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Review Article

Consolidating irrigation management concepts and approaches for improving irrigated agriculture in developing countries

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ABSTRACT

Most of the livelihoods in developing countries (70% in Africa) still highly depend on agriculture while population, water scarcity, and global demand for fresh water by multi-sectors increase from time to time. Among all sectors, irrigation, consuming huge (about 90%) amount of the total, is supposed to fill the limitations of unreliable rainfed agriculture through increased crop productivity to satisfy food demand and inputs for industrial development particularly in developing countries. However, the so far irrigation development has been improperly managed with restricted focus towards construction of hydraulic infrastructures while its organizational issues are being overlooked. Consequently, many of the irrigation schemes do not sustain and perform as per their design expectations in addressing the shortcomings of rainfed agriculture. The unintended malfunctioning of most irrigation schemes could be due to lack of inclusive, integrated and practicable irrigation management guidelines. A literature review was, thus, carried out to consolidate various irrigation management concepts and approaches that may serve as irrigation guides in dealing with management gaps and performance evaluations under specific scheme circumstances as a contribution to self-food security and sustainable development in developing countries. Most of the reviewed literatures agreed that revolution of irrigation management through modernization and reengineering concepts with focus to both "infrastructural" and "organizational" aspects of irrigation systems and various approaches (through ensuring participation in decision making process, conducting regional/spatial/analysis of demand and resources, modernization and optimization, water saving agriculture, etc.) can be consolidated under the umbrella of "Integrated Water Resource Management" in every or cluster of schemes as guide to fix irrigation management problems in those developing countries in particular. Yet, implementation of high tech approaches such as that of "Real-Time Irrigation Scheduling System" can also be an option in realizing better water management in the long run.

Keywords: Irrigation infrastructure, Irrigation organization, Modernization/reengineering concept, Management approaches, integrated water resource management

INTRODUCTION

Livelihoods in developing countries in general and in 70% of Africa in particular are highly dependent on Agriculture (Liette and Barry, 2016) where more than 80% of arable farming is dependent on unreliable rainfed agriculture characterized by low crop yields. Irrigation is, thus, considered as a rational way to alleviate the negative effects of drought and as a policy instrument to get out of poverty and improve rural livelihoods of those countries (Charlotte and Dennis, 2010; Mehretie and Woldeamlak, 2013). Considerable rural livelihood, food security, and nutritional improvement have been demonstrated in Nepal and Bangladesh through proper irrigation development (Mihret and Ermias, 2014). Yet, the global demand for fresh water by multi-sectors is huge and increasing from time to time as population and scarcity grow. Of those demands, the consumption by irrigation, having 29% global cropland coverage (Charlotte and Dennis, 2010) and contribution to 40% of global harvest (Yukio and Yohei, 2005; Shahbaz et al., 2006) as well as

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to 38% GDP (Charlotte and Dennis, 2010), is estimated at 90% (Richard et al., 1999; Wim et al., 2000; Leenhardt and Lemaire, 2002; Enrique and Luciano, 2006; Siebert et al., 2010; Mohamed et al., 2013).

Considering the highly dependence on unreliable rainfed agriculture on one hand and increasing global water demand by multi-sectors on the other hand, efficient irrigated agriculture becomes more important than ever. Indeed, properly managed irrigated agriculture can contribute to sustainable development and environmental equilibrium in dry lands (Simona et al., 2006) where water is scarce and investments on water resource development are mandatory to sustain agriculture (Giordano et al., 2017). And, irrigated agriculture can, thus, be regarded as a main entry for development in rural areas. Through productive irrigated agriculture and secured access to water in a country, it is possible to make significant contribution to poverty eradication (Hall, 1999) particularly in countries, which are frequently affected by drought and famine (Mehretie and Woldeamlak, 2013; Mihret and Ermias, 2014) and where the farmers have mostly small holding of not more than 2 ha per capita on average and continually declining over the years due to population growth (Fitsum et al., 2019). Moreover, it is urgent to develop available water resources and secure irrigation water needs while improving productivity of land and water resources for increased agricultural production to ultimately improve food security and rural livelihoods (Charlotte and Dennis, 2010). Because, securing farmers with access to irrigation water can double agricultural production and even more in some cases (Yukio and Yohei, 2005) and contribute to sustainable livelihoods through increased crop production and opportunities of growing diverse crops round the year, avail on- and off-farm employment, increase resilience against drought, increased income and access to social services and improve their general well-being and practices through consumption, and dietary changes and increased use of productivity-enhancing inputs such as fertilizer and improved varieties (Fitsum et al., 2019).

In principle, a water resources development is supposed to consider both infrastructure and organization. However, unlike the initial investments on constructing hydraulic infrastructures, low focus is usually given to organizational issues (monitoring, maintenance, performance evaluations, etc.) (Enrique and Luciano, 2006). Ultimately, many irrigation schemes do not perform as per their design expectations (for instance: schemes in Ethiopia perform 30% below design capacity while overall efficiency of schemes in India was below 30%) as irrigation alone is no panacea; it can work only if other inputs of the agricultural system are effective (Rao, 1997; Awulachew, 2010; Naomi et al., 2015). Ultimately, sustainability of most irrigation schemes is questionable and their intended contributions are usually unmet while production gain from irrigated agriculture is usually below the expected amount (Mihret and Ermias, 2014).

Global irrigated agriculture is currently being challenged by disintegration among technical, socio-economic and policy issues with negative impacts on the environment (such as water logging and salinity), weak institutional robustness in delivering adequate training, operating and maintaining systems, inefficient use of inputs (water, fertilizer, pesticides, labor, etc.), conflicts, poor distribution and management of irrigation water, poor monitoring and evaluation, low water productivity and infrastructural decay, dilemma whether investments on irrigation are sustainable and have real benefit, negative impressions on their schemes management, limited impact on livelihood (Sarma and Rao, 1997; Shahbaz et al., 2006; Mihret and Ermias, 2014; Naomi et al., 2015). Generally, very little attention is given to impact of improper irrigation on environmental (Asad et al., 2001). Consequently, the improperly managed irrigation practices with unwanted environmental consequences can result in reduced productivity in about one-third of the world’s irrigated lands (Shahbaz et al., 2006). And, such improper irrigation development investments have been criticized as “environmentally unfriendly” due to various manifestations on the environment and unsatisfactory resettlement programs in contrary to its excessive expectations (Hall, 1999). The sub-Saharan African countries, for instance, have been promoting irrigation to enhance food security but their achievement is quite meager; limited to coverage of below 6% of the total cultivated area due to deficient institutions, poor irrigation, infrastructure, mismanagement and corruption though the nature of administration of irrigation schemes affects the efficiency of water use, investment in irrigation infrastructure, and the decision to adopt irrigation practices (Fitsum et al., 2019).

The unintended malfunctioning of most irrigation schemes could be due to various reasons, which include that decisions makers mainly in developing countries might be lacking inclusive, integrated and practicable irrigation management guidelines. It is, thus, quite imminent to review literatures focusing on both infrastructural and organizational dimensions of irrigation systems and consolidate various irrigation management concepts and approaches in dealing with management gaps under specific scheme circumstances and performance evaluations as a contribution to sustainable development in developing countries through properly managed irrigated agriculture.

LITERATURE REVIEW

Irrigation management concepts

Considering the overall poor performances and occurrences of large amount of irrigation water losses in distribution channels and high level of water consumption at plot level in most irrigation schemes in developing countries, there is demand for irrigation management modernization (Berbel and Gomez-Limon, 2000). For improving management of irrigation systems, various concepts available in literatures need to be revisited. This literature review-based study thus attempted to consolidate the “Irrigation modernization” and “Irrigation reengineering” concepts along with various implementation approaches, which can be utilized as irrigation management guide and reference to plan, develop and evaluate irrigation schemes towards aspiring sustainable development mainly in developing countries.

Which are presented in the following sections:

Irrigation modernization and reengineering concepts: Conceptually, "irrigation modernization" used to traditionally be perceived as "introduction of new physical structures and equipment" (Enrique and Luciano, 2006) such as in terms of mere improvement of conveyance structures and conversion of irrigation methods from surface to pressurized irrigation (Dechmi et al., 2003). And, improvement of irrigation structures are in fact considered as ambitious plan by decision makers to improve irrigation efficiency, competitiveness of local irrigated agriculture, rural development, environmental protection and increasing the available water resources. But, recently, there is a shift to a more inclusive concept that considers irrigation modernization as "a fundamental transformation of the management of irrigation water resources to improve the utilization of resources and the services provided to the farmers" through "changes in rules and institutional structures, water delivery services, farmers irrigation scheduling, technical and managerial upgrading and advisory and training services, all in addition to the introduction of modern equipment, structures and technologies" with clear purposes of increasing water productivity, cost effectiveness of investments, reliability and flexibility of irrigation deliveries, and meeting environmental requirements (Enrique and Luciano, 2006). Naomi et al. (2015) similarly defines it as "a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes combined with institutional reforms" with objectives of "to improve resource utilization (labour, water, economic, environmental) and water delivery service to farms" while considering introduction of new crops (high yielding varieties and cash crops) and advanced production technologies". Bedsides, Regev et al. (1990) defines a modernized irrigation as a capital intensive and water-saving while traditional irrigation stands for labor-intensive and inefficient in water use in which modernization of a traditional irrigation was accompanied by a shift to a new crop mix, dominated by high income vegetable crops grown using a modern technology package that resulted into water savings of 50-65%.

Thus, in recent modernization concept, it is emphasized on giving equal focus to both infrastructure development and "nontechnical software" (organizational) to achieve a successful intervention while playing key roles in solving several problems of water shortages, poverty and food production simultaneously (Hall, 1999).

"Reengineering" as a concept, on the other hand, is also stated as "a revolution of fundamental, radical and dramatic change in the thinking and the processes involved in the enterprise activity allowing new activities and new processes to be undertaken", which has been developed and successfully implemented in order to address challenges of business sectors that otherwise would have led to failure. This concept was thus adopted from the successes other sectors have achieved considering the fact that largest national or state irrigation agencies are less successful in the management of their systems as they don't give emphasis on the management tasks.

Indeed, the management issues were not properly and efficiently fulfilled by most state irrigation agencies though they have been successful in building and developing huge projects. Considering irrigation development as a business enterprise and the similarities in terms of system operations it has with other enterprise, the "reengineering" concept has been implemented on the process of irrigation water management as a revolution in the thinking and design of irrigation management and operations by introducing a more service-oriented management to increase production quality and quantity with less water while considering other uses of water and the environment (Daniel, 2001).

Taking the increasingly complex challenges of water management into account, it, indeed, calls upon a revolution in irrigation management and systems operation as coping mechanism. A reengineering process, as a successful revolution in the industrial sector, could be implemented to radically reform the irrigation enterprise, its system management and operation, its traditional methods and some other aspects of irrigation activity. Studying the successful methodologies in other sectors may be adapted effectively to generate modern irrigation enterprises. In other words, the notion of industrial production (transformation of inputs into outputs) can be adopted and applied on the service provision of irrigation agencies to farmers and can thus be applied to modernize any physical infrastructure or/and institutional reforms (ibid).

Structural setup for irrigation modernization and reengineering concepts: For irrigation modernization, two levels of irrigation water management (water management at irrigation district and on-farm water management) are set. The first stands for "functioning of the conveyance and distribution systems and service provision of sufficient water in a timely manner and efficiently for crop production" while the second focuses on "selecting appropriate irrigation methods and strategy according to the water availability, to the characteristics of the climate, soil and crop, to the economic and social circumstances, and to the constraints of the distribution system". Actual application of water as per schedule, even distribution of water over a field, and storage of water in the root zone nearly the amount of soil-water holding capacity are also required in on-farm water management. Yet, plots with best irrigation schedule may be characterized by deficit and/or percolation applications due to management-induced non-uniformity that in-turn calls upon making a trade-off between uniformity, water deficit and percolation (Enrique and Luciano, 2006).

Similarly, two management units can be targeted in an irrigation reengineering setup, which are: state agencies (in charge of the major control of water at basin level) and local agencies (working closely with the users). Besides, the reengineering process has two levels, which are reengineering the irrigation enterprise (to move irrigation agencies towards a more service-oriented management) and reengineering the operation of the infrastructure (for developing efficient and adapted strategies for operations that better fit the needs of users).

At these two levels, the process considers various core values of: customer focus, managing results, empowerment and accountability, teamwork and participation and valuing diversity as well as two major irrigation operation factors of "demand for service" and "resources to provide". Where "demand for service" stands for "spatial distribution of effective demand for water" and "resources to provide" stands for "the spatial distribution of the physical infrastructure that control the inputs to meet the demand" (Daniel, 2001).

Irrigation modernization and reengineering approaches

Participatory approach in decision making: Many developing countries fail to implement and sustain participatory approaches in decision making process as well as on strengthening irrigation management information systems due mainly to lack of will to invest in enhancing the decision-making process, improper design of information systems and lack of consistency with scheme hydrology. And, the main challenge is in shifting from engineering-builders to engineering-managers" (Daniel, 2001). Yet, the degree of success of irrigation projects depends on the participation of all stakeholders particularly the beneficiaries during conception, planning, construction and operation stages. Moreover, the presence of effective water user's association (with clear and active organizational structure) in irrigation schemes facilitates working relationships and efficiency between various entities as well as in making efficient irrigation scheme management possible. Because, it is evident that there is a positive correlation between effective water user's association and better water management. Hence, there is a belief that most of the water management issues shall be sorted out by having an organized water user's association and participatory approach in filling farmer's skill gap, having working maintenance strategy, fair distribution of irrigation water, reliable irrigation water supply and timely delivery of irrigation water (Mihret and Ermias, 2014). And, the very reason of substituting former WUA with Land Improvement Districts (LIDs) in Japan, for instance, was to promote 'fairness' and sharing responsibility in operation and maintenance (O and M) towards sustainability of agricultural water use (Yukio and Yohei, 2005).

In this regard, Uphoff (1986) has developed an analytical framework for elucidating possible farmers' participation activities in irrigation framework with a three-dimensional matrix of activities, which are: participation on physical structure (during design, construction, operation and maintenance); on water-use (in water acquisition, allocation, distribution and drainage); and on organizational activities (in decision making, resource mobilization, communication or coordination and conflict management). In fact, there are many countries that adopted a ''Participatory Irrigation Management (PIM)'' with purposes of involving farmers in irrigation management including O and M and with merits of decreasing wasteful use of water, enhanced durability of irrigation facilities, reduction of government burden, facilitation of cost recovery and equitable water delivery. Typical instances are Turkey and Mexico that have made success in establishing PIM-based projects while monsoon-Asian countries are yet to achieve their goal (Yukio and Yohei, 2005). Also, in the Penaranda River Irrigation Scheme in the Philippines, production at tail end and head end was improved by 1500% and 22%, respectively as a result of participation and improved communication among farmers within secondary canals (Burton et al., 1999). Moreover, the Asian countries, where they involved informal institutions in the administration of irrigation water and applied bottom-up approaches to select participants in irrigation schemes, and there were market linkages for irrigation users, have demonstrated strong and positive link between irrigated agriculture and enhanced productivity and food security that resulted into doubled or tripled incomes of farm households. Thus, organizing farmers as producers or marketing cooperatives would be beneficial (Fitsum et al., 2019).

By stimulating the irrigation management of schemes to ensure accelerated irrigation-based modernization and investments and increase agricultural production for satisfying local consumption, inputs for local industries and foreign exports, a sort of amalgamated approach of establishing self-capable scheme-based institutions having its own (self) organization/institution involving different actors and facilities to enable each scheme operate by itself as farmer-run or jointly-managed schemes are believed to perform better than centrally managed schemes (Naomi et al., 2015). Hence, to realize irrigation modernization and reengineering processes, there need to be quite participatory approach in place.

Regional/spatial/analysis of demand and resources approach: Acquiring knowledge about irrigation water management practices is very crucial to improve the productivity of irrigated agriculture through application of scientific and modern technologies that contribute to improvements of livelihoods while avoiding any adverse effect on social and environment. But, in most irrigation schemes such as in that of the Rift Valley Lake Basin of Ethiopia, very little or no information on appropriate management of irrigation water and crop management practices are made available (Mihret and Ermias, 2014). So, to improve operation of irrigation schemes for optimal water distribution through regional/spatial analysis of demand and resources (supply), it is required to acquire better understanding of the hydraulic behavior of conveyance and distribution systems and control structures. In-depth and updated understanding on the irrigation network would also enable to save unproductive water losses and avoid unnecessary environmental impacts such as water logging that enhance irrigation sustainability (Zeleke et al., 2015). In this regard, Mihret and Ermias (2014) noted that inefficient and poorly managed irrigation water are common practices in Ethiopia due to little efforts to investigate the irrigated land management and water use in the country. Ultimately, those poorly planned and managed irrigation schemes undermine the country's efforts towards improving the livelihoods.

In irrigation systems, allocation and distribution of water are some of the most important activities with spatio-temporal variability that require clear understanding of the interactions among physical, technical, socio-economical and organizational factors that uniquely affect each irrigation system (Asad et al., 2001). Besides, many practices in irrigation systems management are based on the assumption of homogeneity of information throughout a scheme with respect to design of structures. In this regard, the obvious advantages may be in terms of ease of operation, economies of scale, facilitation of maintenance yet there are unrealistic considerations of homogenous performances throughout the irrigation command area and there are factors such as topography influencing the behavior and the performance of the structures, variable cropping patterns within the same scheme and variability of soils and others causing for significant differences. In reengineering and improving the performance of irrigation systems operations and prioritizing operational effort, rejecting the assumption of homogeneity should be taken as one of the major steps. And, irrigation systems need to be categorized based on typology of irrigation systems and subsystems to identify the main types and their characteristics along with their relevant features for management and operations. Due to such spatial heterogeneity, flexibility of water services may vary from one sub-system to another within an irrigation system. Some of the sub-systems may choose a strict rotation while others go for more flexible access to water. The co-existence of different levels of service in a single system represents a technical challenge for managing agencies that require a strong reengineering of the whole operation process. Thus, adapting the physical and institutional structures of management to the current environment and being responsive to the needs of the end users is required, with enough flexibility to cope with short-term changes (Daniel, 2001).

To understand users' reliability requirements and the way to achieve reliability service in irrigation systems, surveys and documentations on a regional/spatial/basis are appropriate. Spatial analysis of demand and resources for operation can be derived in a stage based process: Stage 1: Defining a service on the basis of the analysis of the vulnerability within the command area, Stage 2: Converting the service into service performance indicators: adequacy, efficiency, reliability, and flexibility. Stage 3: Combining the indicators of performance with the sensitivity of the structure to produces the quality of control (H) while reiterating the whole process might be required in making the quality control more feasible. In operation of structures, the degree of control stands for "the range of freedom in which the manager can select the output variable (target) between zero and the given maximum capacity of the system".

If, for instance, a discharge at a gated off-take can be adjusted to any value between zero and the maximum possible, the degree of control can be considered as "high". But, if water depth in a non-regulated canal is non-adjustable, the degree of control is regarded as "zero". Should there is "high" degree control, accuracy of control on the output variable needs to be controlled. Moreover, the sensitivity of control stands for the reaction of the output (the discharge delivered) to input (variation of water depth in the parent canal) of a system (ibid). In line with this, Wim et al. (2000) advises that managers of irrigation systems should include regular performance monitoring by linking field observations and hydrological models in a GIS Environment to capture spatial variations in land and water productivity along with possible reasons for differences.

Modernization and optimization approach: Evaluations of scheme performance and application of optimum amount of water to irrigable land in each scheme are required to achieve intended benefits. The irrigation performance evaluations may focus at various stages of planning, design& construction, operation of facilities, maintenance and application of water to the land. Moreover, it will also be possible to confirm if the scheme is experiencing excessive application losses (implying for need of services or increasing application efficiency and water saving). Because, evaluating and improving an irrigation system will help to operate irrigation systems near their design limits and achieve peak design efficiencies (Sisay, 2016).

Figure 1 presents modernization and optimization map developed by Enrique and Luciano (2006), which describes possible actions to be taken on either or both "structure" and "management" resulting into effects, technical results and possible outputs. Following the alternative paths displayed on Figure 1, the performances of modernized irrigation system can be evaluated in terms of various indicators: reliability, flexibility, efficiency, increased irrigated area, and farmer acceptation. Effects on flexibility and efficiency lead to increased water productivity through high value crops and ultimately to increased yield while offering farmers a number of possibilities to expand the economic productivity of water (Enrique and Luciano, 2006). Indeed, such type of map clarifies possibilities of optimization and modernization of schemes.

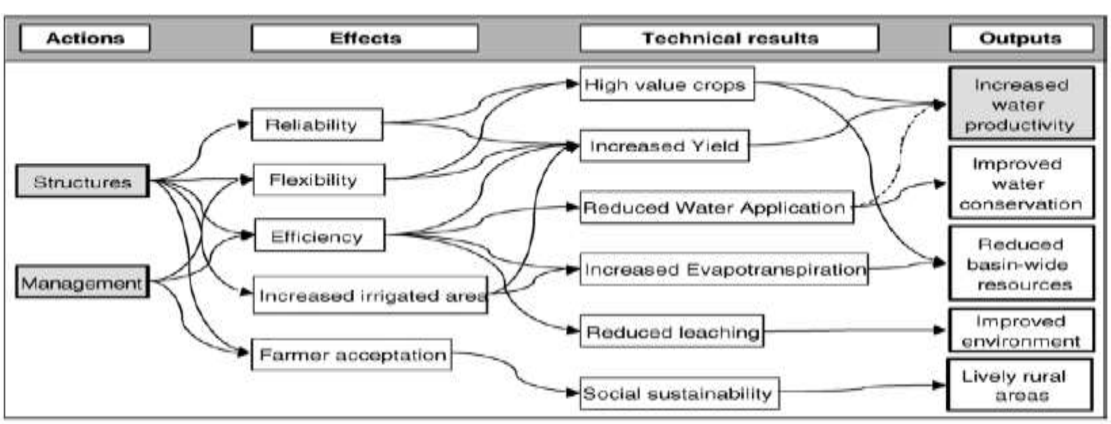

Figure 1. Irrigation modernization and optimization map.

Water saving agriculture approach: Achieving greater yield per unit amount of water is one of the challenges in drylands. Commonly, Water Use Efficiencies (WUE) in many irrigation projects around the world are below the expected levels, which could be due to inadequate irrigation structures, poor on-farm management and/or insufficient water availability (Dechmi et al., 2003). In the Huaihe and Haihe River basins (HHH region) of China, it is noted that more than half of the water is lost as canal systems leakage where about 30% of water could be saved by improved irrigation methods (Hong et al., 2003).

To this effect, Xi-Ping et al. (2006) presented various water saving agricultural activities as shown in Figure 2 and mentions that water saving agriculture can be realized through improvement of on-farm WUE by developing a more drought tolerant crops, breeding crop varieties with high WUE, and implementing various alternatives to raise transpiration efficiency. And, it also mentions possible ways for rational use of irrigation water, effective use of rainfall, and spatial and temporal adjustment of water resources. At field, it is possible to identify water saving and efficient irrigation methods and land management practices through research. For instance, drip irrigation method is known for being more efficient than sprinkler while sprinkler is more efficient than border/furrow. Also, mulching with crop residues (easily practicable, accessible, and low cost for local farmers without possibilities of soil contamination) could improve water use efficiency by 10–20% through reduced soil evaporation, increased plant transpiration and increased soil water retention in the North China Plain and Loess Plateau.

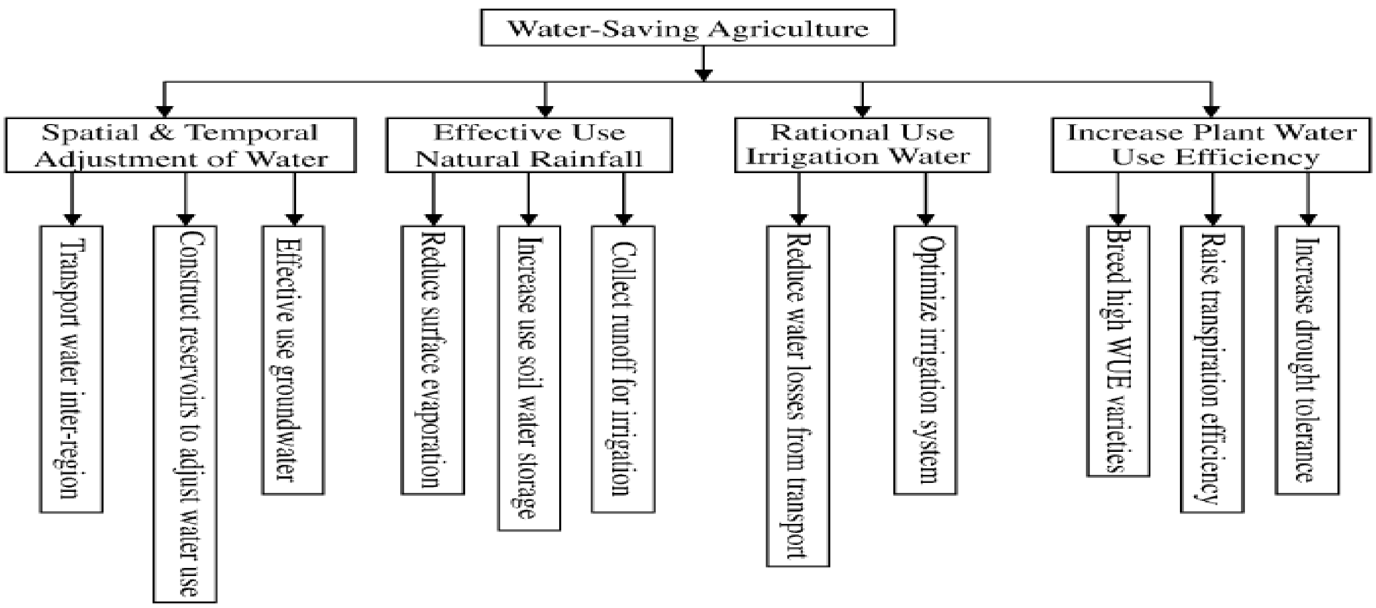

Figure 2. Water saving agricultural systems and components.

Moreover, residue mulching combined with N, P and potassium (K) fertilizers could improve yields by at least 1500 kg ha^{-1}. Plastic mulches can also be used during early growth when temperatures are low (Xi-Ping et al., 2006). On top of introducing water-saving irrigation networks and conservation tillage, other yield limiting factors such as physiological and breeding traits that increase plant WUE and drought tolerance under water-limited conditions need to be identified through research. By making genetic improvement and physiological regulation to understand plant responses to water deficits, it is possible to come up with "biological water-saving" possibilities to ultimately increase crop WUE and drought tolerance (ibid).

Also, further study on identifying new water-saving technologies by combining biological water-saving measures with engineering solutions is recommended bearing in mind that promoting water-saving agriculture can increase water use efficiency and facilitate structural adjustment for the dryland agriculture. Following an establishment of water conservation facilities, better soil management, extension of new crop varieties and a continuous increase in the use of nitrogen and phosphorus fertilizers in China where more than two-thirds of the country's population is poverty-stricken and live in arid and semiarid areas, WUE increased from 0.23 to 0.90 kg m^{-3}. As efforts to increase the WUE, the practiced water-saving agriculture included: Water-saving irrigation (efficient and integrated water saving irrigated farming practice with minimal losses while still achieving a high yield), limited irrigation (a deficit irrigation that requires inducing a soil water deficit at noncritical growth stages while supplementing at critical growth stages), and dryland cultivation (a water-saving agriculture practiced by collecting runoff or rainfall) (ibid).

"Real-time irrigation scheduling system" approach: Considering the increasingly diminishing water supplies in semi-arid regions in general and in places like Valley of Carrizo (with 44, 000 ha and 4,000 users) in northern Sinaloa of Mexico in particular due to recurring, but non-cyclical droughts, a remote sensing based irrigation management conceptual project called "Real-Time Irrigation Scheduling System" was initiated. This approach is capable of measuring meteorological parameters associated with plant-water-stress on real-time towards determining crop water demands (an irrigation scheduling gap at parcel-and district-level). The real-time irrigation scheduling project is a forecasting system that integrates plant, soil, weather, and water distribution network (Figure 3), to schedule irrigation water applications on a plot-by-plot basis and for up-scaling. This system is designed on a computer connected to a modem and with access to a direct phone line so that officers, independent organizations and farmers could be able to access the data (air temperature, relative humidity, solar radiation, precipitation, wind speed and direction, leaf wetness, as well as reference-crop evapotranspiration calculated by the Penman-Monteith method) at (Pedroza et al., 1999). The system is validated and calibrated based on inputs of continuously measured and compared with estimated water balance and crop growing data. The system is capable of making daily routing of irrigation water throughout all seasons and scheme (*i.e.* from reservoir to each plot) to calculate soil and plant conditions and integrate results in space and time. In comparison to traditional/conventional/scheduling, significant improvement in water use efficiency and increased water productivity was recorded for wheat and maize under real-time irrigation scheduling with careful model calibration of field parameters for more precise irrigation applications and subsequent better plant development (Pedroza et al., 1999).

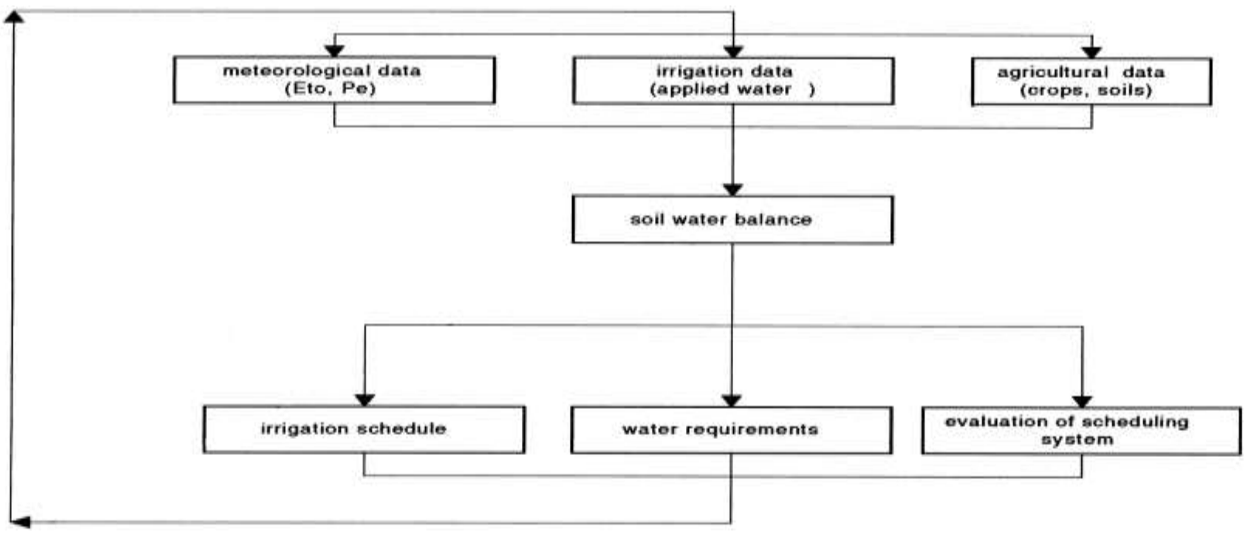

Figure 3. Real Time Irrigation Forecasting Flowchart (after Pedroza et al., 1999).

DISCUSSION

Consolidated irrigation management concepts and approaches

The various irrigation management concepts and approaches can be consolidated under an umbrella of "Integrated Water Resources Management (IWRM)" for every or cluster of irrigation schemes and enable to manage water holistically considering all "cross-cutting" issues and responsibilities of optimizing water allocations among multi-uses and environment by making an institutional reform specific to every country and a policy approaches towards improvement of irrigation development and management. It can be implemented through: promoting integrated technical and socio-economic aspects of water management with purposes of improving agricultural water use efficiency (through effective water metering and cost recovery), enhancing productivity of irrigation systems (through capacity enhancement, institutional reform, better extension and credit, and access to markets), and ultimately avoiding "build-neglect-rebuild" sentiment (Hall, 1999; Charlotte and Dennis, 2010; Mehretie and Woldeamlak, 2013). In line with this, various literatures (Berbel and Gomez-Limon, 2000); Dechmi et al., 2003; Hong et al. 2003) emphasize that water needs to be regarded as a limited resource and economic input (an economic good and production factor) that compel the farmers to change their production systems (from water consuming to less water consuming cops and/or shifting to high value crops with high economic water productivity). Also, the growing awareness of water resource scarcity leading to adoption of water-saving technologies, implementing reasonable water pricing policies (cost recovery mechanisms for securing operation and maintenance) and avoiding the deterioration of physical structures over time. The situation in Spain is exemplary where the farmers are organized in an irrigation unit called "Comunidades de Regantes" (CR) to cover costs of distribution in "cost effective" manner through improvement of water management and making economic return of conserved water as a result of improving the structures as well as making the system "user appreciated" through a ‘‘bottom-up’’ process that develop sense of ownership of users on management responsibilities (Enrique and Luciano, 2006).

Integrated Water Management Scheme (IWMS), a typical instance of IWRM approach, applied in India was meant to create equitable rotational water distribution through changes of cropping pattern, shifting from water consuming and long duration paddy crops to less water consuming crops such as pulses and oil seeds throughout a scheme. This approach definitely improved the irrigation water distribution and enabled to grow and harvest crops throughout the scheme by avoiding water shortages particularly at the tail-end reaches. In other words, this approach contributed to increased area under irrigation, improved water management that led to increased production and productivity per unit of water application (Sarma and Rao, 1997).

Such integrated approach recognizes irrigation scheme as a system with an interconnection of various components: catchment/source, hydraulic structures such as diversion or reservoirs, canals, and off-take or outlet (to deliver irrigation water) and command area (Daniel, 2001) while such system brings about an intimate relation among many more components such as people, crops and water related issues (Wim et al., 2000). Similarly, an integrated water management at basin level is demanded in Metahara scheme of Ethiopia to mitigate the recent vast expansion of irrigations on one hand and excessive water diversion and wastage to saline swamps on the other hand with intensifying competitions for water (Zeleke et al., 2015).

Within an integrated approach, irrigation developments, provided with most important inputs (irrigation water and fertilizer) for high crop production and better water management, maintenance and institutional support (through stakeholders training), can contribute to substantial improvement in food security and poverty reduction at household level as well as to sustainability and economic benefit at country level. Because, there is a strong linkage between properly managed irrigation development and poverty reduction through improving crop productivity and diversification as well as creating job opportunities (Mihret and Ermias, 2014).

Moreover, integrated approach is built on a water balance (of surface, subsurface and groundwater) at a scheme level, which is also considered as a crucial pre-requisite to design a smart information system for an irrigation system (Daniel, 2001). Wim et al. (2000) similarly noted that water accounting studies can be used to identify various users of water in the context of basin-wide water use, and productivity of each use.

Considering the fact that irrigation systems are also characterized by spatial diversity and temporal variability, site specific IWRM approaches and strategies of operations are required to optimize productivity of water. Improvement in productivity primarily depends upon better matching between irrigation supplies and crop demand. And, a more flexible scheduling system (capable of distributing in quantities and times) is necessary for the optimization of crop production (Asad et al., 2001).

In IWRM, various performance indicators such as adequacy, flexibility, equity, and reliability can be applied to understand the quality of water-delivery service (Daniel, 2001). Zeleke et al. (2015) similarly recommended: Adequacy indicator (PA) (delivery performance ratio), efficiency indicator (PF), equity indicator (PE) and dependability indicator (PD) to evaluate whether an irrigation system delivers water at the required rate, at the right place and time and has healthy service. In fact, the contribution of irrigation to sustainable development depends on the degree of consideration of hydrological constraints in rural planning and water management. Issues such as capability of assessing, monitoring crop water requirements and control of water-use demand considerations to gain a better performance of irrigation systems (Simona et al., 2006). Besides, Management Improvement Program (MIP), as an effective way to evaluate and improve the performance evaluation and sustainability of irrigated agriculture, can also be applied to identify strengths and weaknesses of a scheme through performance analysis, involvement of key and joint decision makers, and implementation of joint planned changes by managers. To this effect, the MIP process can be carried out in three typical phases of “diagnostic analysis”, “management planning” and “performance improvement” (Dechmi et al., 2003). In view of MIP, evaluation of irrigation schemes’ management can also be approached through reviewing internal and external actors and factors affecting the system management. In complementary to MIP, Burton et al. (1999) noted that updated status and problems in an irrigation system can be gathered through diagnostic analysis of cause and effect in the form of tree diagrams to ultimately generate solutions for the problems.

Though little focus is usually given to “poor or inadequate water management at scheme and field levels”, it is evident that schemes may have “productive potential being lost or foregone over several years” due to failures to properly and timely maintain irrigation and drainage systems. Regular performance assessment and securing regular feedback of information from the field into decision making can thus substantially improve the performance of water delivery services and maintain accountability (Wim et al., 2000). Based on performances of existing irrigation schemes in a country, it may also be necessary to make appropriate decision between implementing new more interventions and improving the existing ones from the perspectives of enhancing the performance and contribution to advance food security and income of beneficiaries in particular and national economy in general (Mihret and Ermias, 2014).

To improve the situations of the existing unsuccessful irrigation management practices in many of the countries over the globe as affirmed by most of the reviewed literatures, Figure 4 proposes a consolidated irrigation modernization and reengineering concepts and approaches as improved irrigation management guideline towards meeting the aspirations of attaining food security and industrial development in developing countries in particular based on properly managed irrigated agriculture. The guideline maps management approaches, current situation of schemes, levels of organization, technologies (inputs), performance indicators, and final outputs.

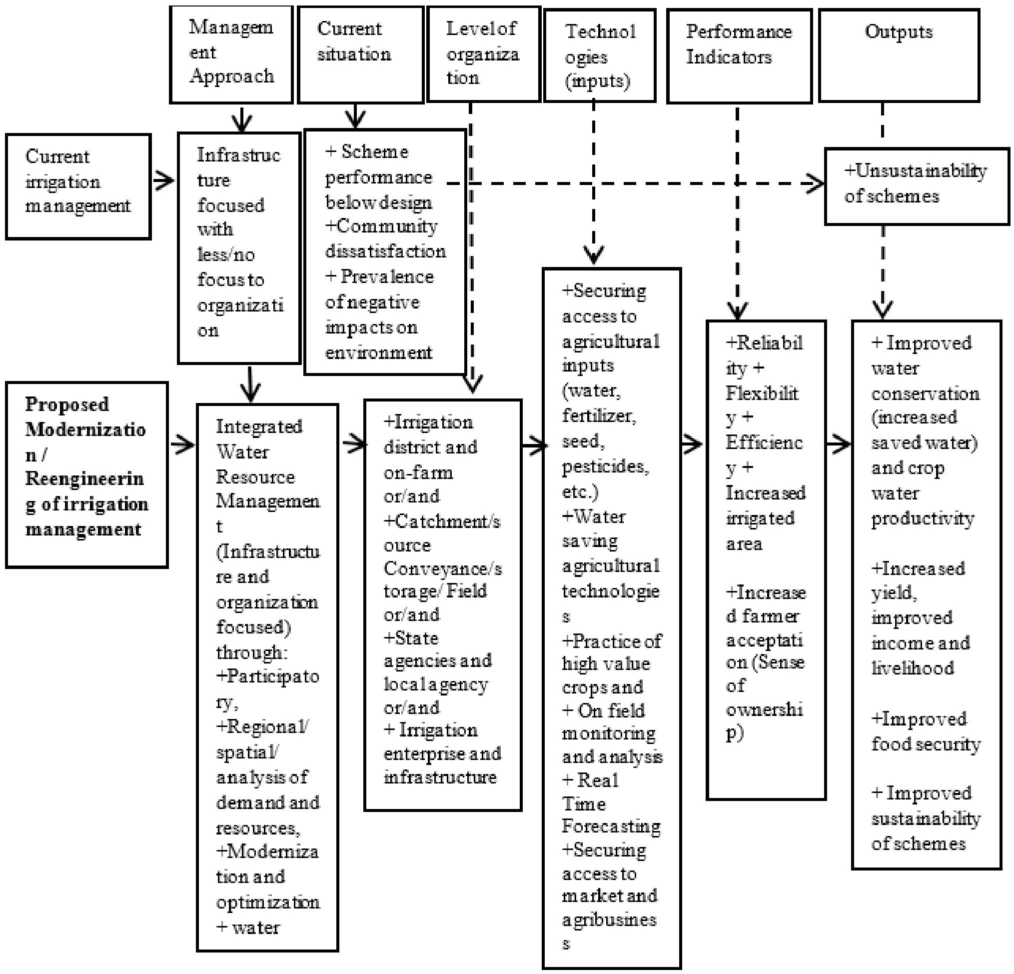

Figure 4. Consolidated irrigation management concepts and approaches.

CONCLUSION

In order to cope-up with an increasing and huge (up to 90%) irrigation water demand on one hand and growing scarcity on the other hand while aspiring at self-food security and sustainable development, applying "Integrated Water Resource Management (IWRM)" in every or cluster of irrigation schemes by focusing at both "infrastructural" and "organizational" aspects of irrigation systems through implantation of the modernization and reengineering concepts and approaches (such as participation in decision making, conducting regional/spatial/analysis of demand and resources, modernization and optimization, water saving agriculture approach, etc.) is of paramount importance. Yet, implementation of high tech approaches such as that of "Real-Time Irrigation Scheduling System" particularly in developing countries can be taken as an alternative option in realizing better irrigation water management in the long run.

CONFLICT OF INTERESTS

There is no any conflict of interests.

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