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A guideline for sustainable irrigation water management: a case of a developing country

Irrigation Water Management (IWM) being considered essential as it contributes to crop production all over the world. Nonetheless, water losses throughout the system, inefficient irrigation practices and lack of attention towards the proper maintenance of existing infrastructure were the constraining factors to achieve the benefits of sustainable use of water. Hence, this paper develops strategies to achieve sustainable water management of irrigation systems. Sixteen semi-structured interviews were conducted for industry professionals in the IWM sector in Sri Lanka as the main data collection method in this study. The collected data were analysed using a code-based content analysis based on the directed approach. The research findings identified four main categories of strategies, namely, engineering, management, operational and regulatory. The findings are substantially beneficial for industry practitioners in the water management sector to overcome the issues in IWM practices regarding the water use efficiency, equity of water distribution, environmental integrity and economic acceptability. This study can be further extended to prioritise the issues and strategies to statistically generalise the findings.

Keywords: irrigation systems; water management; sustainable; strategies; Sri Lanka

Introduction

Irrigation is a sector that manages a large number of complex infrastructure projects, which has significant impacts on the environment (Alamanos et al. 2019). The successful long-term performance of irrigation systems largely depends on the careful management of land and water resources (FAO 2012). Wichelns and Oster (2006) identified that land and water resources are highly threatened by irrigation practices, which then ultimately affect agricultural productivity. Thus, irrigation could be sustained if the foreseeable impacts are limited to the extent, where it enables the people to meet their needs while ensuring environmental integrity.

Effective management of irrigation water is essential to protect water sources, to minimise the environmental impact, and to increase the growth of the economy of the country. The concept of sustainability discusses long-term decision-making on equal and equitable use of natural resources and the related impacts (Lazarides and Goula 2018). Sustainable Development (SD) is a guiding concept for the equal distribution of costs and benefits of environmental and economic growth within the population (Hansmann, Mieg and Frischknecht 2012). Sustainable Water Management (SWM) is linked with SD, allocating water for competing water needs while maintaining the trade-off among the three pillars of sustainability namely, economic, environmental and social sustainability (Gleick 1996). Further, SWM should satisfy the existing water requirements for all uses and users without adversely impacting the potential supply needs in future (Mays 2007).

The increasing population is directly affecting the current water demand due to the competing water needs over the limited resources, which has led to severe water shortages worldwide (Sun et al. 2016). Therefore, as the largest consumer of water, the irrigation sector has to play a critical role in managing water resources (Greenland et al. 2017). In developing countries, the current practices of water management with regards to irrigation sector were not achieving the benefits of sustainable use of water. On the other hand, the increasing environmental issues associated with existing irrigation practices have led to a debate on the impacts of them on the environment (Khachatryan et al. 2019). These necessitate sustainable irrigation and water management for economic development as well as for a sustainable livelihood (De Vito et al. 2019).

Besides, water is a critical factor for the agricultural sector in Sri Lanka, thereby efficient water management is identified as the key to improve the productivity in the agricultural sector and to develop the economy in the country (Chemjong and

Wijesekara 2017). In Sri Lanka, the inefficiency of irrigation infrastructure, which leads to water losses throughout the system and the rise of temperature that increases the evapotranspiration, adversely impact the irrigation water management and thereby generating significant issues in irrigation systems (Wijesekera, 2011). Nonetheless, there is no consensus on past studies exploring ways to overcome those issues to manage irrigation water in a sustainable manner. This study, therefore, develops strategies to achieve sustainable IWM in the Sri Lankan context to fulfil the research gap and the industry need by focusing on the intercession of different disciplines towards improving the operational and management aspects of irrigation systems. The literature review of the study is presented next.

Literature Review

The importance of SWM in the irrigation sector and the issues in IWM in the global context have been discussed in this section referring to the previous studies.

Importance of Sustainable Water Management in Irrigation Sector

The agricultural sector is the largest commercial consumer of water, accounting around 70% of freshwater withdrawal used for food production, which has greater relevance to the water scarcity in a global context (FAO 2012). Accordingly, the irrigation sector can be considered as the largest water user in almost all the countries, which supplies water mainly for the agricultural uses (Greenland et al. 2017). Besides, the amount of current water consumption of irrigation will further increase due to the growth of population and increasing food demand. Hence, there is a need for sustainable water-consuming techniques and strategic improvements regarding technical, managerial and institutional capacities to improve the water management in the irrigation sector (Gutierrez et al. 2014). According to Bakker and Matsuno (2001), the policies shall be made focusing on

all the uses and users of the water in the irrigation systems to ensure an efficient, equitable and sustainable water use under the water scarcity.

Development of irrigation systems is becoming vital for fulfiling the growing demand for crop production under the increasing population (Singh 2016). Sivayoganathan and Mowjood (2003) explain that the water should be delivered to the farmlands adequately, at the appropriate time and it should be consistent throughout the period. Further to the authors, the management authority and the operators are trying to increase the crop per unit volume of water to maximise the efficiency of water use, while the water is distributing to the farms since it is a scarce resource. Hence, there is pressure on water resources management to achieve sustainable water use in irrigation while minimising environmental degradation (Wichelns and Oster 2006).

The irrigation system plays a major role in the agricultural sector in Sri Lanka (Sivayoganathan and Mowjood 2003). Since ancient times, the Sri Lankan agricultural sector has been placed at a predominant place in the country's economy, a higher proportion from the public investment is given to the development of irrigation systems (Shand 2002). However, Shantha and Ali (2014) report that only around 4% out of the total irrigation investment was dedicated to the operational and maintenance purposes of the irrigation systems in Sri Lanka. The land and water resources in Sri Lanka were highly threatened by irrigation practices, which ultimately affect agricultural productivity (Sivayoganathan and Mowjood 2003). This urges the need for sustainable IWM in Sri Lanka to limit the foreseeable impacts to the extent, where it enables the people to meet their needs while ensuring the environmental quality and economic acceptability.

Issues in Irrigation Water Management

Water scarcity is one of the most pressing environmental issues (Chen et al. 2020), which will become a severe constraint in future for fulfilling human needs and for the development of many industries in worldwide (Liu et al. 2017). Even though around 70% of water is diverted into agriculture, the water demand for irrigation is continuously increasing due to the expanding nature of irrigated lands (Cai et al. 2003). Rosegrant and Ringler (2000) express that some countries are transferring water into urban and industrial uses by putting additional stress on the performance of the irrigation sector. Hence, water scarcity has been identified as the most critical challenge in IWM (Jayawardena 2013).

The issues in IWM that challenge the global water scarcity were classified in previous studies as presented in Table 1.

<Table 1>

Given all, the issues in IWM were classified into four main sections in this study as the issues towards the;

- efficiency of irrigation infrastructure,
- equity of water distribution,
- economic acceptability and
- environmental integrity associated with irrigation systems.

The term efficiency is used to express the performance of irrigation systems. It can be applied to each subsystem of irrigation systems such as storage, conveyance, distribution and field application (Pereira, Oweis and Zairi 2002). Marsden Jacob Associates (2003) states that the efficiency of water conveyance is measured by the difference between the amount of water issued from the water storage and the amount recorded at distribution canals. Losses in canal conveyance and field applications were

the major issues that impact efficiency (Poddar, Qureshi and Shi 2014). Moreover, lack of water utilisation was significantly influenced by the efficiency of irrigation water, and ultimately to the SWM of irrigation systems (Hu et al., 2010).

Cai et al. (2003) describe the term equity of SWM as the ability of people to share water use rights including both the benefits and costs in a way that no one should be compensated. Thereby, the water should be allocated and distributed in sufficient quantity and quality inappropriate time to meet the needs of the users (Shilling et al. 2013). In this regard, in-adequate and unstable supply of water were identified as common issues towards the equity of water distribution (A. Zaman, P. Zaman and Maitra 2017). Hence, in-equity of water distribution among the farmers was found to be a threat to social sustainability.

Singh (2016) points out the lack of proper planning and management could result in environmental degradation and declining ecosystems. Valipour (2015) mention that soil and groundwater salinization as a severe problem in irrigation practices, which is becoming a key issue in hydrology as well as agronomy. Apart from that, waterlogging, groundwater depletion and water pollution also cause severe impacts on the associated eco-system and imperil to environmental sustainability (Hussain and Bhattarai 2005).

Financial and economic barriers in the country affect the adoption of new practices in irrigation sector (Greenland et al. 2017). In recent years, the irrigated lands critically affected by the increased production costs and reduction of final product prices (Morillo et al. 2015). However, the lack of marginal benefit over the cost incurred and the opportunity cost of misallocation of water were threatened the economic sustainability associated with agriculture and irrigation sector in the country (Hussain and Bhattarai 2005). The research methodology of the study is discussed next.

Methodology

This research digged into the prevailing issues of existing IWM practices to find strategies to mitigate those issues. Accordingly, the research question of this study was 'what are the strategies necessary to mitigate the issues of existing IWM practices to improve the sustainable performance of irrigation systems?' Unlike quantitative surveys, this research could be better approached through a qualitative survey, which established the meaningful variation within the population and not counted the number of people with the same characteristic, attitude or opinion as in a quantitative survey (Jansen 2010). This was because, the research question of this research could be better answered through a qualitative mean as qualitative methods represent different views, attitudes, experiences, and believes of a set of people and were ideal for research on in-depth investigations with a small number of respondents based on theoretical sampling and data saturation in the analysis (Ritchie et al. 2013). Moreover, sustainability was a holistic approach, which has been developing over centuries (Lazarides and Goula 2018; Wiersum 1995), and as a result, is subjective, which is more suited being investigated through qualitative means. Given all, the qualitative expert interview survey was selected as the research strategy in this study.

Centralising to the purposive sampling method, this study has targeted a sample, which consists of industry professionals in Sri Lanka, who were well experienced and knowledgeable on water management and technical development in irrigation systems. According to Guest, Bunce, and Johnson (2006), a sample size of six interviews could be sufficient to develop meaningful themes, if a higher level of homogeneity is maintained within the sample. The initial sample size in this study was limited to twelve experts. However, following the concept of data saturation (Mason 2010) during the data analysis process, the number of experts involved for interviews in data collection was increased to sixteen numbers. Face-to-face interviews were conducted with the

experts, lasted for around 45-60 minutes. Moreover, the same guideline was used to interview all the sixteen experts to establish the reliability of the research.

The profiles of the respondents are presented in Table 2.

<Table 2>

The interview guideline was structured into sections to gather information related to identifying the issues in IWM practices under four categories derived from the literature namely efficiency, equity, economic acceptability and environmental integrity associated with irrigation systems in Sri Lanka. Moreover, strategies to mitigate the issues were further captured through the expert interviews. The findings obtained from the semi-structured interviews were analysed through a code-based content analysis method based on the directed approach (Hsieh and Shannon 2005) to attain the outcome of this research. The coding comes from the questioning of categories and their relationships and gives provisional answers (Douglas, 2003). According to Strauss and Corbin (1990), coding is the process through which data is broken, and then, conceptualised and reassembled in novel methods. The data obtained through interview transcripts in this study were coded applying N-Vivo codes. Initially, the open coding was done to scrutinise the data, then, the axial coding has been done to identify the relationships between open codes and to regroup them. Finally, selective coding was done to classify the findings to represent the outcome of the research. The next section discusses the findings of the research.

Research Findings

The issues of IWM in Sri Lanka were grouped into four main categories as derived from the literature. Moreover, the issues towards the efficiency of irrigation infrastructure were further classified under three sub-components of irrigation infrastructure namely, water retaining structures (reservoirs), water conveyance and distribution canals and

field applications. The issues identified relating to each category and the strategies proposed by the respondents to mitigate the issues are discussed next.

Issues towards the efficiency of irrigation infrastructure and strategies

Silting, in other words, accumulation of fine particles at the bottom of the structure was a major issue towards the efficiency of water retaining structures as well as water conveyance canals. The main reason for this problem was improper catchment management in irrigated areas. Hence, the respondents suggested catchment management and proper maintenance procedures such as dredging would minimise silting structures. Also, silt detectors and gates can be built to remove silt inside the canals as mentioned by R2. Larger surface areas in reservoirs enable water losses easily due to evaporation. The 'floating solar panels' is a partial solution to be introduced only for a certain extent on the reservoir surface to reduce evaporation losses, without disturbing the aquatic eco-systems. Also, flow water monitoring and keeping a lower water level in upper-stream reservoirs by delivering the additional quantity for down-stream reservoirs will reduce water losses due to evaporation and provide sufficient space to retain an additional quantity of water from sudden rains.

Improper maintenance of spillways and sluice gates in reservoirs brings down the reliability of their working conditions. Hence, installation of accurate measuring devices such as ‘regulators’, ‘measuring weirs’ and ‘gauges’ at turnout gates and appropriate record-keeping would ensure a reliable working condition of the structures, and safe and secure water supply from the reservoirs to the tail-end of the system. R14 argued the potential of introducing a management information system for record-keeping purposes and other operational activities of existing systems. According to R7, cavities in the reservoir bed was another severe issue, which often led to water leakages.

Thus, adopting foundation treatments such as curtain grouting would minimise such weak conditions of foundations and avoid seepage losses.

Leakages and canal erosion cause losses in water conveyance and distribution canals. The concrete lining would be the optimal solution to avoid this problem since it has higher water carrying capacity in contrast to the earth canals. However, the decision on whether or not to do the lining of canals with concrete is decided on the type of underlying soil. Even though it reduces water losses along the canals and improves efficiency, it would adversely affect the groundwater table and associated catchment area that imperil to environmental sustainability. Thus, there shall be a trade-off between the requirement of the concrete lining of canals and the environmental aspects. The 'trapezoidal section' is the ideal section for conveying water in canals at the optimum speed. The advantage of having a trapezoidal section is the friction force of water is less in these types of canals than in canals having a rectangular section. Further, 'cascade structures' can be built within the canal itself with a concrete lining to avoid water loss due to improper drainage.

Evaporation losses are common in canals that could be minimised by introducing closed canal sections. 'Illegal water tapping' was another problem, where some people were diverting water from canals in a prohibited manner. Mismanagement of the canal system was the main reason for this problem. Conducting awareness programmes for the general public on efficient water usage and conservation of natural resources at the regional and national level and taking proper legal actions would minimise the illegal water tapping in such areas. The respondents suggested 'pipelining' as the optimal strategy for the seepage losses in distribution canals since the concrete lining was much more expensive than pipelines. Pipelines would be able to provide pressurised water supply as per the demand in the field water applications for the

downstream farmers as well. This would minimise the social conflicts due to water shortage. Also, it would reduce water losses due to evaporation as well.

Traditional practices of water application such as ‘flood irrigation’ that was commonly used in Sri Lanka leads to huge water losses in fields. Sprinkler irrigation and drip irrigation are considered to be efficient water application methods that are already adopted in the agricultural sector in developed countries. One distinct advantage of sprinkler irrigation is the simple and flexible mechanism of operation, which requires minimum operating skills. It could be used for lands having any type of soil, even for sandy soil or erodible soil. Drip irrigation is another technique, which is used to deliver water gradually into the root system of the plant. Hence, it minimises water losses due to evaporation and run-off in the field application. Respondents suggested that adopting such methods can upsurge the crop production in fields with minimum water requirement, which could improve the economic performance of the irrigation sector.

The low water-holding capacity of soil also causes water losses in fields and deep percolation of water into the ground. The use of carbonic fertilizers instead of chemical fertilizers and the efficient field water application methods would increase the water-holding capacity of the soil. Improper levelling of fields may cause huge water losses as highlighted by R12. Precise land levelling and follow-up contour patterns in farm-land would optimise the water distribution in the fields.

Accordingly, the efficiency of irrigation infrastructure including water retaining structures, canal water distribution and field water application was significant in achieving the sustainable performance of irrigation systems in terms of environmental, economic and social aspects.

Issues towards the equity of water distribution and strategies

Deteriorated canals and imperfect canal designing are the major issues towards the equity of water distribution in irrigation. Rehabilitation together with proper canal designing and installation of regulators and turnouts to divert water was suggested as the remedies for those issues. Regular inspection and monitoring to ensure the proper functioning of such equipment would provide the required flow rate and equal water distribution throughout the system as signified by R1. Most importantly, the irrigation scheduling and decision making on bulk water allocation have to be done by considering all the inter-related system components including the crop water requirement and downstream water requirement, as a whole, to achieve the maximum satisfaction of consumers.

However, the influences coming from various authorities and regulatory bodies in the country influence the integration of system components throughout the system. The respondents suggested irrigation planning through Integrated Water Resource Management (IWRM), which was directed by three key aspects of resources management namely, coordination, participation, and consideration of various levels of authority, to minimise the pressure coming from various disciplines towards the equity of water distribution. Hence, the government intercession with regards to investment in introducing and implementing the IWRM approach to the irrigation systems found to be a strategy to overcome the issues related to irrigation planning in Sri Lanka. Further, the need for an enforceable legal framework and well-defined regulations by delegating authority among regulatory bodies in Sri Lanka were signified to manage water in the irrigation sector.

The tail-end water shortage is one of the major consequences of in-equal water distribution. While up-stream water consumers are getting more water, the tail-end users are troubling with water shortage, instigating conflicts among them. The water loss

during the conveyance was the main reason for this problem. Hence, minimise water losses in canals and implementing strong legal actions to avoid illegal water tapping were highly recommended in this regard. Besides, the lack of water storage, depending on the topography of the country affects the equity of water distribution. Diverting water from other water sources, secondary water feeding and village tank improvement were the strategies proposed by the respondents in this regard. On the other hand, managing geopolitical issues concerning water scarcity are challenging in Sri Lanka and in many other developing countries. However, according to R4, after a careful study of the downstream water requirement, the resources could be proportionately distributed among downstream water receivers. Hence, government intervention regarding managing geopolitical issues and water scarcity are essential to share this limited resource in an equal manner. Thereby, ensuring water-sharing rights through equal water distribution among the farmers found to be a prominent need to achieve social sustainability in agricultural and irrigation sectors.

Issues towards the environmental integrity associated with irrigation systems and strategies

Construction of irrigation infrastructure found to be a severe problem towards the natural equilibrium of regional biodiversity in certain areas. Inundation of a large area with significant hydraulic pressure causes destructions to the eco-system in the area. R5 stated the rescue of animals in the region during staged impounding and replantation of flora in the downstream of the reservoir have to be done in an accountable manner to ensure environmental sustainability. The Environmental Impact Assessment (EIA) suggested as a strategy to predict and minimise the adverse environmental impacts of irrigation projects and to monitor the effectiveness of measures taken in this regard.

Besides, the water pollution due to various reasons such as diversion of drainage into rivers and other streams impacts the quality of irrigated lands and subsequently for the crops in the fields. Thus, proper system designing for canals and drainage flows, and strong legal actions for illegal water management practices would minimise polluting water in the system. The impact of irrigation practices on the environment includes changes to the quality of water and the soil as discussed by the respondents. Overuse of water and poor IWM practices cause waterlogging and rise in ground-water tables in irrigated lands, which cause deep percolation of water into the ground. By adopting efficient field water application methods, lining and covering the canals, and increasing the water holding capacity of the soil, the problem of waterlogging could be minimised. Soil erosion due to traditional farming methods and improper irrigation management was another major issue towards environmental integrity. Proper catchment management and the improved farming techniques were signified to reduce the impact on the environment as well as to ensure a more productive yield. Further, the government intervention in this regard, by allocating adequate investment on technical requirements would favourable in implementing new farming practices in fields. Hence, the strategies to minimise the issues towards environmental integrity contribute to mitigate the impact of inefficient IWM practices on environmental sustainability.

Issues towards the economic acceptability associated with irrigation systems and strategies

Conducting feasibility studies at the on-set of the project is key for the successful project delivery in construction, following different disciplines relating to economic, technical, environmental and legal aspects. The Cost-Benefit Analysis (CBA) is a tool, which is used to evaluate the economic efficiency of irrigation investment as mentioned by R5. The economic performance of irrigation infrastructure is measured by the net

profit earned by the farmers or the net economic benefits generated at the national level through irrigation investment. It is usually measured by the net present value (NPV) of the benefits received by the farmers and the cost of investment on irrigation infrastructure. In this regard, R2 highlighted the need for evaluating the irrigation performance in the country on the basis of seasonal cultivations. In addition, R1 argued that evaluation of economic performance at the national level would be a key for the government to implement strategies to improve the economic growth relating to the irrigation sector. The respondents, moreover, explained, where the economic worth of irrigation infrastructure exceeds the cost incurred, it can be considered as economically feasible.

Operation and maintenance of irrigation systems were significant regarding the cost associated with economic sustainability. The canals were getting deteriorated due to lack of maintenance, demanding a huge cost for rehabilitation. The respondents, further, expressed that the maintenance cost of earth canals was higher than such cost in concrete canals. Though the initial cost of concrete lining was more expensive, it would consume less maintenance cost. Hence, it would be more profitable to lining the canals with concrete considering the efficiency of water distribution with lower maintenance requirement.

The issues of operation and management of IWM would be a threat to the economic acceptability of irrigation system. As discussed by the respondents, the 'participatory management', where the management authorities and farmer organisations work together with a mutual understanding of water delivery and usage would minimise the issues in IWM throughout the operational process and maintenance of the irrigation systems. The perspective of R10 was to replace the supply irrigation method by establishing a water ordering system as per the demand, to reduce the unnecessary water

wastage at field level. However, the respondent further mentioned this can be achieved only through effective participatory management. Besides, by analysing the identified risks involved in water usage for irrigation purposes, and preparing responses and contingency plans would reduce the risk of water inaccessibility and ensure the economic efficiency of IWM. Accordingly, it was evident that the proposed strategies to improve the economic performance would beneficial for achieving economic sustainability associated with irrigation systems. The guideline developed by incorporating the strategies proposed by the respondents was discussed next.

A Guideline for Sustainable Irrigation Water Management in Sri Lanka

The strategies emerged from the data analysis that could be used to mitigate the issues of IWM were classified according to the need of intercession relating to different disciplines as ‘engineering strategies’, ‘management strategies’, ‘operational strategies’ and ‘regulatory strategies’. The ‘engineering strategies’ highlight the intercession of engineering aspects that could be utilised to overcome the issues of IWM during the planning, designing, construction and operational phases of irrigation infrastructure. The intercession of management authorities found to be obligatory to achieve sustainable IWM, which signified as ‘management strategies’ in the guideline. The ‘operational strategies’ have to be experienced at the operational level to ensure efficient water usage in irrigated areas. Finally, the need for government intervention regarding sustainable IWM presented under 'regulatory strategies'. The Guideline was developed incorporating the strategies and mapping their relevance to achieve sustainable IWM through the efficiency of irrigation infrastructure, equity of water distribution, environmental integrity and economic acceptability associated with irrigation systems.

<Figure 1>

Discussion

The findings of the expert opinion survey on issues and strategies towards sustainable IWM in Sri Lanka were in lined with many of the extant literature. Akkuzu, Unal, and Karatas (2007) expressed concrete lining to canals and conduct awareness programmes on efficient water usage as strategies to overcome water losses in canals. Besides, the findings introduced closed canal sections, trapezoidal canal sections and cascade structures for drainage as engineering strategies, flow water monitoring for canals as an operational strategy and strong legal actions for illegal water tapping as a regulatory strategy to minimise water losses in canals. In addition, the management information system for operations has been introduced as a management strategy to improve the efficiency of the system as a whole. The use of efficient water application methods in fields was revealed in the extant literature (i.e. Hamdy, Ragab, and Scarascia-Mugnozza, 2003) as a water management strategy. Moreover, the use of carbonic fertilizers, precise land levelling and follow-up contour patterns have emerged from the survey findings as operational strategies for water-course development in fields. Evans et al. (2003) proposed land-based water allocation and irrigation-based water allocation as strategies for the inequity of water allocation in the management perspective. In contrast, the research findings highlighted the need of government intervention with regards to the equity of water distribution to improve the social sustainability through a well-defined and enforceable legal framework for irrigation system management to overcome the geopolitical issues associated with irrigation systems. Singh (2016) described, bio-drainage systems are more cost-effective and avoid waterlogging and salinization in fields. The author further mentioned conjunctive use of different sources of water prevents excessive groundwater extraction in fields. Similarly, the survey findings revealed efficient water application methods will reduce water losses and increase the water-holding capacity of the soil. Further, government

intervention with regards to investment in such technological aspects was identified as significant to the Sri Lankan context. Cai et al. (2003) emphasised economic efficiency-based water allocation, where the water is allocated for the crops, which bring the highest return and replacing water-consuming crops with water-saving crops as solutions towards economic acceptability associated with irrigation systems. However, in contrast, the survey findings signified establishing a water ordering system instead of supply irrigation as a significant strategy to improve the economic performance of irrigation by minimising unnecessary water loss. The participatory management was also recognised as a prominent management strategy in this regard to utilise irrigation water consumption with the involvement of farmer organisations and respective management authorities on a regional basis.

Conclusion

As the largest consumer of water, the irrigation sector has to play a critical role in managing water resources. However, the current practices of IWM are not achieving the benefits of sustainable use of water. The research, therefore, aimed to develop strategies for sustainable IWM in Sri Lanka. The study adopted a classification derived from the literature to investigate the issues namely, the efficiency of irrigation infrastructure, equity of water distribution, economic acceptability and environmental integrity associated with irrigation systems. Consequently, strategies were investigated to mitigate the issues that emerged from the research findings.

Silting and evaporation losses are the two major issues recognised in reservoirs and canal system towards their efficiency, whereas traditional water application methods such as flood irrigation reduce water use efficiency at field level. Further, the deteriorated canal system, geopolitical issues and tail end water shortage affect the equity of water distribution among the farmers. The water losses throughout the system

result in waterlogging and raising water tables by destructing the natural eco-system in irrigated lands and catchment areas. Moreover, the water wastage coupled with the risk of water shortage impacts the economic acceptability associated with the development of the irrigation sector in the country.

The strategies emerged from the data analysis to mitigate the issues were classified as ‘engineering strategies’, ‘management strategies’, operational strategies’ and ‘regulatory strategies’ as per the needs of engineering, managerial, operational and government intercession. Secondary water feeding and village tank improvement, floating solar panels for reservoirs, closed canal sections and maintaining the trapezoidal canal shape were significant engineering strategies emerged from the research findings to improve the efficiency of irrigation systems by reducing water losses. The findings highlighted key steps to be followed by the irrigation system management to achieve the expected performance while maintaining social sustainability through equal water distribution among the farmers. Irrigation scheduling, irrigation planning through IWRM, participatory management, regular inspection and monitoring of the system were the key strategies proposed with respect to the Sri Lankan context. The study guides to reduce water losses in fields and to increase water holding capacity of soil in fields at the operational level by recommending the use of efficient water application methods in farmlands such as sprinkler and drip irrigation since such methods were novel to many developing countries. Precise land levelling and follow-up contour patterns of farmlands were proposed for water-course development in fields as operational strategies. Regulatory strategies in the guideline highlight the need for government intercession to encourage SWM practices in Sri Lankan irrigation sector. This identifies the emergent need for an enforceable and well-defined legal framework to regulate and manage water resources in irrigation. Further, it emphasised

to evaluate the economic performance of investment on irrigation infrastructure to assess the economic sustainability associated with the system at the national level.

The study developed a guideline incorporating the strategies and their relevance to overcome the issues in efficiency, equity, environmental integrity and economic acceptability associated with the system to achieve sustainable IWM in the context of Sri Lanka. Finally, it can be concluded that the concept of SWM is not yet largely adapted in the context of Sri Lanka. Though the irrigation sector of Sri Lanka possesses the necessary knowledge and capacity to adapt SWM in irrigation, the intercession from all related disciplines and the government is necessary to effectively adapt and sustainably practice IWM in the Sri Lankan context. The proposed guideline can be helpful in such an adaptation.

This research mainly contributes to the knowledge on how to overcome the issues in IWM practices to achieve sustainable IWM in Sri Lanka. The outcome of the research would be beneficial for the industry practitioners in the water management sector, to identify the urgent need of intercessions relating to various disciplines in achieving improved operation and management of irrigation systems in Sri Lanka. The study can be further developed to prioritise the issues and strategies to generalise the findings in a statistical manner.

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Table 1. Categorisation of issues in IWM

Source	Categorisation
Ahmad (1999)	In-efficiency, In-equity, Un-sustainability
Cai et al. (2003)	Risk in the water supply system, Ecological system degradation, Conflicts in water sharing, Infrastructure deterioration
Buyukcangaz and Korukcu (2007)	Technical, Socio-economic, Environmental issues

Table 2. Profiles of the respondents

Respondent	**Discipline**	**Industry Experience (In years)**
R1	Director in the Technical Services Division (Engineer)	33
R2	Director in River Base (A) Management (Engineer)	32
R3	Director in Water Management Secretariat (Engineer)	32
R4	Resident Project Manager (Engineer)	32
R5	Director in River Base (B) Management (Engineer)	30
R6	Deputy Director in Water Management Secretariat (Engineer)	25
R7	Deputy Director of Technical Services Division (Engineer)	24
R8	Resident Project Manager (Engineer)	21
R9	Project Engineer	18
R10	Project Engineer	16
R11	Project Engineer	15
R12	Senior Technical Officer	15
R13	Resident Project Manager (Engineer)	12
R14	Resident Project Manager (Engineer)	10
R15	Geo Technician	8
R16	Senior Technical officer	7

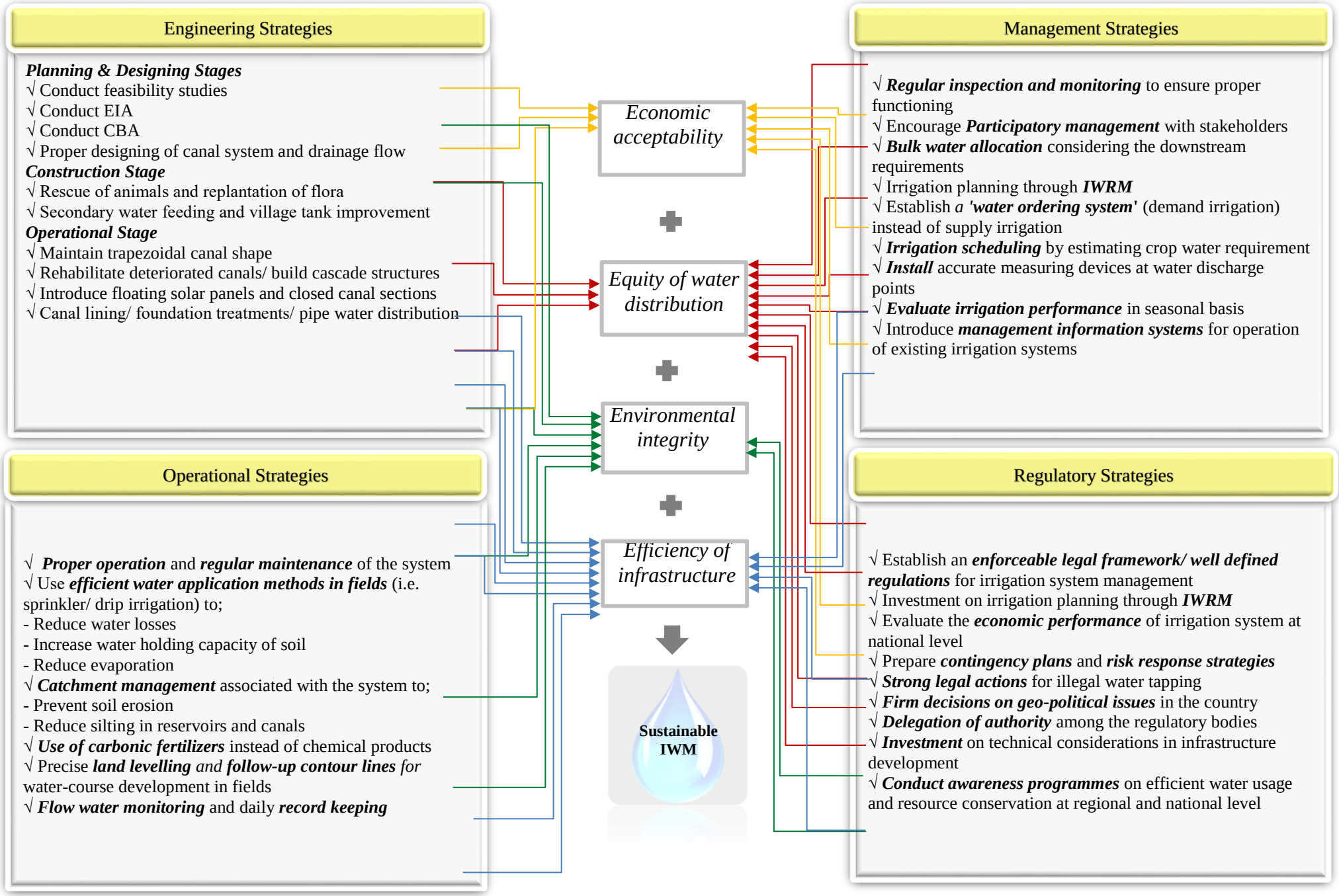


Figure 1. The guideline developed to achieve sustainable IWM in Sri Lanka