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SUSTAINABLE WATER MANAGEMENT IN IRRIGATION SYSTEMS

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Abstract
The increasing demand for water, coupled with its scarcity, has become an unceasing issue worldwide. Therefore, Sustainable Water Management (SWM) has become a major challenge in the 21st century. Irrigation systems are consuming around 60-70% of water around the globe, and thus play a critical role in water sustainability. This paper therefore aimed to investigate the issues due to poor Irrigation Water Management (IWM) practices, and the concept of Integrated Water Resources Management (IWRM) as a tool for SWM in irrigation systems.

Research have identified issues in IWM under four main categories, namely, issues in: efficiency of the system; equity of water distribution; economic acceptability; and environmental integrity. The major issues, which affect to the efficiency of the irrigation systems, were water losses in conveyance channels and field applications. Issues in water allocation lead to inequity of water distribution among the water users. Waterlogging, salinization and ground water depletion are the major issues caused by poor IWM practices. Further, failure to achieve the expected performance over the investment is a threat to the economic acceptability of irrigation systems.

SWM evaluation models are useful in decision making regarding the issues associated with three dimensions of sustainability from local to global level, both in short-term and long term perspectives. IWRM can be identified as an enabling tool in SWM, which can be used in managing water resources as a whole. This paper proposes a conceptual model to address issues in SWM in irrigation sector using IWRM, which can be applied to Sri Lankan irrigation sector to ensure sustainable and economical water management strategies.

Keywords: *Sustainable Water Management, Irrigation Systems, Irrigation Water Management, Integrated Water Resource Management*

1. Introduction

Sustainable Development (SD) is a popular concept in various industries including the construction industry. It is a guiding principle for fair and equitable sharing of benefits and costs associated with environmental integrity and economic development (Hansmann, Mieg, and Frischknecht, 2012). The SWM is linked with the SD, as it requires the trade-off among the environmental, economic and social aspects, while allocating water for competing needs.

The total annual water consumption of irrigation systems worldwide was reported to be around 60%-70% (Liu et al, 2017). Thus, it has to play a critical role in the sustainable use of water. However, the inefficient and uneconomical use of irrigation water, and the poor performance of irrigation infrastructures are affecting to the SWM of irrigation systems (Buyukcangaz and Korukcu, 2007). The environmental issues associated with the development and management of irrigation systems, led to a debate on the impacts of them to the environment. Therefore, the study aims to investigate

- The issues of Irrigation Water Management (IWM)
- Solutions to mitigate them to achieve SWM of irrigation systems
- SWM evaluation models used in evaluating the sustainable performance of water management
- Suitability of IWRM as an integrated assessment tool for strategic planning and management of water resources.

- Propose a conceptual model for SWM in irrigation systems through IWRM

2. Sustainable Water Management

The sustainability concept has been evolving over centuries. It is an integrative concept (Gibson, 2006) with the intersection of environmental, economic and social aspects, which are considered as the fundamental dimensions of sustainability (Hansmann, Mieg, and Frischknecht, 2012). According to the definition proposed by the Brundtland Report, to achieve the sustainability, there should be a development, which meet the current needs without interrupting to the right of future generations to meet their own needs. (WCED, 1987). However, different views and the various arguments on the concepts of sustainability and the SD were coming after the publication of the Brundtland Report (Moldan, Janouskova, and Hak, 2012; Hak, Janouskova, Moldan, and Dahl, 2018). Some researchers argue that SD is a process of achieving sustainability (Moldan et al, 2012), while others maintain that it only concerns the economic development (Moltesen and Bjorn, 2018). However, it can be concluded that the SD should be well-defined to address the fundamental dimensions of sustainability, to achieve economic development with minimum impact to the environment, while ensuring the social well-being.

The SWM is a decisive part of SD, as it requires managing water by balancing the social welfare, environmental integrity and economic efficiency (Melloul and Collin, 2003). Sun et al (2016) highlighted the importance of maintaining the environmental stability through SWM practices for supporting the social and economic development of a country. The Food and Agricultural Organisation (FAO) in 2012, reported the irrigation sector as the largest commercial consumer of water, which accounts for about 70% of water withdrawal in the global context. Therefore, strategic improvements regarding institutional, managerial and technical aspects are essential to achieve SWM in irrigation systems (Gutierrez, Villa-Medina, Nieto-Garibay, and Porta-Gandara, 2014). SWM in irrigation sector can be hindered by various issues of IWM. According to previous research (Ahmad, 1999; Cai, McKinney, and Rosegrant, 2003; Buyukcangaz and Korukcu, 2007), the issues in IWM fall into four main categories, namely, issues towards the efficiency of the system, equity of water distribution, environmental integrity and economic acceptability of irrigation systems. The succeeding section focuses on issues of IWM and the possible causes.

2.1. ISSUES IN IWM

The efficiency of the system can be used to measure the performance of irrigation infrastructures including water retaining structures, water conveyance channels and water distribution channels, and the water use efficiency of field applications (Pereira et al, 2002). As indicated by Marsden Jacob Associates (2003), the difference between the quantity of water issued from the water storage and the amount received to the distribution channels indicate the efficiency of water conveyance. The equity denotes the equal distribution of water among the water users as per their requirements. Cai et al (2003) broadly described the term equity in SWM as the water use rights of the people, including costs and benefits of the water consumption, without impairing the needs of them. Therefore, the water shall be delivered with sufficient quantity and quality, at the right time, up to the tail-end water users in the system (Shilling, Khan, Juricich, and Fong, 2013).

Singh (2016) pointed out that the inefficient practices of irrigation and poor planning and management of the system led to environmental degradation. Therefore, improvement in the IWM is a primary objective of SWM to protect the environment and the eco-system to ensure the environmental integrity. The efficiency of irrigation systems directly effects to the economic acceptability of its investment. Greenland (2017), identified the lack of investment in adopting new practices of IWM is a major barrier to get the benefits of sustainable use of water.

Research have identified various issues arising from non-attention to these categories. Accordingly, *Table 1* summarizes the issues of IWM identified under the aforementioned categories with causes for those issues.

Table 16: Common issues towards sustainable IWM

Identified Issue		Causes of the issue	Reference
Efficiency	Water losses in canals	✓ Seepage losses	Khan et al (2006)
	Water losses in field applications	✓ Non-uniformity of water application due to improper designing and management of sprinkler systems	Poddar et al (2014)
Equity	The inequity of water allocation	✓ Resource allocation based on the equity goal	Zaman et al (2017)
Environmental Integrity	Waterlogging and Salinization	✓ Seepage losses ✓ Percolation of irrigated fields ✓ Inadequate drainage ✓ Over-exploitation of ground water	Donaldson (2013)
	Depletion of ground water	✓ Demand for water supply through pumping exceeds the water supply through recharge from irrigation	Pereira et al (2002)
	Water pollution (Reduce water quality)	✓ High levels of fertilizers and agrochemical use ✓ Deep percolation of water	Howell (2006)
Economic Acceptability	The inequity of income distribution compared to the cost incurred	✓ Fails to earn benefits in the long-term over the initial financial outlay	Cai et al (2003)

2.2. SOLUTIONS TO MITIGATE THE ISSUES IN IWM

Solutions to mitigate the issues of IWM, identified under the four main categories (refer Table 1) are briefly described below.

2.2.1 Efficiency

Concrete lining was identified by Akkuzu, Unal, and Karatas (2007) as the solution for water losses due to seepage in water conveyance channels. Further to the authors, it shall be consist with new concrete mixtures and more economical, durable and long lasting methods, which can withstand the effects of water and soil. Further, the authors revealed that the awareness of the users regarding proper practices, when they are taking water from channels would minimise the water losses in conveyance. Hamdy, Ragab, and Scarascia-Mugnozza (2003) recognised the poor designing and management of sprinkler irrigation led to huge wastage of water in the fields. Thus, they suggested efficient water application techniques such as overhead irrigation and micro irrigation with proper operation and management practices to reduce water losses in the fields.

2.2.2 Equity

According to Evans et al (2003), land-based water allocation and irrigation-based water allocation can be proposed as solutions for the problem of inequity of water resource allocation. Further to the author, in a land based water allocation, an equal amount of water is allocated per hectare of land throughout the watershed and the water is proportionately allocated per hectare according to the requirement of irrigation in irrigation-based water allocation. Therefore, depending on the equity goal, the water allocation has to be done in a fair and equitable manner.

2.2.3 Environmental Integrity

Waterlogging, salinization and ground water depletion were recognised as the major issues towards the environmental integrity due to poor IWM practices. Singh (2016) proposed to install bio-drainage system as a cost effective solution to reduce waterlogging due to inadequate and improper drainage systems. Further to the author, reducing water losses in channel system through lining the channels would avoid the seepage losses and minimise the deep percolation into the ground. Furthermore, Scanlon et al (2012) indicated increasing the use of surface water by improving the efficiency of irrigation techniques and expanding the capacity of existing irrigation infrastructures would reduce the ground water depletion in irrigated areas. The author mentioned that by raising the elevation of dams, the existing capacity of water storages can be increased. Hence, it would be able to retain more quantity of water. Additionally, the quality of water would reduce due to the excessive use of fertilizers in fields and high deep percolation of water into the ground. Thus, A. Zaman, Zaman, and Maitra, (2017) proposed to adapt water disinfection techniques by means of physical, chemical or other alternative method to avoid the water pollution.

2.2.4 Economic Acceptability

The failure in achieving the expected benefits of irrigation infrastructures over the initial financial outlay is a threat to the economic acceptability of the system. The inefficiency of the structures due to water losses throughout the system is the major reason for such failure. Therefore, it is apparent that improved irrigation management would be a solution in this regard. Further, Evans et al (2003) highlighted the economic efficiency-based water allocation, which refers to allocating water for the uses that brings the highest return to ensure economic acceptability.

Literature has discussed various SWM evaluation models, those could be useful in sustainable management of irrigation water. The next section focuses on such models.

2.3. SWM EVALUATION MODELS

Manageable indicators, which are based on well-defined guidelines and principles for evaluating the sustainability, are important to the decision makers to identify the problems, provide early warnings, and to take necessary actions in organizational management (Singh, 2009). Most of the organisations have recognised the need of sustainable evaluation models or tools to clarify how, and to what extent the current activities of the organisation are unsustainable (Singh, 2016). According to Kates et al (2001), sustainability assessments evaluate the integrated nature of the three dimensions from local to global level in both short term and long-term perspectives. Further to the authors, the results would help decision-makers to determine what should or should not be attempted social sustainability.

Evaluation of sustainable use of the water in irrigation systems is important to reduce water losses and enhance the efficient water usage through improved irrigation management (Lou, Cui, and Yang, 2014). Ness, Urbel-Piirsalu, Anderberg, and Olsson (2007), categorised the valuation models into three main sections, namely, Indicators and Indices, Product Related Assessments and Integrated Assessments. According to Russo, Alfredo, and Fisher (2014), the indicators provide simple numerical results, which can be compared in assessing the capabilities of the cases. Further, Life Cycle Assessments (LCAs) and Life Cycle Costs (LCCs) approaches can be identified as product related assessments. The LCAs provide information about the physical system or supply chain regarding land, water and energy requirements (Russo et al, 2014), whereas the LCCs is dealing with general as well as the environmental cost of various alternatives (Hardin and Baumann, 2004). According to Ness et al (2007), the integrated assessments are supported in the decision making process related to policies or a project in a specific area. Further to the authors, project specific models are used for local assessments, while policy related models are focusing on local to global scale assessments. *Table 2* signifies examples for SWM evaluation models.

Table 2: SWM evaluation models

Category	Examples of Models	Source
Indicators & Indices	Water Poverty Index (WPI)	Lawrence, Meigh, and Sullivan (2002)
	Environmental Performance Index	Yale (2018)
	Watershed Sustainability Index (WSI)	Chaves and Alipaz (2007)
Product Related Assessment (LCA/LCC)	Water Footprint	Hoekstra, Chapagain, Aldaya, and Mekonnen (2011)
	Ecological Footprint	Ewing, Reed, Galli, Kitzes, and Wackernagel (2010)
Integrated Assessment	Conceptual modelling	Singh (2009)
	Cost Benefit Analysis (CBA)	Pereira et al (2002)
	Risk and Uncertainty Analysis	Ness et al (2007)
	Impact Assessments (i.e., EIA)	Lee and Kirkpatrick, (2006)

In the context of sustainability assessments, Integrated Assessment (IA) tools are often focused on the foresight and carried out in the cases having the scenario nature (Ness et al, 2007). Further to the authors, many of these IA tools are based on system analysis methods and integrated natural and social aspects. The IA tools are providing more powerful quantifications than the indicator or indices method alone (Russo et al, 2014). Ness et al (2007) identified the conceptual modelling as an IA tool, which can be used to analyse qualitative relationships for visualising and detecting problems, where changes in a given system lead to achieve sustainability.

2.3.1 Integrated Water Resource Management

Integrated Water Resources Management (IWRM) is a process of managing water resources as a whole in a sustainable and consistent manner as recognized by Buyukcangaz and Korukcu (2007). Further to the authors, it provides a practical guide to the management authorities to respond the challenges of SD in the water sector. It highlights the stakeholder management, real time communication and collaboration throughout the system. Therefore, this can be used for decision making by implementing different strategies to address specific SWM issues in various levels of the system. The process of IWRM is depicted in Figure 1.

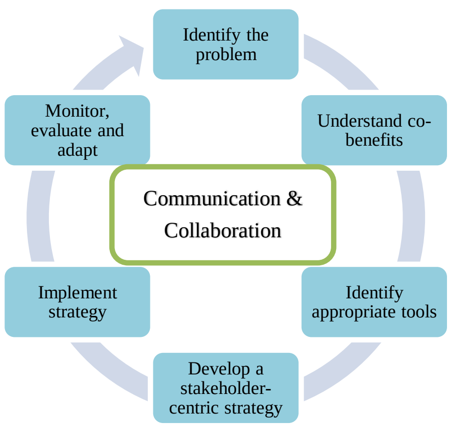

Figure 24: The process of IWRM
(Source: Integrated Water Resource Management Center, 2017)

Ness et al (2007) highlighted that the integrated systems shall address multi-disciplinary nature of environmental, social, technical, economical and legal concerns with long-term and short-term decision making. As shown in Figure 1, IWRM process requires the communication and collaboration of each party throughout the process. Accordingly, the water use can be quantified in terms of the losses, unequal distribution, conservation of the natural eco - system and economic efficiency of the system. Therefore, the IWRM approach would interpret the broad guidelines of SWM into understandable means of IWM regarding operational and maintenance aspects. Therefore, this can be identified as an approach for treating the competing water needs in a fair, efficient and sustainable manner, and as a conceptual solution for water management issues.

2.4. CONCEPTUAL MODEL

A conceptual model is developed as shown in Figure 2, based on the issues identified under four main categories as listed in Table 1. In this model the concept of IWRM is used as a tool for decision making in order to attain the SWM in irrigation systems. Based on this model the strategies to overcome the issues and enhance the sustainability performance of IWM through the process of IWRM can be identified.

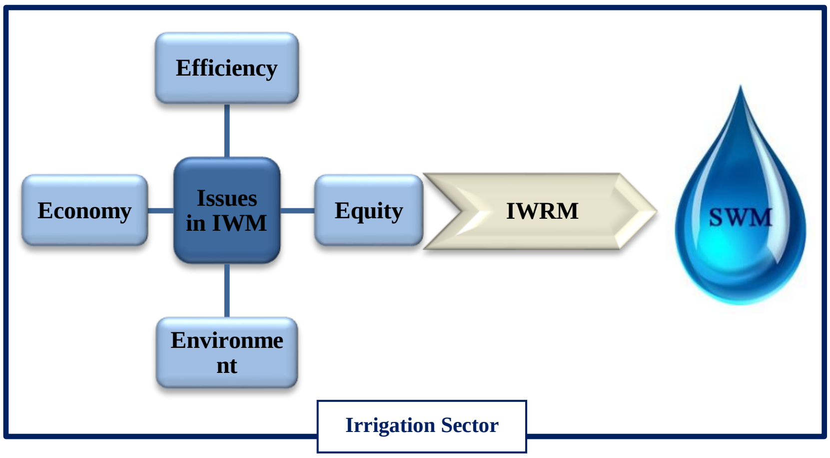

Figure 25: Conceptual model to understand SWM through IWRM

3. Conclusions

This paper presented the findings on sustainable water management of irrigation systems. A thorough literature review was undertaken to investigate the associated issues of irrigation water management and their impact on sustainability. The paper categorized the issues of IWM under four categories, namely, efficiency; equity; environment and economy. Findings suggest that water losses throughout the system, most importantly in water conveyance channels and field applications, reduce the efficiency of the irrigation system. Therefore, canal lining with durable materials would be most economical solution to avoid water losses in conveyance. The use of efficient practices of irrigation such as overhead and micro-irrigation with proper designing and operation would reduce the water wastage at the field level. Moreover, the land-based and irrigation-based water allocation as per the requirement has been identified to protect the water sharing rights of the users.

Poor irrigation practices impacted the environmental integrity in different ways. Waterlogging, salinization and ground water depletion were the main issues towards the ecological stability. The findings revealed that installing bio-drainage systems as a cost-effective solution to reduce waterlogging and salinization in irrigated areas. Further, by increasing surface water supply through expanding the current capacity of water storages could minimise the ground water depletion. The inefficiency and poor performance of infrastructures over the investment in development and maintenance of them were affected the economic acceptability of irrigation systems. Hence, water allocation for the uses, which brings higher return would be reduce the opportunity cost of misallocation of water.

SWM evaluation models are necessary for decision makers at various levels of authorities. Mainly there are three types of models, namely, indices and indicators, product related assessments and integrated assessments. IWRM was identified as an integrated approach for managing the competing water needs in a sustainable manner, and a conceptual model was proposed to use IWRM for SWM in irrigation systems.

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