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STATE OF KNOWLEDGE OF IRRIGATION TECHNIQUES AND PRACTICALITIES WITHIN GIVEN SOCIO-ECONOMIC SETTINGS[†Φ]

KUNLUN DING[1,2*]
[1]*China Institute of Water Resources and Hydropower Research (IWHR), Beijing, China*
[2]*Chinese National Committee on Irrigation and Drainage (CNCID), Beijing, China*

ABSTRACT

This paper is based on the General Report of Question 61 of the 23rd Congress of the International Commission on Irrigation and Drainage (ICID). The Question was entitled 'State of Knowledge of Irrigation Techniques and Practicalities within Given Socio-Economic Settings', covering three sub-questions: adopting precision irrigation and improving surface irrigation to combat water scarcity; using ICT, remote sensing, control systems and modelling for improved performance of irrigation systems; and adaptability and affordability of new technologies under different socio-economic scenarios. Under the Question, 64 accepted papers covering a wide range of topics of irrigation techniques and practicalities were summarized and reviewed with valuable views and state-of-the-art information/knowledge on the topics concerned. It was concluded that improving surface irrigation and precision irrigation are still the major areas in which to achieve objectives of higher agricultural water use efficiency and productivity; that new technologies and their applications in the irrigation sector can help to achieve the objectives; and that to address 'adaptability and affordability' would ensure the real value achieved in practice. © 2018 John Wiley & Sons, Ltd.

KEY WORDS: irrigation; irrigation techniques and practicalities; adaptability and affordability; socio-economic scenarios; ICID Congress

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RÉSUMÉ

Ce document est basé sur le rapport général de la question 61 du 23ème Congrès de la Commission Internationale d'Irrigation et de Drainage (CIID). La Question s'intitulait 'État des connaissances sur les techniques et les pratiques d'irrigation dans des contextes socio-économiques donnés', et couvrait trois sous-questions: adopter une irrigation de précision et améliorer l'irrigation de surface pour lutter contre la pénurie d'eau; utiliser les TIC, la télédétection, les systèmes de contrôle et la modélisation pour améliorer les performances des systèmes d'irrigation; et l'adaptabilité et l'accessibilité des nouvelles technologies dans différents scénarios socio-économiques. 64 articles acceptés dans le cadre de la Question, couvrant un large éventail de sujets concernant les techniques et les aspects pratiques de l'irrigation, ont été résumés et examinés avec des points de vue précieux et des informations ou des connaissances de pointe sur les sujets concernés. Il a été conclu que l'amélioration de l'irrigation de surface et l'irrigation de précision sont toujours les principaux domaines pour atteindre les objectifs d'efficacité et de productivité accrues de l'utilisation de l'eau à des fins agricoles; que les nouvelles technologies et leurs nouvelles applications dans le secteur de l'irrigation peuvent aider à atteindre les objectifs; et que le fait d'aborder l'adaptabilité et l'accessibilité garantirait la valeur réelle obtenue dans la pratique. © 2018 John Wiley & Sons, Ltd.

MOTS CLÉS: irrigation; techniques d'irrigation et aspects pratiques; adaptabilité et abordabilité; scénarios socio-économiques; Congrès CIID

*Correspondence to: Kunlun Ding, Vice President, ICID, Deputy Secretary General, Chinese National Committee on Irrigation and Drainage (CNCID), A1, Fuxing Road, Beijing 100038, China.E-mail: klding2005@aliyun.com
[†]Etat des connaissances sur les techniques d'irrigation et les aspects pratiques dans des contextes socio-économiques donnés.
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INTRODUCTION

Question 61 of the 23rd Congress of the International Commission on Irrigation and Drainage (ICID) was entitled: 'State of Knowledge of Irrigation Techniques and Practicalities within Given Socio-Economic Settings'. A total of 64 papers were submitted from 24 countries and regions—Mexico, Argentina, Brazil, China, Chinese Taipei, Egypt, Finland, Hungary, India, Indonesia, Iran, Iraq, the Netherlands, Pakistan, the Philippines, Russia, South Africa, Sri Lanka, Thailand, Ukraine, United Kingdom, USA, Uzbekistan and West Africa. Question 61 covered the following three Sub-questions:

- *Question 61.1.*Adopting precision irrigation and improving surface irrigation to combat water scarcity;
- *Question 61.2.*Using ICT, remote sensing, control systems and modelling for improved performance of irrigation systems;
- *Question 61.3.*Adaptability and affordability of new technologies under different socio-economic scenarios.

This paper is based on the General Report that was based on the summary reports of the sub-questions and the views on the papers and on the related topics.

Although categorized based on Sub-questions, the accepted papers cover a wide range of topics and some cover more than one Subquestion. A small number of papers are not well linked with the topics of the Sub-questions although they provide useful and interesting information and results. The topics covered by the accepted papers are: (i) precision irrigation, improving surface irrigation or both in Sub-question 61.1; (ii) remote sensing, information and communication technology (ICT), control systems, knowledge management, mathematical models and others in Sub-question 61.2; (iii) water quality and wastewater reuse, modernization of irrigation systems, analytical tools, water management, dam safety, public policy, food security and improvements to irrigation schemes in Sub-question 61.3.

QUESTION 61.1. ADOPTING PRECISION IRRIGATION AND IMPROVING SURFACE IRRIGATION TO COMBAT WATER SCARCITY

Water scarcity is a critical issue for agriculture. In a world where agriculture must continue to compete for a water supply that is becoming scarcer, it is important now, more than ever, for agricultural water users to conserve water. Two methods of combating water scarcity are precision irrigation and improving surface irrigation. Of the the 25 papers in Sub-question 61.1, 9 addressed precision irrigation, 13 addressed improving surface irrigation, and 3 addressed both.

Adopting precision irrigation to combat water scarcity

First, what exactly is precision irrigation? Before answering this question, let us take yet another step back and ask what is precision agriculture? Precision agriculture is an approach to farm management that uses information technology (IT) in an effort to provide the exact amount of water and nutrients to crops in order to maintain their optimum health and productivity (Rouse & Wigmore, 2017). Typically, precision agriculture uses satellite navigation, remote sensing and other technologies to farm while taking into account the variability in soils and crops. Precision agriculture relies on collecting and analysing large amounts of data to assess the conditions of the crops, soils and weather in real time.

For example, sensors in the field can measure soil moisture content and temperature of the soil and air. Drones can be used to provide real-time images of crops. Information obtained from these remotely collected data can be analysed to determine when to apply the optimal amount of water, fertilizers and pesticides. The end goal is help the farmer avoid wasting resources while providing optimal crop yields and profits.

In the past, precision agriculture was typically limited to large-scale farming operations that could afford the cost of the IT infrastructure and equipment needed. However, with advances in technology, and the development of drones and mobile apps, precision agriculture can be implemented in smaller farming operations.

If precision agriculture is defined using large amounts of data to effectively manage a farm on the square metre level, precision irrigation can be thought of as collecting and using large amounts of data to precisely irrigate individual plants. The technology for precision irrigation can generally be classified in one of two ways: the equipment used to gather environmental, soils or weather data and the equipment used to automatically control the irrigation system itself.

Although the term 'precision irrigation' is widely used, there is no commonly accepted definition of the term. To some, precision irrigation has come to mean drip irrigation. To others, it has come to mean irrigation scheduling based on data from local field sensors or other regional/global data. If drip irrigation is a subset of precision agriculture, it means that drip irrigation should apply variable amounts of water both *spatially* and *temporally*. However, a fixed drip irrigation system, once installed, cannot apply different amounts of water to different spatial locations, except according to the way the drip system was installed. Precision irrigation, according to the above definition, has only been applied to sprinkler irrigation where the flow rate from sprinkler nozzles can be controlled remotely.

Methods for maintaining drip emitter flow include physical filtration, pH control (e.g. adding acid) and biological control (e.g. adding chlorine). These are standard practices that have been published and available for nearly 40 years. The papers presented for this question demonstrate that providing appropriate water quality for drip irrigation in a cost-effective manner is a continuing struggle for applying drip irrigation, particularly in remote areas.

Accurate irrigation scheduling with refined estimates of evapotranspiration (ET) is also considered precision irrigation. Yet precision irrigation should consider both accurate irrigation scheduling to define the amount of water needed by the crop and accurate application of the required water (e.g. with both efficient and uniform application).

General overview of the papers

The submitted papers provide a nice balance of theoretical and field studies. Drip irrigation is practised on over 70 000 ha of land in Ukraine where it is important to maintain strict water quality standards to ensure trouble-free operation of drip irrigation systems. In the absence of strict water quality maintenance, system performance may decline drastically (Usaty & Usata, 2017).

Drip irrigation has been found to develop spatial heterogeneity of soil properties, particularly under the perennial crops grown as a single crop for 15–25 years in Ukraine. Such heterogeneity interferes with the normal functioning of the system, as expected according to the design. It develops with increasing the load on the soils due to inadequate water quality and the effect of fertilizers having a local manifestation. The most negative process occurring in irrigated soil is alkalinization. The prevalence of sodium ions over calcium ions facilitates silt peptization, transformation and degradation of mineral and organic components of the soil (Usata & Ryabkov, 2017).

Some researchers suggest that the pressurized irrigation pipe network must be flushed by chemicals with a pH of solution ranging from 2 to 3 at the appearance of sedimentation symptoms in the pipes that aggregate into agglomerates. Maintaining a negative water stability index due to acidification can slow down the processes of sedimentation and reduces the risk of formation of insoluble compounds. They concluded that preventive and remedial flushing was one of the most effective methods of maintaining an irrigation network at the project design level (Kupiedinova, Marchenko, & Tkachuk, 2017).

The importance of organizing farming communities of small landholders and ensuring institutional support for them has been highlighted in a paper to ensure that the benefits of modernized irrigation reach this usually neglected and resource-poor group of farming communities. The authors contend that the centre pivot system, which is considered suitable for large farms, can be shared by multiple users of small landholder groups. Such systems have recently been established in Kenya, Rwanda and Ghana, and are likely in other areas in Africa (Fipps & Traore, 2017).

The Rain Gun Sprinkler Irrigation System is claimed to be suitable for agriculture in limited water and drought conditions in the world. It is mostly suitable for irrigation of standing crops in danger due to extreme water stress or under drought conditions. Using this system, the soil can be brought to field capacity instantly. The Rain Gun Sprinkler Irrigation System is a cost-effective system among all kinds of system and is preferably provided in a movable or portable fashion (Dilipyewalekar, 2017).

A substandard quality of water has a vast range of values of the quality parameter, not all of which are equally harmful to the soil or to crops. In this regard, a decision support system (DSS) has been developed and presented for South Africa for the assessment of irrigation water quality based on site-specific characteristics, using internationally accepted cause–effect relationships. It is envisaged that the DSS will find wider application than just with South African users.

Irrigated agriculture is the backbone of Central Asian economies and those of a large number of agrarian nations where efficient irrigation management is of crucial importance for sustainable crop production. A paper from Uzbekistan claims that ET-based irrigation scheduling has the potential to improve on-farm water-use efficiency. Results from a 2-yr study conducted on a cotton crop in Uzbekistan showed that there can be 25–34% saving of water without any significant change in yields when irrigation is applied using the ET-based scheduling method. This led to an overall increase in water productivity of 34–50%. The pilot plots are representative of 38% of the irrigated area in the Fergana Valley (241 407 ha). If this methodology is widely adopted by water users' associations (WUAs), large amounts of water can be saved, which can be diverted to horizontal expansion of irrigated agriculture, or for other purposes such as supporting ecosystem services (Mukhamedjanov & Mukhomedjanov, 2017).

Researchers spend considerable time and energy ensuring that the estimate of evapotranspiration by the FAO Penman–Monteith model under semi-arid conditions is reliable for use in irrigation planning over their target area. The model, however, requires an exhaustive database of a number of meteorological parameters. The relative contribution of a number of meteorological parameters used in estimating ET by the most adopted FAO Penman–Monteith model was evaluated for the Karaj region of Iran. The most important parameter was found to be maximum temperature, followed by wind speed and then by relative humidity. Working further, they proposed the following equations for ET estimation by the Penman–Monteith model:

$$\mathrm{ET}_{0.\mathrm{FPM}} = 0.298 t_{\max} + 0.742 u_2 - 4.43 \quad R^2 = 0.81 \tag{1}$$

$$ET_{0.\mathrm{FPM}} = 0.205t_{\max} + 0.746u_2 + 0.103 \quad (2)$$
$$R_{\mathrm{mean}} - 3.949 \; R^2 = 0.82$$

In the above two equations, $ET_{0.FPM}$ is the estimate of reference evapotranspiration by the Penman–Monteith model; t_{max} = maximum temperature, u_2 = wind speed and R_{mean} = mean relative humidity (Kanani, Dehghanisanij, & Akhavan, 2017).

Switching over from gravity-based surface irrigation to pressurized drip irrigation, taking in the benefit of the topography and helped by innovative leadership, was carried out in a minor command area in the Maharashtra state in India. The 0.5 Mm^3 (million cubic metres) of water allocated from the Naghtana Reservoir by the government to a WUA is utilized for irrigation through a drip system, which has been made mandatory for all the members of the WUA. As a result, the earlier planned irrigation over 82 ha could be increased to 145 ha. The paper concludes with the remark that it is prudent to use naturally available potential energy at the source for conveying water from source to farm through a pipe network, and if sufficient residual head is available for operation, micro-irrigation with some location-specific modification can be promoted. In this way the saved water can be used to support high-value crops or additional areas for irrigation; simultaneously saved energy in the agricultural sector can be used in other sectors for national development (Bhalage & Sangle, 2017).

In the paper 'Analysis of the technology for precision surface irrigation', it is contended that surface irrigation performance is affected by many factors, such as land levelling precision, irrigation system layout, irrigation control rules and irrigation management. In this context, the real-time feedback control of precision surface irrigation is useful for monitoring the performance of irrigation as it progresses and for taking corrective measures where and when required (Bai, Xu, Li, Zhang, & Wu, 2017).

The paper 'Automatic control system for water-saving irrigation in paddy' has as its focus that the flood irrigation system typically used in China has low water use efficiencies, aggravating the shortage of water. The paper presented the results of a study on a water-saving irrigation automatic control system. It showed that the control system can effectively control the irrigation of paddy fields while avoiding flooding during the rainy seasons (Hejing *et al*., 2017).

In Argentina, 19% of the land is under cultivation, of which 7% is irrigated. It has been estimated that mean water use efficiency is about 30% due to gravity-based surface irrigation. The paper 'Performance of surge flow irrigation in Mendoza, Argentina: present and potential efficiencies', presented a field experiment and simulation models on surge flow irrigation for improving field irrigation efficiency. The results showed a wide gap between field-measured and potential efficiencies, which indicates that the irrigation equipment is underutilized (Romay, 2017).

Improving surface irrigation to combat water scarcity

Surface irrigation has the reputation of having low irrigation efficiencies (Clemmens, 1998). While it is true that surface irrigation performance is low in many parts of the world, it can also be quite high and rival the efficiency of pressurized systems. To achieve these high efficiencies, surface irrigation systems need to be appropriately designed and managed. For many poorly performing surface irrigation systems, low efficiency is due not to surface irrigation itself but to poor operating decisions. Thus, a good surface irrigation system requires simple operations that are less subject to irrigator error (Clemmens, 1998). This also highlights the need for irrigator training for operating surface irrigation systems. However, even well-performing surface irrigation systems have a time during the season when efficiency can be low, for example when the soil moisture deficit is smaller than normal (e.g. early in the season).

Before continuing this discussion, it is important to note that irrigation efficiency is often confused with application efficiency or with fraction of irrigation water consumed (Clemmens, 1998). Burt *et al*. (1997) define irrigation efficiency as the volume of irrigation water beneficially used divided by the difference between the irrigation water applied and the change in storage. Thus, irrigation efficiency is really an after-the-fact determination of what happened to the applied irrigation water. Many people mistakenly believe that water that is not beneficially used is somehow lost and not available for reuse elsewhere. From a water supply standpoint, only water that is consumed or severely degraded in quality is not available for reuse (Clemmens, 1998). Most assessments of surface irrigation systems do not determine irrigation efficiency, since the data required are difficult to obtain (e.g. need to know the actual amount of water used by the crop or need to separate irrigation use from rainfall).

Application efficiency is the performance of an irrigation event and reflects how well that irrigation satisfied the objective of irrigating. It is defined as the average depth of irrigation water contributing to the target divided by the average depth of irrigation water applied, where target means target depth of application, or soil moisture deficit (Clemmens, 1998).

Some reported values of the irrigation efficiency of surface irrigation systems can be misleading because they often reflect the efficiency of a particular event and are based on assumed soil moisture deficit. Alternatively, reported irrigation efficiencies can be inflated if they do not consider distribution uniformity (Clemmens, 1998).

It should be kept in mind that low irrigation efficiencies may not necessarily be bad. In some places, return flow from irrigation is reusable downstream and low efficiencies have little or no impact on available water supplies on a watershed basis. In other places, irrigation return flows are too saline or not recaptured. In those locations, improving irrigation efficiency has a very important role in increasing available water. Low irrigation efficiency may also be an economic choice as the capital investment to improve the irrigation system does not provide an adequate return (Clemmens, 1998).

Even under conditions where surface irrigation has the potential for high performance, this potential is not achieved because of poor design or poor management of the irrigation system. Improved water management and control of flow can help modern surface irrigation systems achieve their potential (Clemmens, 1998). Use of farm reservoirs and wells can reduce the impact of a poor water delivery service. Improvements to land grading and shaping can also lead to improvements in surface irrigation systems. Land slope also plays an important role in the performance of a surface irrigation system. Typically, to improve the performance of an irrigation system, the flow off the field should be reduced or runoff recovery systems installed (Clemmens, 2005). In water-scarcity conditions, it is recommended that the downstream end of the borders or furrows be closed in order to avoid mass losses in the irrigation system.

Computer software packages can also be utilized to make recommendations to improve the performance of surface irrigation systems. A number of software programs have been developed over the last three decades. SIRMOD (Utah State University) and WinSRFR (United States Department of Agriculture Agricultural Research Service (USDA-ARS)) are two of the earlier versions. For example, the WinSRFR program is an integrated hydraulic analysis software package for surface irrigation systems that combines a simulation engine with tools for irrigation system evaluation, design and operational analysis. These and other programs continue to be developed and provide additional tools that can be useful for improving surface irrigation performance. Several papers in this session discuss progress in this area.

Future developments of these software packages should be geared to incorporate the use of physically based infiltration equations in place of the Kostiakov-type relationships in the simulation engine tools while maintaining fast computational speeds.

It is a fact that surface irrigation by gravity flow of water is the most common the world over. Of the surface irrigation methods, there are border, furrow and basin methods of land preparation, suitable for different crops. It is, however, recognized by all concerned that all methods of surface irrigation are wasteful in water use. Since freshwater resources are limited and the much feared climate change may cause great aberrations in the availability and time–space distribution of rainfall, which is the primary source of all fresh water on the earth, the renewed concern about the scientific use of available water resources and minimize its misuse is highly justified. Since agriculture is the largest consumer of freshwater resources and must be sustained to enable feeding the ever-growing population of the world, scientific management of water in its agricultural use assumes great importance.

General overview of the papers

There is a paper on a modelling system called MSSI for surface irrigation design and management. In this system, two-dimensional shallow-water equations and one-dimensional Saint-Venant equations in networks with the Kostiakov empirical infiltration equation were applied to describe unsteady water flows in surface irrigation. Then the finite-volume approach with a fully implicit time scheme was applied to solve the governing equations and can accurately simulate unsteady water flows in basin, border, furrow and furrow-network irrigation. This is the central component of MSSI. The analysis can provide surface irrigation indicators such as irrigation efficiency and uniformity. Use of this two-dimensional basin irrigation and furrow-network irrigation methodology in Ye He Irrigation District, China, gave an irrigation efficiency E_a and irrigation uniformity C_u as 0.65 and 0.78, respectively. These two values meant low performance of this irrigation event. Thus, the basin surface slope, geometry, inflow discharge and inflow location can be reset until high performance indices were achieved (Shaohui *et al*., 2017a).

Scarcity and uncertainty associated with water resources due to climate change are one of the biggest challenges facing agricultural water management. An effective measure can be to increase the efficiency of irrigation in agriculture. However, increasing surface irrigation efficiency affects water resource system indices, including its reliability and vulnerability in combating water scarcity. This was studied in the irrigation system in the Dez Basin in Iran where 4 billion m^3 of water from the Dez Reservoir flows annually into the surface irrigation networks. However, the low network efficiency causes huge quantities of fresh water to be lost each year. The analysed scenarios consisted of combining two modes of changing consumption in the short and long term with management scenarios, including an increase of 5 and 15% efficiency of surface irrigation networks. In the process of simulating scenarios, the resources and uses of water in the Dez Basin were used in two horizons, namely short and long term. The system reliability in achieving the increased efficiencies was evaluated. Simultaneously with system reliability, system vulnerability also needs to be understood. The system vulnerability for the Dez Irrigation

Network was greater in the long run (26% or higher). This means that the catchment area will be more vulnerable over time and this may be on account of climate change. It may be noted that system reliability is more human controlled, but vulnerability is dictated by natural phenomena (Zohrabi *et al*., 2017).

The general objective of the irrigation improvement projects (IIPs) in Egypt was to improve the economic and social conditions of farmers through improvements in structural and management aspects by promoting efficient water use, reducing drainage problems and increasing agricultural production. These projects play significant roles in water saving and increasing productivity through physical improvements. The main weakness of the IIPs is the limitations of implementation of rehabilitation plans, main canal rehabilitation, drainage maintenance and implementation of cost-effective technologies. Therefore, implementing an IIP in a half-hearted way and without a complete package may not yield the desired results. The authors suggest continuous assessment of exact outcomes from the projects to identify the reasons for shortcomings and then act on them suitably (Sayed, Adel, El Hassan, & Watanabe, 2017).

Studies on water-saving efficiency and water resource productivity of paddy rice in Taiwan established an irrigation managing strategy in a water-shortage period. Paddy rice planted on 16 February reached water-saving efficiency of 9.0–38.3%, compared with that planted on 16 January. On water resource productivity, the SRI (system of rice intensification) planted on 16 February was also the best. The paddy rice field irrigation managing strategy established from this research could effectively respond to climate change and the severe water shortage problem in spring in Taiwan. Further, it could advance the distribution and utility efficiency of irrigation water use in water-shortage periods. From the viewpoint of growing days and crop water requirement, the plant date of the first crop being adjusted from 16 January to 16 February, its growing days would change from 141 to 123, and the accumulated crop water requirement from 517 to 496 mm. Thus the paddy rice growing days, crop water requirement and field irrigation water have all shown a decreasing trend according to the adjustment of planting date. The field irrigation water decreases due to extension of the rotation irrigation interval. This finding could be applied to the establishment of irrigation scheduling of paddy rice. On water resource productivity, the SRI would achieve the best results (Chen, Lin, & Lee, 2017).

In Mexico it is estimated that, in nearly 90% of the irrigated area, some variant of gravity irrigation (furrow or border, mainly) has been adopted, which have low application efficiency of 57% and are wasteful of water. Enhancing this efficiency would contribute to water sustainability. Most of the watersheds in Mexico are in an unsustainable situation in which demand grows continuously, as the population grows. To attend to this situation and work towards sustainable development, the National Water Program 2014–2018 envisages achieving water security and sustainability, based on management of this resource. The highest demand for water in Mexico is from the agricultural sector, where it is estimated that 77% of the volume extracted from surface and underground sources is used in irrigation. The main plot improvement method proposed for increasing application efficiency is land levelling, followed by proper irrigation recipes. The main supporting activity was monitoring of water use through measurement. The average increase in application efficiency was 6.38% and water saving was 8.22%, when improvement actions were taken in the irrigated lands (Pérez-Nieto and Hernández-Saucedo, 2017; Castillo González *et al*., 2017).

Faba beans have high nutritional value and are very popular in the diet of Egyptians. As a result of the limited cultivated area in Egypt and expansion in sugar beet cultivation to reduce the sugar production–consumption gap in Egypt, the cultivated area of faba bean was highly reduced. The results of the field study indicated that surface irrigation for faba bean resulted in very low water productivity (< 0.50 kg m^{-3}). The productivity under drip irrigation was better, but less than 1.0 kg m^{-3}. Changing the cultivation method to raised beds increased productivity and saved irrigation water, which could be used to irrigate new areas, but water productivity was still lower than 1.0 kg m^{-3}. The highest water productivity can be attained with cultivation of faba bean on raised beds and intercropping it with other crops, where its water productivity increased to be higher than 1.0 kg m^{-3}, having the potential to reach 6.07 kg m^{-3} in Upper Egypt. Thus, it can be concluded that raised bed cultivation and intercropping faba bean systems can highly enhance faba bean water productivity and combat water scarcity (Zohry & Ouda, 2017).

All over surface-irrigated regions in the world, adverse soil physical characteristics have been and continue to be inhibiting irrigation modernization and improvement programmes. This problem is specific to the shrinking and swelling of clay soils, which are difficult to handle either when too wet or too dry. Experiencing the non-maintainability of conventional lined canals over soft and shrinking–swelling clay soils over a 60 000 ha irrigation area in the Waduk Kedung Ombo (WKO) irrigation systems in central Java, Indonesia, the option of prefabricated canal lining was taken up. This option has satisfactorily and permanently addressed the problem of canal disruption (Priandini & Maddi, 2017).

A ‘small tank cascade system’ of water resource management is common in Sri Lanka, where it contributes nearly 195 000 million t of rice to national production (20% of national production). The natural drainage system in a watershed is blocked by earth bunds in suitable locations to store water, forming a series of tanks along the drainage system, distributed within a microcatchment of the dry zone. Such series are called village tank cascade systems. Traditionally, in the dry zone of Sri Lanka there is at least one tank in each village. The village community makes multiple uses of the tank water, such as for drinking, domestic uses, bathing, inland fishery and for cattle. Increased water storage also contributes towards maintaining the groundwater table (Perera, Jayatillake, & Wijayaratna, 2017).

In the next 30 years, the world's population will increase to about 9.2 billion, affecting water quality and also water availability, causing fierce competition for water among the different sectors. In the face of an increasing shortage of fresh water; partly due to climate change and partly to anthropogenic pressure, attention has focused on the possibility of utilizing waste water, mainly for agriculture. During the last century, agricultural water use increased 5 times and industrial water use 28 times. Of the pollution load from industry, about 60–80% can be treated and the remainder will drain into the rivers without any treatment. Despite various attempts to manage irrigation water (the largest consumer of water) scientifically, the ground truth is that there is a long way to go before agricultural water is actually managed scientifically to minimize its losses, overuse and misuse. Incidentally, agriculture is also a noteworthy water-polluting activity because of competition to increase production by applying more fertilizer, more agro-chemicals and sometimes more water. It is also to be noted that the volume of waste water has also been increasing in leaps and bounds. Some waste waters are treatable to improve their quality for use in agriculture (mainly irrigation).

Waste water treatment effect has been studied using bagasse fly ash layers of different thicknesses as filters. The efficiency of colour remover was 94% at effluent flow rates of 0.45 m^3 day^{-1}, with bagasse fly ash layer thickness of 7 cm. The study, however, was restricted to only removal of colour of the waste water and did not show if other important parameters (BOD. COD, DO and salts including heavy metals) could be controlled through the use of bagasse fly ash in combination with a sand filter (Pongnam & Plermkamon, 2017).

Currently in Mexico, only about half of waste water is treated for reuse. In an effort to increase the amount of treated waste water, it is important to enhance the knowledge of integrated management for using waste water in agriculture. To fulfil this objective, the Mexican Institute of Water Technology has published a book on waste water reuse in agriculture. This publication will be helpful for enhancing the technical capacities of the personnel responsible for water treatment and reuse (Cisneros Estrada, Saucedo, & García Rojas, 2017).

Irrigation development and modernization in all countries have paid attention more to the constructional aspect rather than management for handling water. There has also been a lack of participation of stakeholders in irrigation system development. The goal should be not only to modernize irrigation systems but also development of institutions and human capital and effective collaboration among the stakeholder (community) (Sutiarso, Supadmo Arif, & Murtiningrum, 2017).

SUB-QUESTION 61.2. USING ICT, REMOTE SENSING, CONTROL SYSTEMS AND MODELLING FOR IMPROVED PERFORMANCE OF IRRIGATION SYSTEMS

Water is critical for sustainable development, including environmental integrity and the alleviation of poverty and hunger, and is indispensable for human health and well-being. Imbalances between availability and demand, the degradation of groundwater and surface water quality, inter-sector competition, inter-region and international disputes, all centre on the question of how to cope with scarce water resources.

Efficient water management has been identified as one of the priorities to ensure food security in many areas of the world. On the other hand, smart technologies are nowadays spreading into all sectors of human activity. Remote sensing, modelling, sensors, remote control systems, application of information and communication technology (ICT) are potential tools to improve the efficient use of water to achieve improved performance of irrigation systems,including geospatial and drones, etc., to improve management of soil, water and crops, and to predict and mitigate the impacts of extreme weather conditions of droughts and floods.

By considering the importance of improving the performance of irrigation systems, the ICID, during the 23rd Congress, formulated Question 61.2: 'Using ICT, Remote Sensing, Control Systems and Modelling for Improved Performance of Irrigation Systems' and invited papers for presentation.

General overview of the papers on remote sensing

Planning of water resource use for irrigation is often difficult due to insufficient and untrustworthy recorded data. Inaccuracies in data can only be identified by comparing their values with estimations from alternative methods, e.g. remote sensing. In a study, water supply was estimated based on the normalized difference vegetation index (NDVI) and correlations built upon time series of official statistical data. Correlation between NDVI and the coefficient of irrigation water productivity (CIWP) allows estimation of irrigation efficiency, while the correlation between CIWP and total water supply enables further assessment of the latter. Correlations remain relevant with constant irrigation practices on arid lands where effective agriculture needs continuous irrigation. In the study, the NDVI index was used as the main spectral index for both irrigation area and water supply assessment (Danylenko, Mykhailov, Liutnitski, & Bohaienko, 2017).

A study focused on identification of agricultural drought characteristics and elaborated a monitoring method which could result in appropriate early warning of droughts. Based on remote sensing (RS) technology, an Agricultural Drought Monitoring and Yield Loss Forecasting Method can be used to identify possible intervention areas. With help of the method, the effect of drought on crops can be detected 4–6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital need for global food security and trade. This information can reduce impacts if delivered to decision makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place. Understanding the underlying causes of vulnerability is also an essential component of drought management because the ultimate goal is to reduce risk for a particular location and for a specific group of people or agricultural or economic sector (Nagy, Tamás, & János, 2017).

Researchers believe that adoption of RS technology gives better estimates of irrigated area, salinized area and efficiency of the irrigation system. Also, adoption of this technology becomes essential for planning, design and operation of an irrigation system when the recorded data of ground truth are limited or unreliable (Vlasova, Shevchenko, Shatkovska, & Ryabtsev, 2017). Two remotely sensed vegetation indices, namely enhanced vegetation index (EVI) and NDVI, together with land surface temperature (LST) onboard a moderate resolution imaging spectroradiometer (MODIS) satellite, were used as indicators of vegetation health and vigour. Time series EVI and NDVI were analysed from 2000 to 2016 for the study area. Both EVI and NDVI are available in 250 m resolution, 23 data sets per year. LST are available in 1 km resolution every 8 days or 46 data sets per year. LST were resampled to 250 m and aggregated to 23 data sets per year. Ten digital elevation models (DEMs) for the study area were acquired from an advanced space-borne thermal emission and reflection radiometer-global digital elevation model (ASTER GDEM) in 30 m resolution. An interview was conducted with the farmers in the irrigation district. Finally, it was concluded that EVI exhibited high sensitivity to detecting crop conditions, both healthy and stressful, in response to water availability (Herdianto, 2017).

Reliable estimation of crop coefficients is a prerequisite for scientific allocation and application of water to the cropland. Working on this notion, researchers emphasize that vegetation indices estimated from multispectral images play an important role in K_c estimation and consequently, the crops' irrigation requirement. The object-based image analysis (OBIA) classification algorithm allowed differentiation of crop and soil characteristics, giving more accurate values of vegetation indices and crop monitoring. A linear model was used to estimate K_c as a function of NDVI. The $r^2 = 0.97$ was higher than those reported when using satellite images due to the fact that unmanned aerial vehicle (UAV) images have higher spatial resolution and better separation between crop, crop shadow, soil shadow and bare soil. Using K_c–NDVI models, maps can be generated showing the spatial variation of K_c (De Jesús Marcial-Pablo *et al*., 2017).

A study on a 20-ha maize farm in Karaj, Iran, combined two indices of accumulated growth degree days (AGDD) and NDVI for modelling of maize phenology and determination of the onset of phenological stages. Considering the severe noise and 7 days interval in available multi-temporal images, it was necessary to use smoother methods. For this purpose and to achieve high-quality time series of NDVI, the real-time smoothing method of the weighted least squares (WLS) model was applied. The results of the combined model were compared by two frequently used methods based on AGDD and sowing-based models. The root mean square error (RMSE) using the combined model was the least for all the phenological stages (Ghahreman, Ghamghami, Irannejad, & Ghorbani, 2017).

General overview of the papers on knowledge management

Sutiarso *et al*. (2017) believe that there are five pillars of irrigation modernization in Indonesia: (i) water availability; (ii) irrigation infrastructure; (iii) irrigation management; (iv) institutional irrigation management; (v) human resource (knowledge management base). They have, however, chosen to dwell upon the knowledge management aspect.

A case study paper based in Madhya Pradesh, India, indicates that the development of a web-based management information system (MIS) was a central tool in the process of a significant increase in irrigated area. The paper discusses the genesis and development of this tool under the World Bank-funded Madhya Pradesh Water Sector Restructuring Project (MPWSRP) and the measures adopted to facilitate its development and uptake by the department. The paper concludes that the availability of timely, accurate and transparent data is fundamental to the modern management of irrigation and drainage schemes (Burton & Stoutjesdijk, 2017).

A paper based on a study on 'Real-Time Feedback Control System for Improving Agricultural Water-Use Efficiency of Basin Irrigation' discussed the real-time feedback control system of surface irrigation, including a real-time irrigation information acquisition and transmission module and a central controller. The proposed system has been applied in some irrigation districts and showed effective improvement of water-use efficiency (Wu, Xu, Bai, Li, & Li, 2017).

The paper on intelligent measurement and monitoring of irrigation amount in well- irrigated areas presents real-time monitoring and control technology for irrigation wells, which consist of an ultrasonic flow meter, communication module and control terminals. The study was done in North China and the authors claim that individual farmers can use the technology through use of their prepaid smart cards. Management platforms at different levels, such as city, county, water station and village, can be set up to monitor irrigation water amount and distribution (Jing, Chongbao, & Hong, 2017).

Use of web-based information in planning, designing and monitoring of irrigation systems is termed ‘cloud computing’, essentially a DSS with a much broader scope. In order to solve the problem of inefficient use of water and fertilizer, a paper proposed an intelligent cloud irrigation system to manage the two resources in protected agriculture. The authors claim that the system is of great importance in guiding protected agricultural facilities to achieve high yield, high quality, ecology and safety in production. It improved water use efficiency by 25–40%, fertilizer use efficiency by 15–35%, shortened labour time and decreased the labour force sharply (Qinghong, Xinlan, Shuai, Hejing, & Qunchang, 2017).

Information and communication technologies (ICTs) are an indispensable tool for improving the performance of irrigation systems. Their implementation requires an approach adapted to the needs of the actors, ensuring their optimal appropriation for the achievement of lasting results. The innovative methodology used to integrate ICTs into the PARIIS-SIIP program from the formulation phase, and the results obtained at this stage of development as well as recommendations for the successful implementation of the program were presented (Figuères, Onimus, & Ouédraogo, 2017).

The researchers of a greenhouse experimental study on tomato presented a DSS that could be used to help greenhouse growers improve their current fertigation practice (Martinez-Ruiz, López-Cruz, Ruiz-García, Pineda-Pineda, & Prado-Hernandez, 2017).

A paper from Indonesia mentions that irrigation management for its modernization requires effectiveness and efficiency in the operation of the irrigation network. Monitoring and remote control technology used in this research is the application of reporting of a website-based operation, measurement of volumetric discharge, and an electromechanically controlled water gate. Problems encountered in implementation were also discussed (Hidayah, Prihantoko, & Hutadjulu, 2017).

A physical model along with a software program was used to evaluate the uniformity coefficient of centre pivot sprinkler irrigation systems in Iraq. The objective was to examine the improvement of the uniformity coefficient by changing the water supply from the pivot point to the middle of the main pipeline. Based on the result of this study, the author concluded that the software program can be used as a tool to predict the behaviour of the sprinkler system under different layouts and different operating pressures (Al-Katb, 2017).

In a study in China, the finite-volume approach and a fully coupled model for a canal–field system was developed to simulate unsteady flow simulation for a canal–field system in an irrigation district. Using the approach and the model, the water distribution and gate control in the experiment area was optimized. The optimized solution revealed that water consumption could be reduced by about 21% compared to the present situation (Shaohui *et al.*, 2017b).

Three PI tuning methods for downstream water level control were used and three methods for tuning and designing PI controllers for downstream control were evaluated. The evaluation criteria were: effectiveness of tuning; and potential for practical application on an actual canal in the field. The analysis results of the methods and recommendations are presented. The paper examines three methods for tuning and designing PI controllers for downstream control: iterative, Ziegler Nichols and bump tuning. The methods are evaluated using three criteria: how easy each method is to understand and utilize; effectiveness of tuning; and potential for practical application on an actual canal in the field. The analysis results of the methods and recommendations are presented in the paper (Stringam, Wahlin, & Wahl, 2017).

In a paper from Iran, the hydraulic behaviour of the canal and operational scenarios are simulated using the ICSS (irrigation canal system simulation) hydrodynamic model. The canal performance was evaluated using adequacy, efficiency and equity indices. The results show that application of managerial operations has improved the adequacy and efficiency indices by about 5–10% for all intakes, and the equity index has improved by 4% for the whole canal (Ostovari, Monem, & Hashemi Shahedani, 2017).

A mathematical model study was carried out in southern Finland on groundwater table behaviour in a subsurface drained land using the three-dimensional (3-D) FLUSH model. Based on the study, the authors conclude that the effect of drain spacing had a more visible effect on groundwater table depth than on water balance components (Warsta *et al.*, 2017).

In addition to the above, there were two papers which were not directly linked to the theme of Question 61, but were indirectly linked to some of the issues related to the Question. Briefly, these papers are:

- *folded plate technology*. This paper from India on folded plate earth-retaining and bank-stabilizing structures provided useful and valuable information on structural/ constructional aspects of river training and management works (Dinkar & Panday, 2017);

- *ecological water diversion*. This paper from China analyses RS images to evaluate the practice of ecological emergency water diversion to Nansi Lake in China. The paper provides useful information of RS utilization for ecological purposes (Qu, Wang, Li, Hu, & Zhao, 2017).

SUB-QUESTION 61.3. ADAPTABILITY AND AFFORDABILITY OF NEW TECHNOLOGIES UNDER DIFFERENT SOCIO-ECONOMIC SCENARIOS

New technologies in irrigation are continually being developed. Methods of applying irrigation water, determining crop water requirements, using low-quality water, providing drainage, improving water storage and delivery systems, forecasting droughts and floods and improving the knowledge of those involved in the storage, delivery and application of irrigation water are some of the areas where new technology is helping to improve the production of food throughout the world.

Almost 25% of the world's countries suffer from different levels of water stress. Access to newly generated technology in agriculture should be a human right more than an option for farmers, especially those with fewer economic assets. Since agriculture is the sector that uses the most water (around 69% worldwide), special emphasis is needed to increase irrigation water use efficiency which in some countries is very low (including conveyance, storage and application). The electromechanical efficiencies of pumping equipment should be taken into account when computing global efficiencies.

The development of new irrigation-related technologies does not automatically result in better irrigation practices and thus more food production. New technologies must be put into use before they can be of value. Putting a new technology into use requires that it be adaptable, economically beneficial and acceptable to those who will use it. This may be a very difficult task when implementing some new technologies, and thus, testing and experiments are needed. Pilot demonstrations and extensions with continuous improvement for their adaptability and affordability under different natural and socio-economic scenarios are necessary. For example, something that may work very well in a small laboratory environment may not be feasible in the natural environment of an agricultural field. Also, something that works very well in the laboratory may not be accepted by those who would use it in the field because it is cumbersome or unfamiliar to them.

The adaptability of new technology to various climatic, environmental and socio-economic conditions is a significant factor in determining its validity. A new concept that provides a significant efficiency improvement in one geographical area or socio-economic setting may not be useful at all in another. For example, the computerization of a pivot sprinkler system will have little or no value in a part of the world where the farming takes place on hillside terraces or where farmers cannot afford computers or sprinkler systems. A modern efficient electric irrigation pump is of no value if there is no electricity available to drive the pump.

Newly generated technology encompasses a process of transfer or training for users independent of their socio-economic level. Experience has shown that at the field level it is difficult to convince farmers to adopt any technology if it does not imply an economic return in the short run. Moreover, if the new technology requires a financial investment, farmers will think twice about its adoption, especially those farmers with low economic capacity, unless a special subsidy is provided to assist them. In this framework, the development of technology should take into account farmers' needs from the social point of view and from the state of the natural resource (water) and the ecological points of view. The former should yield technology of easy application that is understandable and inexpensive and the latter should yield technology that does more with less water and has a small energy footprint.

Within irrigation districts or water user organizations, the aim of new technologies should imply an increment in operational efficiency and in the way data are gathered to plan and operate better or improved irrigation systems. New technologies at the irrigation district or water user organization level could also include improved policies, processes and administration. Irrigation technology does not necessarily imply piping or canal lining, or high-tech or complicated equipment, or expensive ways of pumping or distributing water within fields. Rather, it should imply better water management through better practices. New technology for irrigation districts or water user organizations must also be applicable and affordable for varying conditions.

It should be understood that there are different levels of technology needs and adoption according to the socio-economic level of farmers and water user organizations. One big mistake that governments have made is to try to increase the level of water efficiency of farmers and water user organizations from a very inefficient platform to the highest level of water use efficiency while neglecting the cultural, social and economic situation. The goal of increasing water use efficiency should proceed in a succession of steps towards achieving the desired level over time. Let us say that there are three categories of farmers in terms of water use efficiency: A, B and C, with A being the most efficient and C being the least. It is a mistake to try to move farmer C to level A in the short run. It will be more affordable and successful to move farmer C to level B and farmer B to level A. This procedure may cost time and money but will yield results that are more promising. Trying to move farmer C directly to level A will likely result in the farmer giving up on any improvements because they are beyond his or her physical, mental or economic capabilities to implement them. The situation dictates the level of technology that is needed.

The land tenure and/or the land size of landowners (or land operators) are also important factors for the adaptation of new irrigation technologies, particularly in developing countries. For example, in China, it is difficult for traditional small household farmers to use drip irrigation because, to them, drip irrigation is not affordable and is complicated in management. However, in recent years many farmers have been transferring their lands by contracts to large-scale centralized land operators. As a result, drip irrigation and automatic control irrigation systems have developed quickly, as land operators can afford, manage and get benefit from the new irrigation technologies applied. It may be true that the small land scale and weak economic strength of farmers are major constraints for adaptation of new irrigation technologies in many developing countries, such as drip and sprinkler irrigation. However, it was also found that there is a simple, low-pressure drip irrigation technology (with elevated water tanks near the field to provide the low pressure needed) for small-scale farmers in India that reportedly worked well for small field plots. This, once again, shows the importance of 'adaptability and affordability' of new irrigation technologies.

Introducing technology that is beyond the capabilities of the water users to implement will result in disaster. If farmers or water user organizations become frustrated trying to implement new technologies they will probable revert to the old methods they had been using and which they are comfortable with. This will often result in the abandonment of infrastructure or ideas that could eventually be used for more efficient use of water for agriculture. Farmers and water user organizations should participate in the decision-making process when any new technology is to be introduced. Here is where transfer of technology and training play a main role. The commitment of water user organizations participating in governmental programmes needs to include the training of their personnel and farmers to assure the success of the improvement plan.

General overview of the papers

The solar disinfection (SODIS) process uses the intense ultraviolet radiation from sunlight shining through a non-opaque container filled with non-potable water (grey water) to kill undesirable pathogens, rendering the water safe to drink. This method was used for irrigation of tomato seedlings and not for obtaining potable water. The authors describe a research project in this area in Brazil. However, no information on the adaptive potential or the affordability of the process is given (Aleman, Silva, & De Souza Pereira, 2017).

Researchers in Brazil presented a greenhouse experiment for the determination of the weekly crop coefficient of tomato seedlings. The authors contend that often in practice, production systems do not operate under efficient management, not because of a lack of technology or capital, but because decisions are improvised, random, careless or subjective (Aleman & Bastos, 2017).

Attributing the earlier misuse of irrigation systems in Ukraine as the reason for decline of the system, the authors of a paper have called for immediate action for their technical modernization, and of effective technical solutions as a prerequisite for sustainable development of irrigated farming. Though the Congress was a good place to discuss the adaptability and affordability of new technologies the authors did not pursue this (Romashchenko & Dekhtiar, 2017).

A paper from China has presented some very good concepts on balancing needs, population growth, social knowledge, etc. Although the technology presented in the paper may not be new, its application is still valid. Moreover, various traditional forms of irrigation should be systematically researched not only for their engineering value, but also their sociological and ecological value (Yunpeng, Xuming, Ruoxi, Jun, & Jiangang, 2017).

There has been a proposal to initiate a new groundwater management policy in Mexico. A paper in this regard discusses the need to allow users to have more of a voice in regulating groundwater extraction. Such a move would enhance the effectiveness of the new management policy (Casillas, González, Espinosa, González Bernal, & Bernabe, 2017).

The authors of a paper discuss a study of two sample national irrigation systems that face water shortages and destructive floods during the dry and wet cropping seasons, respectively. The paper reflects on some of the shortcomings of earlier attempts to introduce new technology and discusses ways to make sure future new technology is adaptable and affordable. They feel that the basic approach to identification of appropriate irrigation modernization options includes: (i) critical analysis of the logical consistency of the design of the physical structure, system operation and water supply; (ii) assessment of the physical capacity of the irrigation structures to perform their functions; (iii) due consideration of social acceptability of selected irrigation technology and water users' vision of the future modernized irrigation system; (iv) integration of effective local solutions to evident design shortcomings into the modernization plan (Delos Reyes & Schultz, 2017).

The authors of a paper from Mexico feel that there are technologies available to overcome the adverse consequences of weather extremes and resource degradation but few will be able to pay for it. However, land improvement through drainage is considered an economic solution to the salinity problems in Mexico (Arias *et al*., 2017).

The authors of a paper from Indonesia on the competitiveness of modular canal lining discuss replacing damaged canal linings with precast concrete sections and compare that with stone masonry linings. The authors indicate that users generally will easily accept and apply this technology because of the advantages in terms of strength, lifespan and maintenance costs. However, users have perceptions that stone masonry lining is better in terms of ease of construction, construction time and cost of construction (Sofiyuddin, Uzae, & Mulyadi, 2017).

There are several papers presented under Sub-question 61.3 which are either not related or very remotely related to the theme of the Sub-question. One such paper on rainfall distribution and vegetation greenness from Natal, South Africa, claims that water storage for the present and future remains critical for economic and social development in South Africa. A paper from Taiwan deals with monitoring the safety of a dam structure. A paper from Mexico discusses the maintenance of irrigation infrastructure by removing sediment from the water conveyance network. A paper from Pakistan discusses groundwater conditions and its future, from the standpoint of its importance in agriculture. A paper, very distantly connected with irrigated agriculture, evaluates the effects and type of tourism in the Hsinchu City area using the 'travel cost method' of multicriteria decision-making. A paper, better related to the theme (or water resources and irrigation) from Mexico, discusses the value and opportunities of using solar power to operate pumps for agricultural water. A paper proposes two tools for assessing the need for, and prioritizing the work to upgrade, small storage tanks in Sri Lanka. The author of a paper on a physical model study in Mexico discusses using a physical model to determine the flow through a tunnel. The data were then used to make recommendations for changes to the tunnel to improve the flow. The model work and results are commendable but cannot be clubbed together with other work, as this has been the only paper of its kind (Maponya & Mpandeli, 2017; Huang *et al*., 2017; Ramón & Nazario, 2017; Hassan *et al*., 2017; Chiueh and Liu, 2017; Robles Linares Gándara, 2017; Perera *et al*., 2017; Maldonado, 2017).

SUMMARY

Question 61 had three Sub-questions, namely 61.1, 61.2 and 61.3. The themes of the Sub-questions and the number of papers received under them are given below:

- *Sub-question 61.1*. Adopting precision irrigation and improving surface irrigation to combat water scarcity (25 papers);
- *Sub-question 61.2*. Using ICT, remote sensing, control systems and modelling for improved performance of irrigation systems (22 papers);
- *Sub-question 61.3*. Adaptability and affordability of new technologies under different socio-economic scenarios (17 papers).

In all the Sub-questions, there were a few papers that were not directly linked to the Sub-question theme. However, irrigation is a very broad subject and encompasses the entities of water, land and human resources. So linkages do exist, though they may not be clear. In this section, therefore, those weakly or indirectly linked papers are also included.

Freshwater scarcity is of global concern and feared to be aggravated in the future. As expected, therefore, a number of researchers have addressed this issue. As water resources cannot be created in addition to what nature has provided, several authors have highlighted the efficient use of water resources to minimize undesirable and avoidable losses of water: in its storage, conveyance, application and use. Loss or wasted irrigation water is manifested in soil salinization, waterlogging, unworkable soil conditions, particularly in shrinking and swelling clay soils. Hence a set of papers across countries has addressed this issue. The water quality aspect has not escaped the researchers' attention. This is an important aspect and a management issue, as while on the one hand, fresh water cannot be created, poor-quality water always increases in quantity and deteriorates in quality due to anthropogenic activities of the ever-growing population.

Since surface irrigation by the gravity flow of water over cropped land is the most common the world over, attention to improving surface irrigation efficiency is naturally expected. Also, such attention has been greater in water-scarce arid and semi-arid countries and regions. There are papers on the correct estimation of crop water requirements based on which type of irrigation water is applied in the field. Web information-based estimation (alternatively known as 'cloud computing'), an advanced method of estimating real-time-based crop water requirements, has been used. A point of interest is that the topics of research and application that earlier used to be in the domain of research and educational institutions, have now also spread to executive departments. The case is similar with model studies, including physical and mathematical models.

Real-time monitoring of irrigation and appropriate follow-up action have been applied in some irrigation districts and have shown effective improvement of water use efficiency. Similarly, intelligent measurement and monitoring of irrigation amounts in well-irrigated areas involve real-time monitoring and application of control technology for irrigation wells, which consist of an ultrasonic flow meter, communication module and control terminals. Obviously, such systems and methodologies improve irrigation performance. Further, even individual farmers can use the technology by using prepaid smart cards. Management platforms at different levels, such as city, county, water station and village, can be set up to monitor irrigation water amounts and distribution.

Thus, the 64 papers in Question 61 appear to have addressed all the relevant issues related to irrigated agriculture and some of the papers have even gone beyond them.

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This General Report was prepared and integrated largely based on the summary reports of the Sub-questions prepared by the Panel Experts/Co-chairs and the views on the papers submitted and their expanded views on the related topics beyond the papers.

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