are clarified, this can complement or even replace HMM strategies where they are not developed.

Since there was no case study where the PES scheme was developed with the main purpose of financing irrigation and drainage schemes, the thought of our research group could be a novel idea, i.e., "Developing PES schemes for the operation of agricultural water control infrastructure as a complementary finance mechanism for operation, maintenance and repair".

In our next research, we hope to contribute to PES from the operation of AWCSs through developing hydrological and soil erosion models for the sustainable management of water resources in small-medium sized catchments in Eastern Uganda.

4.3. Recommendations in PES for the Operation of Irrigation Water Management Infrastructure

PES is currently an environmental policy instrument [5], e.g., up until now, PES considered green infrastructure such as upstream forest management to preserve /improve water quantity and quality. We want to make it a sustainable irrigated agriculture policy instrument. Our research team thus proposes the idea: "Developing PES schemes for the operation of irrigation and drainage infrastructure as a complementary finance mechanism for operation, maintenance and repair" (Figure 2).



(**a**) (**b**)

Figure 2. (**a**) Schematic of the existing financing mechanism for AWCSs. Here, only the direct beneficiaries of irrigation water service pay for the service, while the community indirectly receives free ESs, sometimes even unaware of their very existence; (**b**) Schematic of a traditional financing mechanism coupled with a PES financing mechanism for AWCSs. Here, the indirect beneficiaries pay for the ESs flowing from the operation of AWCSs, complementing ISF.

In Figure 2, to transition from (a) to (b), ESs flows should be measured and valued so that the potential buyer and seller can be aware of their existence and benefits, enabling smooth and transparent PES transactions. Our research group then took on the task "to develop a coupled hydrological-sedimentation model for sustainable water resources management of small to midsized catchments in Eastern Uganda".

To ensure better estimates of the number of ESs, a monitoring network coupled with easy and accurate models is useful [31]. Ideally, the contribution of each farm to water quality and/or yield should be measured. However, having an observation and monitoring network adds to the cost of the PES program. In addition, the monitoring methods might not be able to precisely quantify ESs from a management practice or even precisely identify the exact contributor of the ES. Therefore, the role of hydrological and water quality modelling should be explored.

Furthermore, when it is impossible or difficult to estimate marginal PES generation from a land management practice, a relationship between the adopted management practice and the expected ES flow can be found through scientific investigation. This was done systematically before the implementation of the Vittel PES program [40]. In the case studies described above, there was no report of a specific link between management practices and ES flow. In the Kumamoto case study, scientists reported a rise in Lake Ezu levels and attributed it to aquifer replenishment due to the PES scheme, but this has not been confirmed with certainty. In the Uluguru Mountains, studies have yet to confirm the impact of the land management practices on water quality and yield.

Previous research recommended private and public sector engagement to ensure the sustainability of irrigation and drainage projects or PES schemes [18,37,47]. Additionally, de Groot et al. recommend mainstreaming PES by streamlining it in policy and legal frameworks [44]. When the policy and legal frameworks are lacking, strong enforceable contract law should be created [40].

To ensure their sustainability, PES schemes should be appropriate to the socio-economic condition and ability of the stakeholders. It would be most ideal to have a smooth transition without the need for massive training, whenever possible.

Activities that maintain the productivity of the land might be most sustainable. In Perrot-Maître, since farmers continued to carry out their farming activities, only at a sustainable scale was the scheme judged to be sustainable, as compared to some management practices in Uluguru Mountains where farming had to be substituted for an ES suitable intervention, e.g., terracing. The Uluguru Mountain program risks collapse when the project period ends because terraces occupy agricultural lands and will thus be reconverted when payments cease. On a positive note, the sustainability of the Uluguru Mountain program was in the fact that traditional methods were used in the construction of the bench terraces. The Kumamoto case was easier to implement, as farmers did not require any additional technical training, did not give up farmland and did not need additional resources to flood their fields. This is in contrast with the other PES schemes studied, where the changes required were drastic. In Kumamoto, there was no loss of production, no need to compensate for opportunity cost and no investment in learning costs linked to adopting new technologies. Additionally, only service was paid.

The willingness to accept a PES program and pay for the generated ESs was dependent on the opportunity cost [48–50]. The importance of estimating the opportunity cost of PES schemes to ensure the sustainability of the interventions was emphasised [36,51]. They further recognised the need to secure the long-term participation of the stakeholders to meet the timescale requirements to restore the ecosystem functions. To achieve this (long-term stakeholder participation), we recommend a participatory strategy between buyers, sellers and other stakeholders to ensure the sustainability of PES schemes, akin to PIM in the Japanese setting.

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