Analysis of issues in sustainable water management of irrigation systems: case of a developing country

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Abstract

Purpose – Sustaining the irrigated agriculture, while conserving the natural eco-system, are the two main objectives of sustainable water management (SWM) in irrigation. Achieving both the objectives simultaneously is a complex task in most developing countries. This requires a holistic approach of understanding the issues in irrigation water management (IWM) from social, economic and environmental perspectives. Therefore, this paper aims to analyse the issues towards the SWM of irrigation systems in Sri Lanka to help maintain a stable relationship between the aforementioned two objectives.

Design/methodology/approach – Qualitative interview survey was selected as the research strategy to achieve the research aim. 16 semi-structured interviews were conducted with experts in IWM sector to collect data in the Sri Lankan context. Data were analysed using code-based content analysis, based on directed approach.

Findings – Findings revealed the issues in SWM in terms of efficiency of irrigation infrastructure; equity of water distribution; environmental integrity and economic acceptability. Most of the issues were related to the inefficiency towards SWM of irrigation systems. Conflicts among water users, especially the people in downstreams aggravated the problem of equity of water sharing. Depletion of groundwater and waterlogging were the major issues towards environmental integrity. Loss of water happened due to the issues in different irrigation infrastructure components hindering economic acceptability.

Originality/value – Theoretical contribution includes an analysis of issues in IWM from a sustainability perspective. Practical implications include an overview of deficiencies in the SWM to generate appropriate strategies to achieve sustainability for decision-makers such as policymakers in the irrigation sector in developing countries similar to Sri Lanka.

Keywords Irrigation systems, Irrigation water management, Sri Lanka, Sustainable water management

Paper type Research paper

1. Introduction

The increasing growth of population in the world directly affects the current water demand due to higher competition over the limited amount of water resources, which has led to severe water shortages worldwide (Banerjee and Hermans, 2020). Overuse of surface water and unsustainable consumption of non-renewable ground water has been a challenge to the current capacity of water resources and to ensure food security (Ahmed, 2020). Therefore, the sustainable management of water resources has become a major challenge in the 21st century (Sapkota, 2019). Sustainable water management (SWM) is a major component in sustainable development (SD), which is accounting for similar kind of issues as sustainability (Russo *et al.*, 2014). Mays (2007) highlights that there is an inherent relationship between SD and SWM

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because of the requirement of water to achieve the development in a country, without impairing the water needs of the future. The total quantity of annual water consumption of irrigation systems was reported around 60–70% in the global context (Phadnis and Kulshrestha, 2012). Hence, the provision of irrigation systems remains important as it provides water for agricultural production, especially in arid and semi-arid regions, to ensure a more productive yield (Singh, 2016). Thereby, the irrigation systems have to play a critical role in water sustainability (Greenland *et al.*, 2017). According to Cai *et al.* (2003), the irrigation systems are managing the various types of structures starting from the water retaining structures, water conveyance and distribution canals up to the field-water application. Further to the authors, the requirement of water distribution systems is being increased due to the higher demand for irrigation water worldwide.

Large-scale irrigation systems, which are extensively invested by the government and the foreign donors are contributing to the agricultural as well as the socio-economic development in most of the developing countries in Asia (Lam, 2006). The irrigation system plays a major role in the agricultural sector in Sri Lanka (Sivayoganathan and Mowjood, 2003). As a developing country, since ancient times, the agricultural sector in Sri Lanka has been placed at a predominant place in the country's economy. A higher proportion of 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 is dedicated to the operational and maintenance purposes of the irrigation systems in Sri Lanka. Lam (2006), who studied Nepal and Taiwanese reports, asserts that in most of the cases, these projects are not economically viable since they have failed to perform at a satisfactory level. Singh (2016), studying in the Indian context, recognises that the efficiency and long-term success of irrigation systems largely depend on the appropriate planning and management by the relevant authorities.

Due to the higher needs of crop production, it is difficult to sustain the traditional practices of farming with the use of canals and rivers (Cai *et al.*, 2003). Hence, the expansion of the capacity of irrigation systems is essential to cope with the high demand for crop production (Hussain and Bhattarai, 2005). Ugwu *et al.* (2006) identify the need of a sustainable assessment of those techniques and practices, which are to be implemented in different levels of the irrigation system development project, starting from conceptual design, operational process to the maintenance and decommissioning stages. More importantly, the lack of proper irrigation management in the operational and maintenance stages can adversely affect the environment and imperil sustainability (Phadnis and Kulshrestha, 2012). Therefore, Sun *et al.* (2016) identify the requirement of SWM practices to minimise the environmental, social and economic issues and ensure the integration of those three pillars in all stages of water management in irrigation. Before investigating the sustainable practices to mitigate the issues, a detailed analysis needs to be carried out on the issues in each stage of irrigation projects, particularly related to environment, social and economic aspects. Accordingly, this paper intends to bring in a critical analysis of the issues towards SWM of irrigation systems in a developing country, with a specific focus on Sri Lanka.

2. Literature review

Literature review discusses the significance of SWM in irrigation, an overview of the irrigation system in Sri Lanka and issues associated with irrigation water management in the subsequent section.

2.1 The significance of sustainable water management in irrigation

SD balances environmental resource protection, social progress and economic growth and stability now and for the future (Isa *et al.*, 2018). As an integral part of SD, SWM is of

paramount importance to maintain environmental stability, which will ensure the social and economic development of a country (Sun *et al.*, 2016). Irrigated agriculture provides water for more than half of the agricultural production internationally, especially in arid and semi-arid regions (Habteyes and Ward, 2020). Therefore, the irrigation systems play a major role by contributing to ensure the food security and production of a more productive yield in the global context (Sapkota, 2019). Irrigation systems are associated with various types of structures starting from water retaining structures to water distribution canals. The requirement of water distribution systems is being increased over the years due to the higher demand for irrigation water combined with an increased need for cultivation (Cai *et al.*, 2003). As per Phadnis and Kulshrestha (2012), irrigation sector is the largest water consumer, and the total quantity of annual water consumption of irrigation systems was reported to be around 60–70% in the global context. Therefore, SWM is vital for the growth of irrigated agriculture to protect the natural eco system while serving for food security (Habteyes and Ward, 2020). Accordingly, there is a need for sustainable water-consuming techniques and strategic improvements regarding technical, managerial and institutional capacities to improve the SWM in the irrigation sector (Gutiérrez *et al.*, 2013). Ugwu *et al.* (2006) also stressed the importance of developing policies focussing on all the uses and users of the water in irrigation systems to ensure an efficient, equitable and sustainable water use under the water scarcity. In today's context, by identifying this requirement, many policy agendas have been introduced focussing SWM in irrigation. As mentioned by Liu *et al.* (2017), the SD goals released by the United Nations in 2015 set forth a target to ensure sustainable freshwater supply and withdrawal in the coming decades. The authors further highlight that improving the efficiency of irrigation systems is one of the key objectives in this agenda.

2.2 Irrigation system in Sri Lanka and its significance

Sri Lanka is composed of two-third dry zone area, and therefore, irrigation system remains crucial to agricultural activities (Köpke *et al.*, 2019). Since ancient times, the agricultural sector in Sri Lanka has been placed at a predominant place in the country's economy, and a higher proportion from the public investment is given to the development of irrigation systems (Shand, 2002). As mentioned by Köpke *et al.* (2019), the irrigation technology of the ancient Sri Lankan hydraulic society was based on an intricate, highly integrated cascade system of tanks and canals. This ancient irrigation system in Sri Lanka was transformed during the British colonialism with new technological advancements and administrative behaviours with expertise knowledge that came from western countries (Zubair, 2005). According to Sivayoganathan and Mowjood (2003), the gravity irrigation is the main irrigation system in Sri Lanka, which can be classified according to the source of water as tanks and reservoirs and based on the size of the system as major/large, medium and minor/small irrigation systems. As pointed out by Abeywardena *et al.* (2019), the tank-based irrigated agricultural system in the dry zone of Sri Lanka is one of the oldest historically evolved agricultural systems in the world. The main components of the system consist of a connected series of man-made tanks constructed in shallow valleys to store, convey and utilise water for paddy cultivation. These cover water storage system, water conveyance system including main canal, branch canals, distribution canals and field canals, and command area which refers to the farm plots that are receiving water through the canals (Sivayoganathan and Mowjood, 2003). The small and medium tank systems in Sri Lanka were developed and managed by the local communities from ancient times whereas the construction of large tanks across several hectares in size went along with the later implementation of a centralised management structure in the country (Abeywardena *et al.*, 2019). As mentioned by Lam (2006), while large-scale irrigation systems are extensively invested by the government and foreign donors in most of the developing countries in Asia, in most of the cases, Sri Lankan irrigation projects are not economically viable since they have

failed to perform at a satisfactory level (Lam, 2006). Therefore, to ensure the efficiency and long-term success, appropriate planning and management by the relevant authorities are essential (Lam, 2006; Singh, 2016).

2.3 Issues associated with irrigation water management

The issues associated with IWM, which lead to raising the challenge of water scarcity has been discussed in the literature under different categories. Ahmad (1999) categorised the issues of irrigation water management (IWM) as inefficiency, inequity and unsustainability. Further, Cai *et al.* (2003) identified the issues of IWM in their research, related to the risks in the water supply system, ecological system degradation, conflicts in water sharing and infrastructure deterioration. Furthermore, Buyukcangaz and Korukcu (2007) found technical, socio-economic and environmental issues with regards to the IWM in their study. Given all, the issues associated with IWM in global context could be categorised into four main sections, namely efficiency, equity, environmental integrity and economic acceptability, which is referred to as 4Es in this research.

As explained by Pereira *et al.* (2002), usually, the term efficiency is used to express the performance of irrigation systems. Further to the authors, efficiency can be identified concerning each sub-system of the irrigation systems, i.e. efficiency of water retaining structures, conveyance canals, distribution canals and field application. Marsden Jacob Associates (2003) reported 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. Further to the author, water losses during the conveyance and distribution system will aggravate the problem of the efficiency of irrigation systems. Hence, as identified by several researchers (Ahmad, 1999; Khan *et al.*, 2006; Singh, 2016), canal conveyance losses and field application losses are the most common issues related to the efficiency of IWM.

The equity denotes the equal distribution of water in each irrigation subsystem, and this is calculated from the supplier's side (Usman *et al.*, 2015). However, in areas, where there are water shortages, this can be calculated from the consumer's perspective as well. Therefore, to ensure effective IWM, the water should be delivered in sufficient quantity and quality in appropriate time to meet the needs of all the users (Shilling *et al.*, 2013). However, as reported in previous studies, the inadequate or unstable supply of water is an issue that is prevalent in the existing irrigation systems (Khan *et al.*, 2006; Singh, 2016)

According to Singh (2016), the soil and groundwater salinization is a severe problem in irrigation practices, which is becoming a key issue in hydrology as well as agronomy. Further, waterlogging in irrigated lands causes problems to environmental integrity as it damages structures and spreads endemic diseases (Pereira *et al.*, 2002). Moreover, depletion of ground water, lack of drainage and water pollution have also been discussed as issues related to IWM (Khan *et al.*, 2006). If the initial financial outlay is considerable, the associated benefits of irrigation systems will be substantial and long-term (Lamm and Trooien, 2003). However, financial and economic barriers critically affect the adoption of new practices in the irrigation sector (Greenland *et al.*, 2017). The commonly cited economic issues of IWM include lack of marginal benefit over marginal cost and the opportunity cost of misallocation of water (Hussain and Bhattarai, 2005).

3. Research methodology

This study aims to analyse the issues in SWM of irrigation systems in Sri Lanka. Hence, the research question of the study was established as, "what are the issues and their consequences and implications in SWM of irrigation systems in Sri Lanka?" According to

Yin (2014), "what" type of research questions are exploratory and can be studied using any research strategy (experiments, survey, case studies etc.) given the goal is to develop pertinent hypothesis and propositions for further inquiries. The qualitative approach is ideal for research on in-depth investigations (Ritchi *et al.*, 2013). In comparison to quantitative surveys, this study could be best approached through a qualitative survey that identified significant population variance and did not count the number of people with the same characteristics, attitudes or opinions as in a quantitative survey (Jansen, 2010). Sustainability is a holistic approach, which has been developed over centuries (Saunders and Hughes, 2018; Wiersum, 1995), and as a result, is subjective, which is more suited being investigated through qualitative means rather than a quantitative method. Accordingly, a qualitative interview survey (Jansen, 2010) was selected as the research strategy.

Interviewees were selected via purposive sampling, a method proven to be effective, when collecting data from experts in the studied area (Tashakkori and Teddlie, 2003). Accordingly, 16 professionals associated with operation and maintenance of irrigation infrastructures, bulk water allocation from reservoirs and distribution across the country were selected based on the nature of practice and years of experience following the concept of data saturation (Mason, 2010). Interviewee profile is given in Table 1. The professionals associated with the technical development of irrigation systems in Sri Lanka were engaged with developing and operating water managing software, hardware and other information facilities including the communication networks related to operation and maintenance of irrigation infrastructure. The professionals in water management division were engaged in bulk water allocation for all the water needs associated with irrigation areas. Making decisions on water allocation and distribution to the fields across the country were the main roles performed by them. Profiles of the respondents are presented in Table 1.

Semi-structured interview design with less structured questions was adopted as it allowed to raise further questions instantly, whenever required (Berg, 2009). The interview guideline was structured into sections to identify the issues in IWM practices under four categories derived from the literature, namely, issues towards the water use efficiency of irrigation infrastructure; equity of irrigation water distribution; economic acceptability and environmental integrity associated with irrigation systems in Sri Lanka. Subsequently, the causes for the issues and their consequences were identified as the next step of the analysis of issues. The collected data were analysed using code-based content analysis method based on the directed approach (Hsieh and Shannon, 2005).

4. Research findings

All interviewees used their proficient knowledge and experience gained through their engagements in the irrigation sector to elaborate on the current practices of IWM in Sri Lanka and the associated issues for SWM. It was revealed that each and every issue in IWM has occurred due to faults at the design stage or due to lack of maintenance or due to the operational matters detailed as follows:

(1) Design issues – outdated canals, silting, breakdown in the spillway, weak foundation conditions, insufficient capacity to carry additional water quantity during sudden rains, deep percolation of water into the ground, defects in canal designing

(2) Maintenance issues – Silting, evaporation, canal erosion, leakages, earth collapsing, sedimentation, cavities in the reservoir bed, vegetation, water seepage, water runoff, waterlogging, soil erosion

(3) Operational issues – illegal water trapping, outdated practices (eg; flood irrigation method), not following the irrigation schedule, geo-political issues regarding water,

Respondent	Discipline	Nature of organisation	Industry experience	Educational background	Gender
*R*1	Director in the technical services division	Technical services	33 years	a, f	Male
*R*2	Director in river base (A) management	Water resources development	32 years	a, d, e	Female
*R*3	Director in water management secretariat	Water management secretariat	32 years	a, b, g	Female
*R*4	Resident project manager	Dams and reservoirs operation	32 years	a, b	Male
*R*5	Director in river base (B) management	Water resources development	30 years	a, c	Male
*R*6	Deputy director in water management secretariat	Water management secretariat	25 years	a, g	Male
*R*7	Deputy director of technical services division	Technical services	24 years	a, b, f	Male
*R*8	Resident project manager	Dams and reservoirs operation	21 years	a, c	Female
*R*9	Project engineer	Downstream development	18 years	a, d	Male
*R*10	Project engineer	Downstream development	16 years	a, f	Male
*R*11	Project engineer	Downstream development	15 years	a, e	Female
*R*12	Senior technical officer	River basin management	15 years	h	Male
*R*13	Resident project manager	Dams and reservoirs operation	12 years	a, b	Male
*R*14	Resident project manager	Dams and reservoirs operation	10 years	a, e	Female
*R*15	Geo technician	Land use planning	8 years	a	Male
*R*16	Senior technical officer	River basin management	7 years	i	Male

Note(s): Legend of educational background of the respondents
[a]: Bachelor of Science in engineering
[b]: Master of Science in agricultural engineering
[c]: Master of Science in construction project management
[d]: Master of Science in water resource management
[e]: Postgraduate diiploma in construction project management
[f]: Diploma in hydrology
[g]: Master of Engineering in hydraulic engineering
[h]: National vocational qualification (level 7)
[i]: National vocational qualification (level 5)

Table 1.
Profile of the interview respondents

> influences coming from various authorities, devastate the natural equilibrium of biodiversity, water pollution, overuse of water

Besides, it could conclude that the majority of the issues occur due to malpractices in maintenance activities of the irrigation system of Sri Lanka. All interviewees declare that the

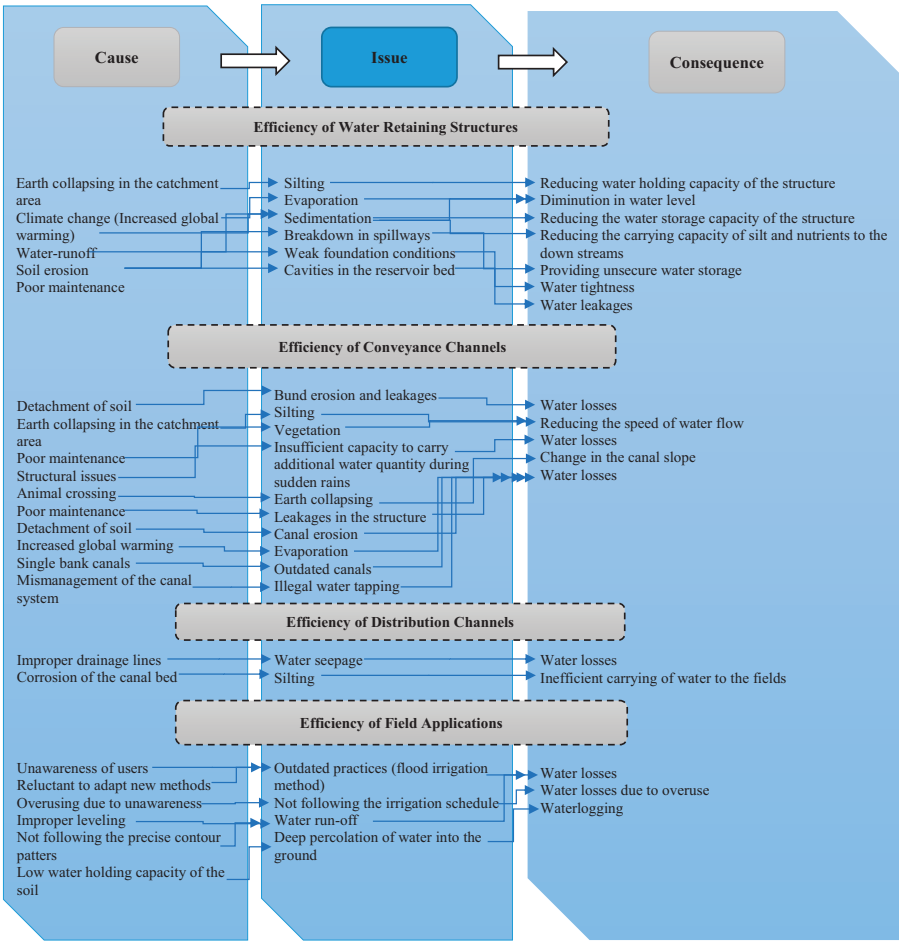
current practices of water management are not sufficient to deal with the increasing water demand. Therefore, there is a need for identifying and further analysing the current issues to come up with effective strategies to achieve a SWM. Accordingly, analysis of issues towards SWM based on causes and consequences was carried out under the sub-categories of efficiency, equity, environmental and economic (4Es). This is because 4Es provide a proper basis for opening up the issues with a sustainability perspective elaborated in subsequent sub-sections.

4.1 Issues in efficiency of irrigation infrastructure

Efficiency issues will be discussed following the four major structures in irrigation systems namely, water retaining structures, water conveyance canals, water distribution canals and field applications (refer Figure 1).

Issues in efficiency of water-retaining structure. The primary uses of dams and reservoirs are to provide water for irrigation, hydropower generation and domestic and industrial uses. In the case of irrigation, water storage is very much important, when the river flows are not enough but there is a higher demand for irrigation water. Having adequate, reliable and secure water storage is necessary to maintain the water demand consistently. However, in Sri Lankan context, there are several issues in those structures, which affect its efficiency. Most of the respondents highlighted "silting" as the main reason for the inefficiency of water-retaining structures. It was happening due to earth collapsing in the catchment area. As a result of silting reservoirs, the water holding capacity of the structures would be reduced. *R*3 stated, "*We are raising the spills to hold more water quantity in the reservoir. But, this is not the right solution to this problem as this can be done only for one, or two reservoirs*". Evaporation due to increased global warming was another issue as highlighted by the respondents. The reduction of the water level due to the evaporation depends on the size and depth of the reservoir. Further, the large open surfaces of reservoirs easily enable water losses by evaporation. Sedimentation was another problem, which causes the diminution in water flow while decreasing the potential water-storing capacity of the structures as explained by some of the respondents. Further, it decreases the carrying capacity of silt and nutrients to the downstreams. According to the explanations given by the interviewees, because of the improper maintenance of spillways and sluice gates, the reliability of its working condition goes down. As a result, it would not be able to provide secure and safe water storage. Besides, another highlighted problem is about structural issues of reservoir bed and foundation, which lead to inefficiency of the system. Accordingly, the majority of the respondents pointed out water tightness as an issue towards efficiency due to the weak conditions of the foundation. Further, the cavities in the reservoir bed is another serious problem, which often leads to water leakages.

Issues in efficiency of conveyance canals. The efficiency of water delivery in an irrigation system is measured by the difference between the amount of water diverted at the dam and the amount recorded in measuring devices at distribution canals. A proportion of water diverted from reservoirs was lost during its conveyance to the receivers. All the respondents agree that water losses during the conveyance affect the efficiency of the canals. Due to bund erosion and leakages, water losses are happening through bunds. Majority of the respondents state that silting and vegetation would decrease the efficiency of conveyance canals by reducing the speed of water flow. Besides, the insufficient capacity to carry additional water quantity during sudden rains would affect water losses in some canals. Leakages in the structure and canal erosion also lead to water losses in conveyance canals. Some of the respondents complained about the structural issues in conveyance canals, which cause the inefficiency. It is highlighted that the "trapezoidal section" is the optimal section for conveying water in canals. The advantage of having a trapezoidal section is the friction force



[Guide for reading the table: Causes and consequences are connected using arrows with the respective issue]

Figure 1.
Efficiency related issues in sustainable water management in irrigation system in Sri Lanka

of water is less in these types of canals than in canals having a rectangular section. There are various reasons, which disturb the slope of the canal such as earth collapsing due to animal crossing and growth of vegetation. By agreeing with that, *R*9 further stated "*The main cause for the inefficiency of water conveyance in canals is changing the canal section*". Moreover, the improper drainage lines going through the canals would also reduce the efficiency of water conveyance as explained by the respondents. Supplementary, evaporation causes water losses in conveyance canals similar to the losses in water retaining structures. Another issue emphasised is that outdated canals are still using for irrigation water conveyance. In such systems, the canals are built at the existing ground level. It is stated that when the top of the bund is aligning with the existing ground level, it would be collapsed due to rainwater drainage. Then the water conveyance will get disturbed. The water losses are happening in places of "single bank canals". Interviewees explained that when the canals are going through wetlands, it is difficult to build canal bunds in both the sides of the canals. In such situations, the wetlands will get filled with water up to the water level of the canal. This ultimately affects

the efficiency of the whole system since it is unable to convey water to the fields at the right time. In addition to the issues described above, "illegal water tapping" is another problem, where some people are trying to obtain water from canals in a prohibited manner. Mismanagement of the canal system is the main reason for this problem.

Issues in efficiency of distribution canals. The distribution canals convey water from main conveyance canals to the fields, which comprise open canals and pipelines or a combination of both. As proven in the literature, losses in distribution canals would aggravate the problem of efficiency in the system. Most of the respondents state that distribution canals also have similar issues as mentioned under issues towards the efficiency of conveyance canals. Most of the respondents highlight "seepage" as a common issue in distribution canals, which leads to water losses. Silting is again identified as an issue towards the inefficiency of distribution systems. When the water is coming from the outside with drainage, silt is depositing at the bottom of the canal. Further, this can happen due to corrosion of the canal bed when water is flowing inside the canal. Due to this problem, the canals may not be able to carry water for the fields. Respondents explain that silting as a huge problem in outdated canals, which are still using for irrigation water distribution.

Issues in efficiency of field application. The field application method shall provide an adequate amount of water to meet the requirement of crops consistently without unnecessary wastage. When choosing the best method for applying water into the fields, the consideration has to be given not only to the technical viability but also to the ease of operating and maintaining such a method. Most of the respondents agree that the traditional practices of water application lead to huge losses of water in the fields. Further, it is identified that the flood irrigation method as a low-efficient water application method is commonly used in Sri Lanka. In this system, the farmers will receive water from pipes or field canals for the topmost basin in their field. After the top basins are filled with water, the water will gradually flow to the basins at the next level. In such a way, all the basins will be irrigated in the farmland. It is revealed that this method leads to a huge wastage of water. The direct application of water to each basin would reduce the wastage of water. The crop water requirement in fields is gradually changing during its cultivation period. Not following the irrigation schedule, which is prepared according to the crop water requirement is another issue identified by the respondents. Due to the unawareness of the users, huge water wastage has occurred. It is indicated that only around 30% of water quantity is received by the fields out of the total quantity issued from the water storage. The remaining quantity has been disregarded for conveyance and field losses as explained. *R*11 emphasised, *"Though the water has been allocated as per the crop water requirement based on the previous data, farmers are not satisfied with that system. Then they make troubles to the operators"*. Moreover, improper levelling of fields may cause huge water losses. Levelling the field with a slight slope would collect and retain water, without run-off from the land. It is mentioned that there are some tail ends having larger slopes in the land. In such places, the water will run-off rapidly without collecting and remaining in the field. It can be deduced that not following the contour patterns and improper levelling of fields would lead to water wastage due to uneven distribution. Moreover, due to the low water holding capacity of the soil, a certain amount of water would be lost in the fields. It is mentioned that the low water-holding capacity of soil would impact the deep percolation of water into the ground.

4.2 Issues in equity of water distribution

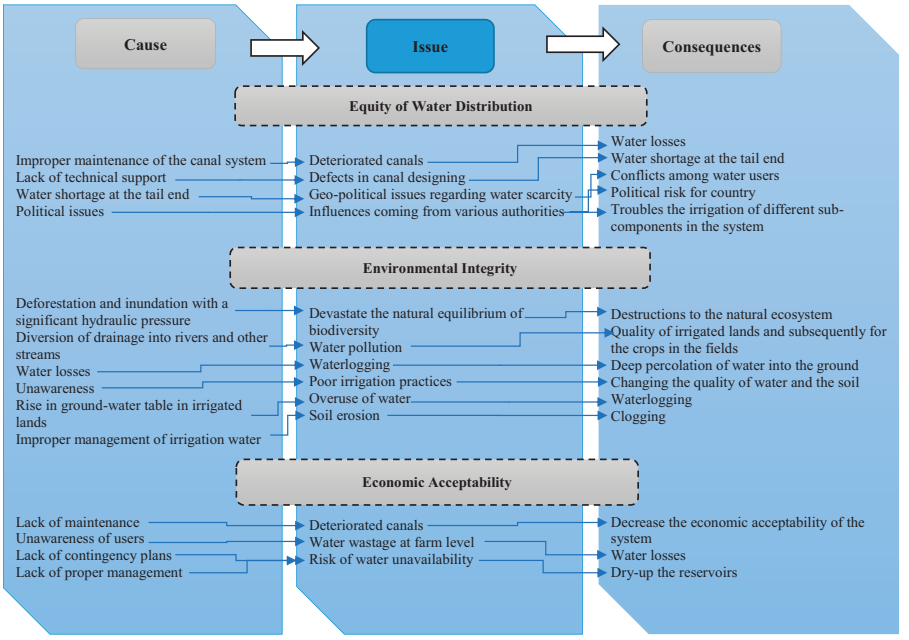
The water should be delivered in sufficient quantity and quality at the right time to meet the needs of the users. According to the expert interview data, it was identified that inefficiency of the system, inadequacy of water supply, inequity of canal water distribution and the sequence of water delivering are the main causes towards the inequality of water distribution (refer Figure 2). Majority of the respondents states that deteriorated canals lead to the

inequity of water distribution in the system. Further, improper maintenance of the canal system is the major reason for this issue. Besides, the defects in canal designing is an issue towards the equity of water distribution. Few respondents identified the tail-end water shortage as a problem of inequal water distribution. *R*1 explained, *"While up-stream water receivers are getting more water, downstream users, or the tail end users are troubling with water shortage"*. It is stressed that due to the water shortages at the tail end, conflicts can happen among the downstream water users. The water loss during the conveyance is the main cause of this problem. Besides, the illegal water tapping during the conveyance is caused by the equity of water distribution. Further, it is highlighted that managing geopolitical issues regarding water scarcity is difficult. The lack of water storage in some areas affects the equity of water distribution. This depends on water availability and the efficiency of water distribution throughout the system.

4.3 Issues in environmental integrity

The irrigation systems denote modification to the existing ecosystem by extracting water from available water resources and diverting water for dry zones using built structures as identified in the literature. Therefore, there can be impacts on the environment due to the establishment of irrigation infrastructures. Figure 2 depicts a general elaboration of the issues, causes and consequences of environmental integrity. According to the experts, the impacts of irrigation projects on environmental integrity can be divided into three main categories described as follows:

Issues derived from construction process. Construction of irrigation infrastructures is very complex since it needs advanced technologies of construction methodologies and a large number of resources. This includes dams, reservoirs, conveyance, distribution and field



[Guide for reading the table: Causes and consequences are connected using arrows with the respective issue]

Figure 2.
Equity, environmental and economic issues in sustainable water management in irrigation system in Sri Lanka

canals. There are several impacts on the environment during the construction process of those infrastructures. The construction of irrigation structures leads to the destruction of the natural equilibrium of regional biodiversity. *R7* stated, *"Due to the inundation of large area with significant hydraulic pressure, there can be destructions occurred to the eco-system in the area"*.

Issues derived from water distribution and operation. Irrigated lands receive water from surface water supplies or extracted ground-water. The quality of water in water sources and the method of delivering water to the fields affect the environmental integrity. Most of the respondents highlight that water pollution impacts the quality of irrigated lands and subsequently for the crops in the fields. Diversion of drainage into rivers and other streams is the main cause of water pollution during the water conveyance. Interviewees declare that illegal water management practices are the main causes of this problem. Besides, it is evident that improper management and operation of water distribution also affects sustainability. The rising water tables could happen due to water losses during the conveyance. Further, the rising water tables lead to waterlogging in certain areas due to deep percolation of water into the ground.

Issues derived from irrigation practices. The impact of irrigation on the environment includes changes to the quality of water and the soil. Experts highlight that overuse of water and poor IWM lead to the problem of waterlogging and rise in groundwater table in irrigated lands. Further, the increased groundwater level in irrigated areas leads to high deep percolation of water into the ground. It is evident that the traditional practices of irrigation reduce the efficiency of the system and lead to unnecessary wastage of water. Soil erosion is an issue towards environmental integrity, which occurs due to improper management of irrigation water.

4.4 Issues towards the economic acceptability

The demand for irrigation water is increasing with population growth and climate change. Moreover, the inefficiency of existing infrastructures and lack of investment to repair and maintain the structures aggravate the need for investment on new irrigation infrastructures. Hence, economic acceptability is the main consideration in investment in irrigation projects. Figure 2 depicts several issues towards economic efficiency identified by the respondents during the operation and maintenance phase. As explained by the experts, canals were getting deteriorated due to lack of maintenance, and it would incur a huge cost for rehabilitating those. Accordingly, this would be a threat to the economic acceptability of the system.

4.5 Discussion of research findings

The findings of the qualitative expert opinion survey on issues in SWM of irrigation systems were in line with many of the extant literature. According to Ahamed (1999), the issues associated with the irrigation systems are the main causes of lower productivity in the agricultural sector. Following the categorisation derived from the previous research (Ahamed, 1999; Cai *et al.*, 2003; Buyukcangaz and Korukcu, 2007), the study investigated issues in the efficiency of irrigation infrastructure, issues in the equity of water distribution, issues in environmental integrity and issues towards the economic acceptability. The term efficiency is used to express the performance of irrigation systems as mentioned by Pereira *et al.* (2002). Water loss throughout the system was the most common issue related to the efficiency of IWM (Khan *et al.*, 2006). Conforming to the literature findings, the respondents' complaint, the inefficiency of the system affects the performance of infrastructure to achieve objectives in an economic perspective, associated with the agricultural sector. Further, the water losses adversely impact the ground water table in irrigated areas having waterlogging

and salinization was in line with Singh (2016). Additionally, the survey findings revealed, sedimentation, which was another problem towards the efficiency, causes the diminution in water conveyance through the canal system. This decreases the potential water storing capacity of the structures (Shilling *et al.*, 2013) and the carrying capacity of silt and nutrients to the downstreams as explained by the respondents. This influences equal water distribution among farmers. Hence, it was clear that the efficiency issues identified in the study indicate the issues imperil to the economic, environmental and social pillars of sustainability. Furthermore, the study further investigated the issues in the equity of water distribution, environmental integrity and economic acceptability in a detailed manner, which addressed the threats to the social, environmental and economic perspectives of sustainability, respectively.

5. Conclusions

This paper aimed to critically analyse the issues in SWM of irrigation systems in a developing country, with a specific focus on Sri Lanka. Accordingly, the issues were analysed based on the efficiency of irrigation infrastructure; equity of water distribution; environmental integrity and economic acceptability for a better explanation of issues from the perspective of sustainability. The issues towards the efficiency were further categorised into another four sub-components namely; the efficiency of water retaining structures, water conveyance canals, water distribution canals and field applications. It could be concluded that most of the issues are related to the inefficiency towards SWM of irrigation systems in Sri Lanka. Experts revealed that the water losses in canal conveyance and field application are the major issues, which reduce the efficiency of irrigation systems. The improper maintenance of structures and associated catchment area was the reason for water losses in canals. Further, inefficient water application methods in fields worsen the problem of water loss. The water should be delivered in sufficient quantity and quality at the right time to meet the needs of the users. Nevertheless, the inequity of water allocation in Sri Lankan irrigation affected the water-sharing rights of the users. Conflicts among water users, especially the people in downstreams aggravated the problem of water-sharing rights. Moreover, the establishment of irrigation infrastructures destructed the natural eco-system of irrigated areas. Furthermore, the depletion of groundwater and the waterlogging were recognised as major issues towards environmental integrity due to poor practices of IWM. Further, silting is the major issue in the components of the irrigation system. Deteriorated parts and outdated practices were common issues, which restrict the SWM of the irrigation system in Sri Lanka. It could be identified that improper maintenance had become the common cause for generating the majority of the issues. Further, a loss of water happened due to the issues in different components of the system and generated issues towards environmental integrity and economic acceptability.

The knowledge generated through this study has significant practical implications for the decision-makers such as policymakers in irrigation sector in developing countries similar to Sri Lanka, to have an overview of the deficiencies in the SWM to generate appropriate strategies to achieve sustainability. This study has a theoretical contribution in terms of analysing the issues in IWM from a sustainability perspective. The research was limited to analyse the SWM practices of irrigation systems in the Sri Lankan context. It was focussed on the perceptions of management authorities towards IWM practices and technical development in irrigation systems. The experts were selected, who had experience in water management and technical development of irrigation systems. The issues associated with operational and maintenance phases were investigated through the research. Further research can prioritise these issues by ranking them based on the severity of the consequences identified in system management to ease the process of developing strategies

to achieve SWM in irrigation in developing countries. Consequently, the strategies can be investigated to overcome the issues identified in the study.

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