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RESEARCH ARTICLE

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# Ecosystem services of irrigated and controlled drainage agricultural systems: A contemporary global perspective

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**Abstract**

Irrigated agriculture provides 40% of the world's crop-based foods but often with a negative impact on the environment. It is important to recognize that in addition to providing food and fibre, irrigation and controlled drainage systems can be optimized to provide additional ecosystem services and mitigate climate change by using resources in a more efficient way. Contemporary case studies were identified from around the world, including flood control by paddy fields in Japan, water quality enhancement and wastewater reuse in South Africa and Taiwan, micro-/meso-climate regulation in Ethiopia and Japan, controlled drainage and sub-irrigation to maximize carbon sequestration and minimize leaching in Finland, and groundwater table management to reduce irrigation water and pumping requirements in Turkey. Irrigation infrastructure, such as rice paddy terraced landscapes (Japan) and large dams and canals (Australia), have also achieved notable additional ecotourism job creation. Case studies were analysed in terms of funding opportunities and compared using the Common International Classification of Ecosystem Services system. It is recommended that planning frameworks be developed that seek to optimize ecosystem services such as the ones discussed above. Policy should be updated to recognize these services and provide incentives to irrigators and water management entities accordingly.

**KEYWORDS**

controlled drainage, ecotourism, evaporative cooling, poor quality water, sub-irrigation, water harvesting

**Résumé**

L'agriculture irriguée fournit 40% des denrées alimentaires à base de cultures dans le monde, mais elle exerce souvent un impact négatif sur l'environne-

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ment. Il est important de reconnaître qu'en plus de fournir des aliments et des fibres, les systèmes d'irrigation et de drainage contrôlé peuvent être optimisés afin de fournir des services écosystémiques supplémentaires et d'atténuer le changement climatique en utilisant les ressources de manière plus efficace. Des études de cas contemporaines ont été identifiées dans le monde, notamment la lutte contre les inondations dans les rizières au Japon, l'amélioration de la qualité de l'eau et la réutilisation des eaux usées en Afrique du Sud et à Taïwan, le règlement du micro/méso-climat en Éthiopie et au Japon, le drainage contrôlé et la sous-irrigation pour maximiser la séquestration du carbone et minimiser le lessivage en Finlande, et la gestion de la nappe phréatique pour réduire les besoins en eau d'irrigation et en pompage en Turquie. Les infrastructures d'irrigation, telles que les paysages de rizières en terrasses (Japon) et les grands barrages et canaux (Australie) ont également permis la création d'emplois supplémentaires dans le domaine de l'écotourisme. Les études de cas ont été analysées en termes de possibilités de financement et comparées à l'aide du système de classification internationale commune des services écosystémiques. Il est recommandé de mettre en place des cadres de planification visant à optimiser les services écosystémiques tels que ceux mentionnés ci-dessus. La politique devrait être mise à jour pour reconnaître ces services et fournir des incitations aux irrigants et aux entités de gestion de l'eau en conséquence.

**MOTS CLÉS**

drainage contrôlé, ecotourisme, refroidissement par évaporation, eau de mauvaise qualité, sous-irrigation, collecte de l'eau

## 1 | INTRODUCTION

Irrigated agricultural systems provide 40% of the world's crop-based food on 20% of the land, while rainfed systems account for 60% of crop-based food on 80% of the land (Food and Agriculture Organization of the United Nations [FAO], 2021). It has been estimated that between 306 and 367 Mha (million hectares) of arable and cultivated land are under irrigation (FAO, 2021; Meier et al., 2018), and from 186 to 200 Mha are artificially drained (Ayars & Evans, 2015; Smedema et al., 2000). Withdrawing 70% of the world's fresh water, irrigation can have detrimental effects on the environment, including soil salinization (FAO, 2021), overuse of groundwater (Dalin et al., 2017) and reduction of biodiversity (Dasgupta, 2021). Furthermore, drainage of organic soils enhances $CO_2$ emissions and undesirable nutrient loadings to their recipient watercourses (FAO, 2021).

Across irrigated and drained landscapes, the most important ecosystem service (ES)—defined as a provisioning service of nature—is food production itself (FAO, 2022). In addition to irrigation and drainage promoting economic development of rural areas, a wider range of other ESs can be provided, including supporting services (e.g. healthy soil), regulating services (e.g. flood control) and cultural services (e.g. recreational or spiritual benefits) (FAO, 2022). These ESs are produced concurrently with provisioning (food and fibre production) ESs, for example a higher income for women (United Nations World Water Assessment Programme [WWAP], 2014) or delivering water for groundwater reservoirs (Tanaka et al., 2010). However, these benefits are not always recognized by decision makers and politicians, which may result in abandoning the traditional sustainable irrigation systems and loss of the associated ESs at the same time.

Moreover, increasing competition for natural resources and climate change also necessitate that we reduce the environmental footprints of crops produced under irrigation and artificial drainage. In some cases, this may mean doing things differently from conventional mainstream practices to add or enhance ESs. For example, under certain conditions water can be stored in soils using controlled drainage. This can reduce greenhouse gas (GHG) emission as well as reduce nutrient pollution and prevent acidity generated through the oxidation of sulphides, which results in less discharge of better water quality entering watercourses. Groundwater tables can be kept higher by *sub-irrigation*, which targets better drain discharge quality and reduced environmental footprint (Österholm et al., 2015).

The aim of this paper is to provide different contemporary examples of how irrigation, sub-irrigation and controlled drainage can provide additional ESs and/or be improved to reduce negative environmental impacts. This is to provide ideas on the broad benefits that can be achieved and identify ways that these systems can be designed or modified to enhance productivity and sustainability. The estimation of the monetary values of these ESs is not simple and can be ambiguous. Therefore, a second aim is to present how monetary values of ESs have been or could be evaluated and how compensation schemes by government and the private sector may be devised. A third aim is to consider not only the benefits, but also controversial issues related to them. Real case studies are used to illustrate ESs provided by irrigation and controlled drainage for the public and the authorities. Thus, a fourth aim is to increase awareness of the ESs and sustainable intensification options amongst a range of stakeholders so that these services can be applied more widely in land use planning, recognizing that there is a substantial potential, both locally and globally.

## 2 | MATERIALS AND METHODS

The case studies presented here were selected from a larger group of case studies submitted by the members of the International Commission on Irrigation and Drainage (ICID) Working Group-Environment (WG-ENV) (Figure 1). Criteria for selection included representing a wide range of ESs for different agro-ecological zones and considering both irrigation and drainage interventions. The common focus was additional ESs that can be provided, or a creative means for the sustainable intensification of irrigation and controlled drainage systems. The case studies were grouped under the broader categories of (i) flood control; (ii) micro- and meso-climate control; (iii) water quality enhancement; (iv) controlled drainage and sub-irrigation to reduce off-site impacts; and (v) ecotourism.

The monetary value of providing ESs or implementing sustainable intensification is often challenging to evaluate, and therefore we collated potential value propositions varying from payment for ES (PES) (Okiria et al., 2021) and subsidies that compensate the environmental protection expenditure they incur (Ministry of Agriculture and Forestry of Finland [MMM], 2024a; MMM, 2024b). To critically evaluate the advantages and disadvantages of irrigation and controlled drainage we also undertook a strengths, weaknesses,

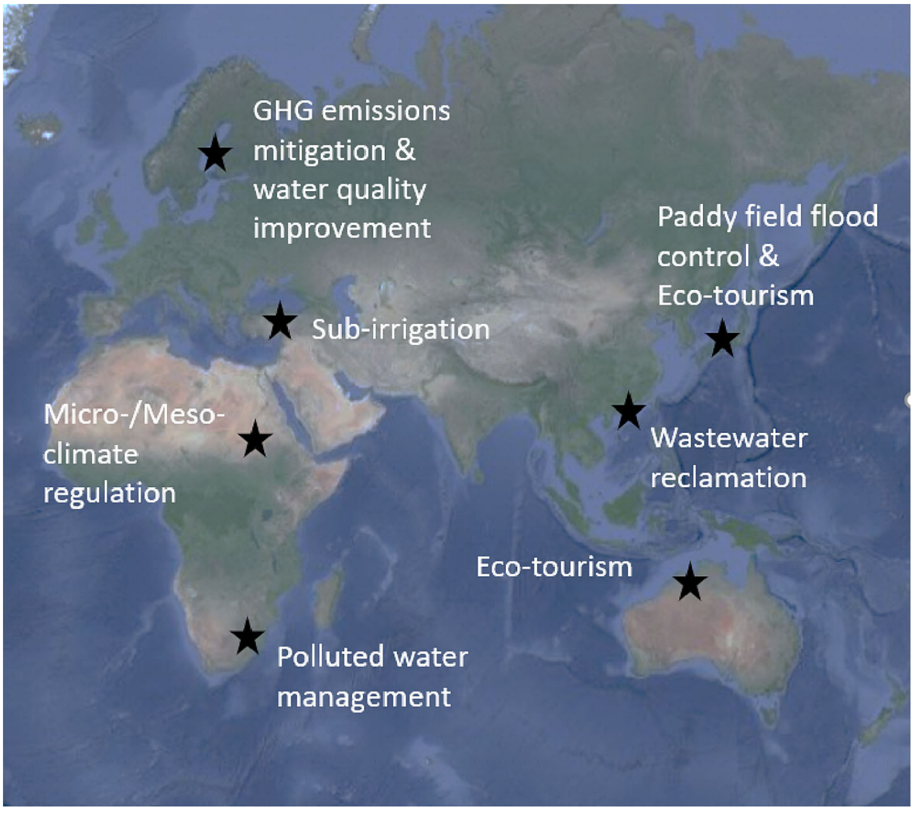


**FIGURE 1** The location of the case studies of ecosystems services of irrigation and controlled drainage. GHG, greenhouse gas.

opportunities and threats (SWOT) analysis based on the results of our case studies. The SWOT analysis has been structured to understand the benefits in relation to the detrimental impacts or risks of irrigation or controlled drainage.

## 3 | RESULTS AND DISCUSSION

### 3.1 | Case studies

#### 3.1.1 | Flood control

Flood control in Japan using paddy fields

Paddy fields contribute to increasing the water storage capacity of river basins, lowering the peak flow of rivers and increasing groundwater recharge. A number of studies have been conducted for the flood control function of paddy rice fields in Japan and monsoon Asia from the early 1980s. These studies have shown that lowland paddies, together with irrigation canals and reservoirs, act as buffers and increase the overall water storage capacity of the systems (Hatcho et al., 2022). However, a recent trend in the increased abandonment of cultivated paddy areas in Japan may cause a rise in the peak discharge of downstream river flow.

In recent years, proactive measures of enhancing water-storing functions and regulating floods by paddy fields have been proposed and tested (Hatcho et al., 2022). One such measure is to install outflow-regulating devices at the outlet of paddy fields (paddy field dam [PFD]) (Figure 2), so that the peak runoff can be reduced and delayed by storing more water in the paddy fields at the correct times (Kobayashi & Kouno, 2016; Miyazu et al., 2013; Oishi et al., 2019). The function of a PFD has been analysed by Yoshikawa et al. (2009) in several paddy areas in Niigata prefecture (an administrative division), utilizing a kinematic wave model for mountain and urban areas, and a water balance simulation for paddy fields for runoff analysis, which confirmed the effectiveness of a PFD for regulating peak discharge. Hatcho et al. (2022), by using the Hydrologic Modelling System of the Hydrologic Engineering Centre (HEC-HMS) of the US Army of Corps of Engineers, also analysed the impacts of a PFD on the reduction of peak flow and the time lag of discharge at plot level in a small basin in Nara prefecture, Japan, which has a mosaic landscape of semi-urban areas with scattered paddy fields, forest and residential areas.

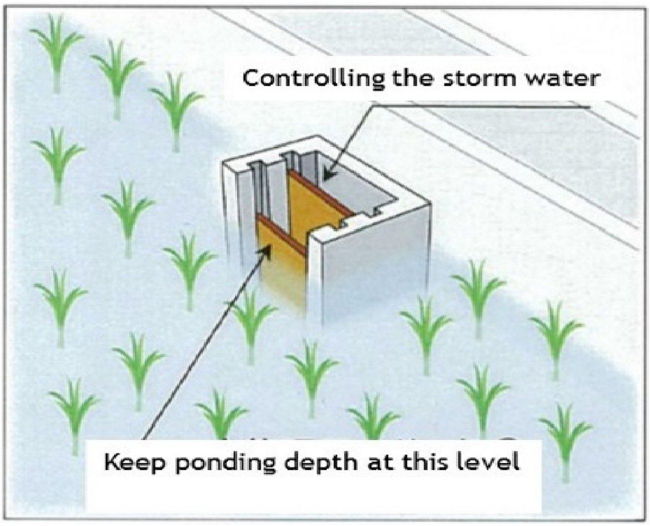


FIGURE 2 Installation of a paddy field dam (Hatcho et al., 2022).

Despite the effectiveness of a PFD several issues have been recognized when introducing it, such as the discrepancy in valuation between beneficiaries (downstream no-farm communities) and practitioners (farmers and irrigation organizations), the framework for supporting farmers in its installation, operation and maintenance, and identification of strategic locations in the context of river basin management (Oishi et al., 2019; Yoshikawa et al., 2011).

#### 3.1.2 | Micro- and meso-climate control

Micro-climate control by paddy fields in Asian countries

One prediction of climate change is the warming by more than 4°C of many urban areas in the world by the end of the century (Chapman et al., 2017). Therefore, there is an urgent need for climate-sensitive urban development and support for green infrastructure intervention as an effective means for reducing urban heat stress (Zhao et al., 2021). Evapotranspiration from paddy fields absorbs a significant amount of heat due to the latent heat exchange resulting in reducing the ambient temperature of the surrounding area, especially in the summer (Yokohari et al., 1998). This climate mitigation function has been recognized in periurban areas where paddy and urban lands are scattered and in urban fringe areas. The temperature effect is higher where the paddy area is larger and is applicable up to 150–200 m downwind of paddy areas (Yokohari et al., 1998). The conversion of paddy fields to other land use and land cover types causes microclimate change. Urbanization has resulted in reduced paddy areas of many Asian countries, which, in turn, reduces the amount of microclimate cooling. In contrast, land surface temperatures were reduced with the expansion of irrigated paddy fields in the semi-arid western region of China from rainfed corn fields and swamp over 10 years (Liu et al., 2019). There was an idea to develop a policy to retain paddy fields upwind of urban lands to lower the ambient temperature (Wu & Yang, 2003). The economic valuation for the air-cooling attribute of paddy fields was assessed and the result showed it to be significant in Taiwan (Huang et al., 2006).

To estimate the large-scale effect of climate mitigation, meteorological parameters can be used for the quantification of the function. These data can be linked with GIS and remote sensing to evaluate the impact in large areas (Cheng et al., 2008) by application with the available heat balance models. Tan (2004) showed an approximate 8°C temperature difference between paddy field and urban land cover using the thermal band of Landsat satellite image in the study.

Recent studies in field-scale temperature change in paddy fields are concerned with damage to rice plants and reduction of rice yield and quality due to high water temperature (Nishida et al., 2021). Water temperature is affected by ambient temperature, water flow, ponding water depth and plant stage of paddy (Xie et al., 2021). Therefore, the way paddy water management is applied has implications for controlling the microclimate of paddy fields and their surroundings.

#### Micro- and meso-climate regulation due to irrigation/water harvesting in Ethiopia

As discussed in the previous section, irrigation water aids in microclimate regulation through the consumption of latent heat thr water evapotranspiration. Such an effect is not only evident in the case of open water ponds, such as paddy fields, but also if water stored in the soil is then evapotranspired. Castelli et al. (2019) studied the effect of meso-climate regulation induced by water harvesting in the Tigray region, northern Ethiopia. Water harvesting can be defined as the *process of concentrating precipitation through runoff and storing it for beneficial use* (Oweis & Hachum, 2006). Such technology can in some cases be considered as a form of irrigation through runoff farming, storing water in the soil. Castelli et al. (2019) demonstrated that in the Enabered river basin, Tigray, the implementation of water harvesting, coupled with landscape restoration technologies, cooled down summer temperatures by up to 1.74°C. This effect was visible for almost all years after water harvesting implementation, except for 2009 when extreme temperatures occurred. Therefore, the effect of cooling induced by water harvesting was evident in normal years, but not for very extreme events. Similarly, such technology is proven to be more effective in bridging short dry spells of 5–15 days that represent the first source of crop failure, rather than allowing to buffer prolonged droughts (Rockström et al., 2002). The effects studied in the Enabered river basin were visible at the meso-scale (from 100 m to 100 km), and not only at the micro-scale level.

### 3.1.3 | Water quality enhancement

#### Controlled drainage and sub-irrigation—reducing non-point source nutrient leaching as well as pollution from acid sulphate soil fields in Finland

Controlled drainage and sub-irrigation have been studied to improve the quality and quantity of yields during dry summers since the beginning of the twentieth century. Later it was observed that they are sustainable and provide regulating ESs by reducing drainage discharge through increased evapotranspiration during normal or dry summers, which decreased the nutrient loading to recipient watercourses (Evans et al., 1992; Paasonen-Kivekäs et al., 1996; Virtanen et al., 2016; Wesström et al., 2001; Wesström et al., 2014). The reason for the decreased loads of nutrient was not only decreased discharge, but also lower concentration of substrates due to different redox processes in aerobic compared to anaerobic soils. The effect of controlled drainage and sub-irrigation in peat soils is receiving increased attention in Finland currently. Preliminary results indicate that the thicker the peat layer above the subsurface drains, the more N and dissolved P that leach (Pham et al., 2023; Yli-Halla et al., 2022).

On the western coast of the Baltic Sea in Finland, cultivated acid sulphate fields are at least partially responsible for the inferior ecological and chemical status of surface waters of that area (Westberg et al., 2012). This is due to the fact that large amounts of acidity and toxic elements are leaching from acid sulphate fields to recipient watercourses due to oxidation of sulphides in the soil (e.g. Roos & Åström, 2006; Toivonen & Boman, 2024). Controlled drainage and sub-irrigation can be used by farmers to increase yields in dry summers (Figure 3). Dry summers also promote oxidation of sulphides in acid sulphate soils. Therefore, water management measures which keep soil saturated with water for longer also provide regulating ESs because they simultaneously inhibit the oxidation of sulphides which results in decreased leaching of metals and acidity from acid sulphate soil fields (Bärlund et al., 2005; Virtanen et al., 2016).

Sustainable drainage (the regulation of ESs) has been supported by awarding subsidies to farmers for investment in control wells and the maintenance of controlled drainage in acid sulphate and peat soils according to Finland's CAP Strategic Plan under the European Union (EU) Common Agricultural Policy (MMM, 2024a). One

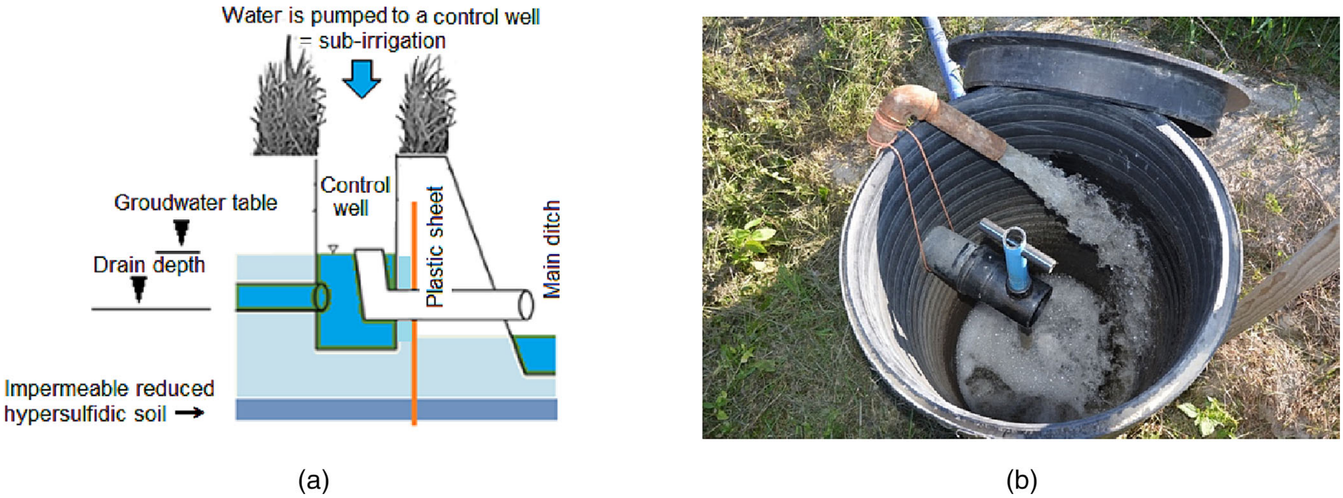


FIGURE 3 (a) Schematic figure of the function of controlled drainage and sub-irrigation. In sub-irrigation water is pumped into the control well when the groundwater table drops. In controlled drainage the water outflow is controlled by the well, but if there is no rainfall groundwater drops down. (b) pumping of water into a control well in a sub-irrigated field in Finland (photo by Seija Virtanen).

option to calculate the value of the regulation of ESs is evaluating how much the purification of nutrients in water would cost in sewage plants (Haataja, 2000). Similarly, the costs of neutralization and purifying of the toxic concentration of elements in leaching water from acid sulphate soils could be calculated.

### Filtration of nitrate from groundwater using smallholder irrigation

Smallholder farmers in sub-Saharan Africa (SSA) often have limited access to fertilizer, and nutrient deficiencies lead to drastically reduced crop yields (Falconnier et al., 2020; Masso et al., 2017). On the other hand, water resources are continuously being polluted due to fertilizer runoff from commercial farms, as well as various other anthropogenic activities sometimes combined with poor wastewater treatment infrastructure (Mudaly & Van Der Laan, 2020).

The production of nitrogen (N) fertilizer has a high environmental footprint in terms of eutrophication, acidification (soil, terrestrial, aquatic) and GHG emissions. High nitrate levels can cause methaemoglobinaemia in infants, with the World Health Organization setting the maximum nitrate concentration at 50 mg $L^{-1}$ (Cotruvo, 2017).

To address widespread poverty, the South African government supports various smallholder farmer initiatives, such as the Rooiwal Agri-park in Gauteng Province. Groundwater analyses indicated that due to the high N (95 mg $NO_3$-N mg $L^{-1}$) there is no need to apply additional fertilizer to crops grown on the land and irrigated with this water. This would likely be the case in other populated areas in SSA, and if this information is known it can assist in identifying suitable locations to establish intensive smallholder farmer schemes with appropriate crops.

Removal of these nutrients (seen as pollutants in other contexts) from the system by crops or pasture can be seen as an ES. While the idea of using marginal quality waters in agriculture is not new and there are many associated risks (in fact smallholder irrigators often only have access to using marginal quality water) (Qadir et al., 2007), identifying suitable waters for which irrigation can reduce nutrient pollution and viewing such a system as an ES to be paid for could assist in sustainably financing such schemes. Human and environmental health risks must always be carefully considered when using waste or polluted water (Qadir et al., 2007).

### Reclaimed water as promising alternative for irrigation in Taoyuan, Taiwan

In Taoyuan City, Taiwan, municipal, industrial and agricultural sectors compete for limited water resources (Tsai et al., 2019). In the context of climate change, when extreme droughts occurred approaches to stop paddy field irrigation were often employed to ensure sufficient supply of water to municipal and industrial sectors, so as to secure domestic and economic activities (Chiueh & Huang, 2015). Because Taoyuan City has a population of more than 2 million people, if most municipal wastewater was collected and treated, the reclaimed water could be used as a renewable water resource. Thus, reusing reclaimed water will be a countermeasure to tackle the challenges caused by water resource shortage during droughts (Chiou et al., 2007). The local government is currently actively promoting private participation in build–operate–transfer (BOT) projects of constructing sewer systems and associated municipal wastewater treatment plants (which are called water resource recovery centres, abbreviated as WRRCs) in Taoyuan City. It is estimated that the total processing capacity of all WRRCs will reach 371,000 t of sewage water per day in Taoyuan City, which is approximately equal to a reclaimed water flow rate of 4.3 $m^3$ $s^{-1}$. Based on the irrigation water requirement of a paddy field with loamy soil (the dominant soil type of farmland in the Taoyuan area), 4.3 $m^3$ $s^{-1}$ of irrigation water could supply approximately 2500 ha of paddy fields. Using reclaimed water for irrigation could not only utilize the nutrients contained in the water for crop growth (thus, reducing the demand for fertilizer) but also alleviate the pressure of water resources shortage caused by extreme droughts. Therefore, the Taoyuan City government has been actively engaged in studying issues associated with using reclaimed water from WRRCs for irrigation, such as identifying suitable crops, water quality constraints and regulative limitations, with promising results in preliminary studies (Chen & Liu, 2015). Transporting reclaimed water from WRRCs to farmland could be through piping or through discharging it into irrigation canals nearby. While transporting through direct piping is costly and restrictive due to land acquisition for pipe installation, it is recommended to transport reclaimed water from WRRCs to farmland through the already constructed irrigation canal system in Taoyuan City, in order to minimize the cost and maximize the quantity of reclaimed water to be transported. At present, however, reclaimed water from WRRCs for direct irrigation has no precedent in Taoyuan City. Therefore, the local government is looking for cooperation with relevant irrigation associations to promote demonstration projects to increase farmers' and the public's confidence in the practice of using reclaimed water from WRRCs for irrigation.

#### Use of irrigation as part of a saline mine water management strategy: a case study for the Vaal basin, South Africa

As a result of many of the large-scale mining activities in the Witwatersrand goldfields, South Africa, coming to an end over recent years, a critical point has been reached for the management of poor quality mine water that is, or will soon be, decanting from the mine voids. The water is contaminated primarily by the oxidation of sulphide minerals. Depending on the composition of the rock substrate with which the water reacts, the pH may be strongly acidic, and the dissolved salts dominated by acidic metal sulphate (mainly of iron [Fe] and aluminium [Al]) or neutral to alkaline in which case the dissolved salts are dominated by basic metal sulphate, mainly of calcium (Ca), magnesium and sodium. The water requires treatment to neutralize the acidity, including that which develops when dissolved iron is oxidized at the surface. The typical treatment involves liming, which precipitates the more hazardous metals as sludge (especially Fe, Al and manganese but also nickel, zinc, copper and other trace metals such as arsenic and uranium) but leaves the water too saline with residual sulphate to achieve fitness-of-use objectives for the Vaal Barrage and further downstream (Department of Water Affairs [DWA], 2013).

Work done using a steady-state chemical equilibrium model showed that when calcium sulphate-rich mine water is used in irrigation, a significant quantity of gypsum precipitates (becomes insoluble) in the soil, reducing salt loads in the irrigation return flows (Du Plessis, 1983). This gypsum precipitation mechanism was confirmed in the laboratory, glasshouse experiments, field trials and on commercial scale cropping systems under pivot irrigation with mine water from the Mpumalanga coalfields (Annandale et al., 2019). This immobilization effectively results in soil salinity levels being much lower than would be the case when irrigating with saline waters which do not have $Ca^{2+}$ and $SO_4^{2-}$ as the dominant ions, enabling the cultivation of a range of commonly grown field crops.

There are four components to consider in managing irrigation with saline mine water: (i) the chemical quality of the irrigation water; (ii) the hydrological setting of the irrigated area; (iii) the management of the leaching fraction; and (iv) the fate of the drainage water. Compared to the more energy-intensive water treatment technologies such as conventional reverse osmosis (RO), a major advantage of including irrigation in a treatment strategy is the low treatment cost while using the water in a productive manner, and potentially a lower environmental burden from the salt load. A life cycle assessment revealed that the latter option yielded markedly reduced impacts in terms of global warming potential, non-renewable resource (fossil fuel) depletion and acidification potential. An economic analysis estimated that more than 300 producers could benefit financially by each cultivating a 40 ha irrigation pivot as a separate business unit if provided with the water.

### 3.1.4 | Controlled drainage and sub-irrigation to reduce off-site impacts

#### Controlled drainage and sub-irrigation to decrease GHG emissions in Finland

Controlled drainage and sub-irrigation are topical issues concerning the mitigation of (greenhouse gas) GHG emissions in Finland where the agricultural sector accounts for approximately 12% of GHG emissions and a significant part of that originates from organic soils. Drainage and cultivation of peat fields promote aerobic decomposition of organic matter, and therefore $CO_2$ and $N_2O$ emissions on peat fields are much higher than those on mineral soils. Drainage is a prerequisite for cultivation in Finland where the most common drainage practice is subsurface pipe drainage (67%) (LUKE, 2013). These systems can be modified for controlled drainage or even sub-irrigation in flat fields, and with this procedure the groundwater level can, to a certain degree, be regulated (Figure 3).

GHG emissions decrease when the groundwater table is closer to the soil surface. The findings from peat soil (Regina et al., 2015) showed that $CO_2$ and $N_2O$ emissions decreased some 25% when groundwater was raised from the depth of 0.70 to 0.30 m. That resulted in lower yields than in the case of optimal water management. Thus, in that case there is a trade-off between provisioning and regulating ESs, in other words less yield but also less GHG emissions. It has even been proposed to afforest or rewet less intensively cultivated peat fields (Kekkonen et al., 2019). In order to keep productive organic soils in cultivation a state-of-the-art measurement is in use in ongoing research projects of this issue in Finland (Gerin et al., 2023). In an acid sulphate soil field, where the regulation levels were 0.60 and 0.70 m below the soil surface in summer and in winter, respectively, depending on weather conditions yields both decreased and increased compared to conventional drainage, but $N_2O$ emissions were lowest in a sub-irrigated experimental field in summer (Yli-Halla et al., 2020).

Controlled drainage and sub-irrigation provide regulating ESs by way of decreasing GHG emissions and cultural ESs by sustaining rural communities. Regulating ESs have been supported by awarding subsidies to farmers for investment in control wells and the maintenance of controlled drainage in peat fields and acid sulphate soil fields according to Finland's CAP Strategic Plan under the EU Common Agricultural Policy in Finland (MMM, 2024b). Also, lower yields in this case should be compensated. The value of regulating ESs in this case can be calculated based on $CO_2$ equivalent not emitted from the fields times the price of carbon equivalent in carbon markets.

### Shallow groundwater usability in irrigated agriculture to reduce environmental impacts: a case study from Turkey

Recently developed controlled and shallow drainage systems developed in the Erzincan Irrigation Scheme, Turkey, aim to prevent excessive drainage from the root zone and maximize benefits derived from groundwater (Fayrap, 2018). Groundwater as a source of water supply has a number of important advantages compared to surface water: it is often of a higher quality, better protected from pollution, less subjected to seasonal and long-term fluctuations and often more evenly distributed over large areas (Zektser & Everett, 2004). Maintaining a certain level of groundwater is crucial to prevent negative environmental effects, as soil salinity is highest at the lowest groundwater table level. Controlled drainage also conserves fresh water by utilizing capillary rise from shallow groundwater tables to supplement consumptive use. Studies have shown that in utilizing groundwater, less irrigation water will be needed in the period when water consumptive reaches the peak level.

Kruse et al. (1985) reported that maize can fulfil 55% of its water requirement from groundwater with a salinity level of 6.0 dS $m^{-1}$ and at a depth of 0.60 m. Similarly, Meyer et al. (1996) observed that the water requirement of alfalfa can be met by 13–55% from groundwater at a depth of 0.60 m, depending on the soil type and water salinity.

Part of the 10,723 ha of the Erzincan Irrigation Scheme on the Euphrates river was selected as a research area, which was gradually drained and allowed for irrigation by the State Hydraulic Works in 1964. The research area is situated on the left bank of the Euphrates river. The correlation between the groundwater level and the amount of water used in irrigation was determined by utilizing the spatial distribution of depth to the lowest groundwater table maps of the Erzincan Irrigation Scheme area for water years 1992–2009 and yearly irrigation water consumption data.

An open drainage system was established alongside the irrigation network. A closed drainage system was also constructed, starting in the 1980s, and put into operation segment by segment. The open drainage system included main drains, gatherer and tertiary drains, and surface drains. Surface drainage network systems consist of discharge and collector drains linked with secondary drains. Concrete pipes are used for subsurface drainage networks. The drains are typically 1.50–2.00 m deep with an inner radius of 0.16–0.20 m. Subsurface drains are spaced 100–120 m apart in the fields.

The amount of irrigation water used decreased as the groundwater table level approached the surface. For groundwater tables between 0.50 and 1.00 m deep, there was a significant inverse correlation between irrigation water and groundwater table depth. The location of the groundwater table at a depth of 1.00–2.00 m in the lowest groundwater table maps had a significant positive correlation with the amount of irrigation water used. When the groundwater table fell below the effective root depth

**TABLE 1** Optimal levels of groundwater tables for different crops in Turkey.

| Plant species | Depth to groundwater table (m) |
|---|---|
| Wheat | 1.40 |
| Barley | 1.00 |
| Cotton | 0.90 |
| Sugar beet | 0.80 |
| Maize | 0.90 |
| Alfalfa | 1.00 |
| Tomatoes | 0.75 |

of plants, there was a significant increase in the amount of water used for irrigation. The reduction of irrigation water use due to shallow groundwater tables indicated the use of groundwater to meet plant water needs.

Crops such as wheat, beans, sugar beet, vegetables and fruits are grown in the research field. Table 1 shows the optimal groundwater table levels for crops grown in Turkey.

For plants to develop normally, the groundwater table level must be below the effective root depth. However, with carefully planned and managed groundwater table management systems, plants can still take advantage of groundwater with low salt levels. Monitoring the groundwater table level during the irrigation season is necessary for plant growth and environmental conditions.

### 3.1.5 | Ecotourism

#### Ecotourism: social effect of paddy rice landscape on communities

Japanese history of rice cultivation and culture has been centred on water, and society has been strongly tied with rice. With this historical background, paddy water has been used for multiple purposes, such as cooking, washing, fire prevention, snow melting, and recreational activities like fishing and swimming, besides being used for irrigation, and are considered a part of the local ecosystem and rural scene (Matsuno et al., 2006). A preference for paddy landscape area originated from the perception of familiarity, beauty and repose (Yamamoto et al., 1998), and the degree of familiarity of paddy landscapes can be explained by the impressions of artificiality and complexity (Tanokura et al., 1999). Particularly, terraced paddy fields are essential components of Japan's rural or *satoyama* landscapes (Fukamachi, 2017). *Satoyama* is defined as a cultural landscape consisting of rural communities and the secondary environments that surround them (Ministry of the Environment, Government of Japan, 2008). Terrace paddies are commonly used to grow rice on hilly or mountainous terrain and have the capacity to control erosion and surface runoff while distributing irrigation water from plot to plot.

On the other hand, the decline and ageing of farm households as well as the abandonment of farmlands in recent decades have resulted in the economic stagnation of rural communities, especially in mountainous areas. Therefore, tourist initiatives such as the so-called *agri-tourism*, *green tourism* and/or *ecotourism* are considered as tools to revitalize rural communities (Chen et al., 2018) and, consequently, preserve the landscape of rural farming systems. The Ministry of Agriculture, Forestry and Fisheries of Japan has promoted rural-stay leisure activities (called countryside stays Japan: *nou-haku*) and, at present, has selected 554 areas nationwide for this promotion measure (Ministry of Agriculture, Forestry and Fisheries [MAFF] Japan, 2014).

The owner system is a unique way of farming in Japan (Kieninger et al., 2011; Qiu et al., 2014). It is an agricultural programme where non-farm or urban people who would like to experience working in paddy fields can participate and maintain the area throughout the year. These people are involved in farm activities, such as land preparation, rice planting, weed mowing, harvesting and non-farming social activities. They would normally pay an annual fee and, in some systems, receive rice products.

In addition, the globally important agricultural heritage systems (GIAHS) sites initiated by the FAO and World Heritage Irrigation Structures (WHIS) selected by ICID are expected to be attractive tourist destinations and increase visitors. At present, 11 sites in Japan are designated as GIAHS, of which three sites are practising paddy rice irrigation, and 42 irrigation structures were selected as WHIS.

### 3.1.6 | Ecotourism in northern Western Australia

In the Ord River Scheme, Western Australia, irrigation continues to underperform (e.g. Petheram et al., 2008), but irrigation infrastructure creates a number one tourist attraction (Tourism Western Australia, n.d.). The boat ride along the Ord river from Kununurra to the Lake Argyle dam takes tourists from the original Kununurra diversion dam upriver to the Ord river dam and is consistently voted the number one tourist attraction in the eastern Kimberley region of northern Western Australia (TripAdvisor, website). In 2023, tourism constituted the third-highest economic sector in the region (after mining,

TABLE 2 Ecosystem services, benefits and valuation methods, classified according to the Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting, version 5.1 (Haines-Young & Potschin, 2018).

| Description | Country | Ecosystem service | Ecosystem service type | Country | Valuation method | Support funding by the government | Reference case study |
|---|---|---|---|---|---|---|---|
| Paddy fields used for irrigation help in mitigating floods | Japan | Regulation of baseline flows and extreme events | Regulation and maintenance (abiotic) | Japan | Replacement cost method (RCM)<br>Contingent valuation method (CVM) | Support for installing outflow regulating devices at the outlet of paddy fields | Section 3.1.1 |
| Controlled drainage and sub-irrigation reduce fertilizer outflow in the environment | Finland | Mediation by other chemical or physical means (e.g. via filtration, sequestration, storage or accumulation) | Regulation and maintenance (abiotic) | Finland | Compensation costs/price of element purification in sewage plants | Support for control wells and maintenance of controlled drainage in acid sulphate fields | Section 3.1.3 |
| Filtration of nitrate from groundwater | South Africa | | | South Africa | Inorganic fertilizer price of nutrients in water | None yet | Section 3.1.3 |
| Saline water is used for irrigation and some ions are immobilized in the soil reducing the salinity of the outflow | South Africa | | | South Africa | Price of reverse osmosis or similar filtration treatment to clean the water | Support for research and a pilot site | Section 3.1.3 |
| The presence of water harvested for irrigation favours the mitigation of temperatures by soil moisture–temperature coupling | Ethiopia | Regulation of temperature and humidity, including ventilation and transpiration.<br>Meso-climate regulation | Regulation and maintenance (biotic) | Ethiopia | Alternative cost method, e.g. air conditioning.<br>Rural areas: increase in crop production due to lower temperatures and less heat stress | None | Section 3.1.2 |
| Tourism on historical paddy fields | Japan | Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions | Cultural (biotic) | Japan | Travel cost method | Support for promoting agritourism | Section 3.1.5 |
| Tourism on irrigation channels | Australia | Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions | Cultural (biotic) | Australia | Tourism Board figures | Major irrigation scheme support and dam construction | Section 3.1.5 |
| Controlled drainage and sub-irrigation to decrease greenhouse gas emissions | Finland | Regulation of chemical composition of atmosphere and oceans | Regulation and maintenance (biotic) | Finland | Price of $CO_2$ equivalent in carbon markets | Support for control wells and maintenance of controlled drainage in peat fields | Section 3.1.4 |

dominated by the now-closing Argyle diamond mine, and agriculture) and represents 12% of jobs and 10% of wages in the region (Regional Development Australia Kimberley, 2023). Tourism activities generated by the lake include scenic tours by boat, plane and helicopter, scuba diving, gastronomy tours, fishing tours, canoe treks, swimming carnivals and self-supported water sports, bush walking and mountain biking. Lake Kununurra, formed behind the original diversion dam, is now a Ramsar-listed wetland, while Lake Argyle boasts the largest population (35,000) of Johnston river freshwater crocodiles in the world.

## 4 | DISCUSSION OF ESs BASED ON THE CASE STUDIES

Climate change and more extreme events necessitate increased investment to maintain current irrigation and drainage infrastructure and to develop them further to increase resilience. Our case studies show that similar measures have been developed in extremely different conditions that can lead to the provision of multiple ESs. The services provided by the case studies analysed in the present paper, together with current or possible methods of funding, are summarized in Table 2. A SWOT analysis was generated in conjunction with Table 2 to understand the potential implications of selecting different strategies to enhance ESs (Table 3).

Conducting a SWOT analysis in the context of climate change and infrastructure for irrigation and drainage is crucial for identifying strengths to leverage, weaknesses to address, opportunities for innovation and threats from environmental and socio-economic factors. This strategic approach informs decision-making, optimizes resource allocation and enhances resilience and ESs amidst increasing extreme events.

It should be noted that physical (abiotic) features and/or biotic processes can provide ESs in irrigation and drainage systems. It should be noted that ESs are not only provided by traditional irrigation (Fleming et al., 2014), and how in many cases trade-offs between ESs and related disservices (Power, 2010) are limited, while positive effects prevail. This is evident, for instance, in the case of South Africa, where the decrease of salinity in drainage water is not excessively impacting soil salinity.

In Turkey, a shallow groundwater table saves irrigation water through carefully monitoring and controlling salinity and the depth of the groundwater table. In Finland in acid sulphate soils, a shallow groundwater table is desirable to prevent the oxidation of sulphides and the formation of acid discharge water. In peat fields, shallow groundwater also mitigates GHG emissions by slowing down the decomposition of organic matter in water-saturated soil. The shallow groundwater table is implemented in all these cases by controlled drainage or sub-irrigation and generates regulating ESs in addition to provisional ESs.

The infrastructure of paddy fields cools ambient temperature in nearby urban areas and the recommendation is to conserve paddy fields upwind of urban areas in Asian countries. The flood and erosion control generated by paddy fields are also well-established ESs. Rising air temperatures, however, also mean higher water temperature that may negatively impact rice growth, which must be taken into account in future. The same regulating ESs (cooling) are also found in water-harvesting areas in Ethiopia that are distinctly different from paddy field systems.

TABLE 3 Strengths, weaknesses, opportunities and threats (SWOT) analysis of ecosystem services of irrigation and controlled drainage.

| Strengths | Weaknesses |
|---|---|
| Irrigation | Irrigation |
| Reduced risk in crop production compared to rainfed | Depletion of fresh water |
| Higher yields per area | Possible increases in temperature in humid areas |
| Climatic cooling | Disruption of local land use and ecosystems |
| Soil and ecosystem preservation | Increased land management required |
| Socio-economic benefits | Controlled drainage and sub-irrigation |
| Controlled drainage and sub-irrigation | Suitable only in flat fields |
| Win–win option for environment and farmers, better yields and less nutrient loading | No replenishment of water during the driest time |
| Lower GHG emissions | |
| **Opportunities** | **Threats** |
| Irrigation | Irrigation |
| Potential for new markets | Depletion of groundwater, reduced streamflow |
| Ecotourism | Pollution of freshwater resources |
| Use of irrigation planning also for cooling and micro-climate control | Irrigation cooling may not be effective for extreme heatwaves |
| GHG capture and storage | Salination of soils and local waterways |
| Controlled drainage and sub-irrigation | Loss of biodiversity |
| Better yields and less loading of nutrient and/or toxic solutes | Controlled drainage and sub-irrigation |
| Improved water quality in receiving watercourses | Decrease in yields during wet summers and heavy rainfall |

Moreover, paddy fields, irrigation water dams and other related infrastructure can generate cultural ESs due to their beauty and many recreational options, creating jobs in tourism in addition to agriculture. Many other irrigation systems have this potential.

Irrigation can generate maintenance ESs using recycled water. Nutrients (especially nitrate) and irrigation water can be delivered to farmers simultaneously. This saves farmers money and reduces the carbon footprint of fertilizer provision. Recycling wastewater for irrigation also alleviates shortages of fresh water during extreme drought periods when the crops are most vulnerable. In that case it must be ensured that wastewater can safely be used.

## 5 | CONCLUSIONS

Over and above the maintenance of current irrigation and drainage infrastructure to minimize the virgin land that needs to be converted to cultivation, new investment should aim to enhance or introduce new ESs offered by these systems. This review highlights that irrigation, sub-irrigation and controlled drainage have the potential to produce ESs beyond food and fibre production with multiple possible benefits to the environment.

Irrigation systems are extremely diverse, so local knowledge will be key in maximizing ESs. With the severity of climate change now evident, what were traditionally *non-marketed services* (Millennium Ecosystem Assessment, 2005) may now become marketed services, for example the carbon credit system. So, whereas traditionally the focus of irrigation development has been on food production, population settlement and rural development, new developments should move away from being anthropocentric and aim to maximize ESs, and more research on the benefits should be prioritized. Long-term ESs by irrigation, sub-irrigation and controlled drainage have not been adequately researched.

Therefore, critical evaluation of positive and negative effects is required when evaluating existing irrigation and drainage schemes and planning new ones, which often have very different characteristics around the world, to make them more sustainable. In such an evaluation, all ESs produced by water management must be considered in a holistic way.

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## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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