Development of an ICT-based layer model for improving managerial decision making on water issues in arid and semi-arid regions

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Abstract—**Fresh water is an essential element for human survival and land-based life forms. Right quantity and quality of fresh water is a fundamental element for human continued existence and land-based life forms. About 97% of earth water is salt water and from remaining 3% only 0.4% fresh water is available for human use. Many countries of the world are facing problem of inadequate drinking water supply, management of wastewater and basic sanitation. About more than one billion peoples did not have access to the safe water and two billions are lack of safe sanitation. This is a constant challenge for several regions of the world. Effective water management is very important to overcome the water problems. Nevertheless, with the use of Information & communication technology (ICT) techniques, this situation can be improved. In this research paper we have discussed the essential factors that effects on different water issues in arid and semi-arid resigns, moreover these water problems are classified into structured, semi-structures and unstructured. To improve the managerial decision making on water challenges; we also have proposed an ICT based layer model with consideration on operations, operational management, tactical management and strategic management.**

Keywords-Water challenges, managerial decision making, operational management, tactical management, strategic management, layer model.

I. INTRODUCTION

Life is not possible without water; right quality and quantity of water is very important for life. We can say that water is lifeline for human beings, for animals and for food crops.

Most important usage of fresh water includes agriculture, industry, domestic, recreational, and environmental activities. Sufficient quantity and quality of fresh water is important for every human-being on earth. Some countries are facing the biggest trouble of water related crises due to limited available quantity of fresh water. Every year millions of peoples die due to water related diseases and it can be the reason for economic damage throughout the world [1]. In many part of the world; there is gap between water supply and demand. The most important reasons for this gap are enlighten in next section problem definition.

It is estimated that 97% of available water on earth is salt water and most part of the remaining 3% of fresh water is in polar icecaps, glaciers, in atmosphere or underground. About 0.4% water is available for human use [2].

In next section of our paper we have discussed different issues that effect on water-crises or water-problems in arid and semi-arid region of world. These problems can be further divided into structured problems, semi-structured problems and unstructured problems. We also have proposed an ICT based four layer model that can be beneficial to improve the managerial decision making to overcome the water challenges. This model will be based on water operation & actions, water operational management, water tactical management and water strategic management. At the end we have presented the mapping of each layer with ICT techniques used.

II. WATER PROBLEMS IN ARID AND SEMI-ARID COUNTRIES

Arid and semi-arid countries face water issues, problems and constraints. The literature review enable us to divide those problems into two main categories: natural and human-made.

A. Natural problems

Certain countries are facing the biggest problem of water related crises or limited available quantity due to the following reasons.

*1) Limited water quantity on the earth:*One of the reasons for water crises is the limited available quantity of fresh water on earth. According to the water pollution factsheet [2], 97% of available water on earth is salt water, which is unusable and only 0.4% from the remaining 3% fresh water is available for human use.

2) Unbalance precipitation distribution: Unbalanced precipitation is another reason for water crises in some countries of the world specially aridity based countries receive least amount of precipitation. There are three main factors that

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affect the global distribution of precipitation, i.e. circulation of the atmosphere, nearness to large bodies of water, and topography. Estimated average annual precipitation on the earth is about 1050 millimeters per year [3], this amount of rainfall depends upon the location on earth. Regions those are found in equatorial zone get highest rainfall; middle latitude zones get moderate amount and only little amount of rainfall in deserts [4]. Some part of the earth get heavy rainfall like European countries but some countries only get very small amount of rainfall.

3) Climate change: Many countries of the world are already struggling due to the water crises and continues change in climate also affects the quantity, quality and accessibility of water supply because of its close connection with water cycle. "*Climate warming observed over the past several decades is consistently associated with changes in a number of components of the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff* [5]." Change in climate can cause to increase the demand of water for farm irrigation, sprinklers, and for gardens.

B. Human made problems

Human beings have a significant role to increase water crises: i.e. population increase, urbanization and poor water management infrastructure and absence of ICT.

1) Population increase: Continues growth in population plays important role to raise the demand of water. According to United States Census Bureau [6], currently estimated world population is 6.91 billion, and is continuously increasing and it will be 9 billion in 2044.

According to [7], most populated region of the world is Asia which is home for more than 4 billion peoples, about 1 billion peoples are in Africa, 733 millions are in Europe, Latin America and the Caribbean region has 589 million, Northern America has 352 million and Oceania/Australasia has 35 million populations. Developing countries are already facing water stress and at the same time these countries have high growth rate, which cause the increase in water demand.

2) Change in life style or Urbanization: Change in life style or urbanization also increase water demand. Statistics shows that less developed countries have high urbanization growth rate as compared with developed countries. This trend is creating more pressure on water crises for less developed countries. Urban population in less developed countries was 813 million in 1975, which is increased 2266 million in 2005, but in developed countries it was 704 million in 1975 and 344 million in 2005 [8].

3) Poor water management infrastructure: Flood plays important role in water and property loss in developing countries due to poor water management infrastructure and limited storage capacity. As an example in July 2010, due to heavy monsoon rain in some part of Pakistan cause flood in most of the regions, and estimated damage was about $43 billion [28]. Also in Saudi Arabia, due to the poor sewerage system caused serious flooding in Jeddah and Riyadh in November 2009 and May 2010 respectively [20].

4) Limited or absence of ICT: Another reason for water crises is that currently developing countries have limited or absence of ICT uses to manage the water resources. In most of the reigns, we are unable to detect water leakage automatically in distribution pipes, to detect the water waste in big water reservoirs, water overflow etc.

In developed countries Information & Communication Technology (ICT) is successfully implemented in weather and rain observations systems, educational curricula development [9], medical treatment, agriculture, social sciences research [10] etc. Some applications that are using ICT are Global Atmosphere Watch, Remote Automated Weather Stations, Automated Surface Observing Systems; Sea Surface Temperature buoys [11 and 12].

III. Water Problem Classification

Before providing any solution to any problem, it is crucial to know its type. Regarding this aspect, several approaches have been proposed from which we choose the degree of complexity type. Based on this, water problem in arid and semi-arid regions are classified as [13]: structured, semi-structured and unstructured. Each type of this classification is briefly described in the following.

A. Structured Problems:

Problems for which the existing state and desired state are clearly identified, and the methods to reach the desired state are fairly obvious. For example: digging a well in arid and semi-arid region is a structural problem. If we know where and how much we need to dig to reach water, then the actual operation of digging the well has fairly structured process.

B. Semi-structure Problem

Problems for which the existing state and desired state are partially clear and the methods to reach the desired state cannot be found by computer solver alone. For example, to select a good location for a well in arid and semi-arid region is a semi-structured problem. The decision in this case can be influenced by many issues such as water aquifers levels, different government agencies and some socio-environmental concerns.

C. Unstructured Problems

Problems for which the existing state and the desired state are unclear and, hence, methods of reaching the desired state cannot be found. For example: to develop a social awareness to build water sharing network between a well owner and his neighbors can be an unstructured problem. The presence of different constraints and multiple stakeholders makes the problem complex and unstructured.

IV. Proposed Layered Model to Support Managerial Decision Making

Problem solving in water space necessitates the synergy of multi-disciplines such management, management science, engineering, decision making, economical studies, social science, etc. The scope of this work is limited to considering managerial decision making as a layered model solution. From management point of view, four managerial levels can be mentioned: operations, operational management, tactical management and strategic management. From decision making perspective, this is proportional to the types of problems discussed in section 3. These types are: structural decision (i.e. deals with structured problems), semi structured decision (i.e. concerns with semi-structured problems), and unstructured decision (i.e. related to unstructured problems).

According to managerial point of view our proposed layered-based model consists of four layers. From bottom-to-up, first layer is water operation & actions, operational management, water tactical management, and top most layer is water strategic management. Other than these four layers water consumers, water resources and water technologies are also very important stakeholder to get the solution of water problems. Each layer will be discussed in detail; layered model is shown below:

Water Strategic Management (WSM)
Water Tactical Management (WTM)
Operational Management (OM)
Water Operations and Actions (WO & A)

A. Water Operation & Actions (WO & A)

Water operation and action is first layer from bottom-to-up in our proposed layered model, which talks about the different operations and actions that can be used on water resources to get the water using available water techniques. It can be further subdivided into the digging, boring or drilling, water pumping, water transportation, water distribution, buying, selling, and water detection.

1) Digging, boring or drilling: It is a process to get the ground water from the underground aquifers.

2) Water pumping: Water pumping is a technique to get water from one water source and move to another location. Different types of pump can be used for this purpose.

3) Water transportation: Water transportation is the process of shifting water from one place to another place over a large distance. Transportation method can be pipelines, canals, tunnels, tank truck, tank car, tank ship etc.

Some big water transportation projects are Grand Canal of China or Beijing Hangzhou Grand Canal, California Aqueduct, Great Manmade River, Keita Integrated Development Project, Kimberley Water Source Project, and Goldfields Pipelines.

4) Water distribution: It is a process of delivering the fresh water to its consumers. Water distribution system infrastructure can comprise of network of pipes, valves, pump station, and storage tanks.

5) Water Detection: Water detection is a process to identify the presence of water, to determine the quality of water or to find out that it is suitable for drinking or not, to determine the location and depth of water etc. Water detection can be classified into ground water detection and leak detection. Different type of devices and sensors are available to perform all above operations.

6) Water permissions: In most of the countries all over the world, it is very important to take permission from higher water authorities to perform any activity related to water e.g. digging well, water pumping, water transportation, water distribution, selling and buying etc.

For example in Saudi Arabia, before to dig a well it is very important to get a license from ministry of agriculture and water, and it must lists the stipulations, technical specifications, well digging contractors with their administrative and technical capabilities.

B. Water Operational Management (WOM)

"Generally operation management is the direction and control of the process that transform inputs into outputs. It entails the design and control of systems responsible for the productive use of raw materials, human resources, equipment, and facilities in developing goods and/or services".[14]

Water Operational Management is second layer from bottom-to-up in our layered model which defines the low range planning such as scheduling, monitoring, maintenance, water pollution detection, blockage detection and leakage detection of the ongoing project. This planning is also called first level management and is directly managed by front line managers such as the supervisory managers, foreman, section officers, superintendent etc, [15]

It can includes following activities;

- Assign the different actions to the non-management employees/workers and regularly guiding and giving them instructions.
- To manage the different equipment, tools, and material to achieve the required goals.

- To manage the quality and quantity of production.
- To communicate the staff/workers problems, suggestions, and recommendations etc. with high level authorities and project goals and objectives to staff.
- Staff building and training is also handled in this layer.
- Periodical report generation related to the project progress.

C. *Water Tactical Management (WTM)*

Water Tactical Management (WTM) is third layer in our proposed model. Tactical management is a process in which middle managers develop medium range plans and budgets and specify the policies, procedures, and objectives of the project. They also acquire and allocate resources and monitor performance of the project [15].

Overall goals and objectives that are defined by the top most management of organization in layer four of our model are handed to the tactical management in third layer and this layer make his own plans, policies, and procedures to achieve the overall project goals. Normally the flow of the decision is from top to bottom and flow of data is from bottom to up.

D. *Water Strategic Management (WSM)*

Water Strategic Management is a top most layer in our proposed model. Strategic management is concern to the organizational top management like CFOs and CEOs, it involves setting the direction for the organization, developing the overall project goals, making strategies, policies and defining the objective for new projects, and to maintain the relationships with outside world. They also monitor the strategic performance of the ongoing projects and its overall direction [15].

According to Hugh Howes [16] "Strategic planning for water examines the neglected relationship between planning for water and spatial planning. It provides the background to sustainable water management and assistance to spatial planners in understanding the complex water environment". It can includes;

- To insure that water supplies are sufficient that fulfills our future requirements.
- How we can reduce the risk from floods or disasters.
- How to manage our waste water efficiently.
- How to build desalination plants.

V. ROLE OF ICT IN SUPPORTING MANAGERIAL DECISION MAKING

In section 3 we have shown that managerial decision making for problem solving in general and in water aspects can be classified into four levels; operations, operational management, tactical management, and strategic management. The scope of this section is pertained to classify ICT according to managerial decision making levels and mapping of our proposed model with the ICT role. Each type of this classification is briefly discussed below:

A. *Operational Support*

Operation and Actions are interrelated to each other but have different meanings in our proposed model; operation refer to detect the problem and to find out the possible solution, whereas action refers the actual implement of that solution. For example in water detection; detecting the exact location of water is an operation, while to drill it using some instrument to get the water is an action.

Water operations and action layer of our proposed model involved all the software used in ICT to perform different water operations like drilling, boring, pumping, leakage detection, water transportation, water distribution, water detection, and water permissions. These software's can be classified into system software, application software, utility software, data base system, data backup and recovery software etc. As we know that to perform above stated operations; wireless sensor network is commonly used ICT technique, so we have some specialized operating system and simulators for WSN. Which are briefly discussed next;

As an example; irrigation systems that are using ICT require different type of software's e.g. software to send data from sensor, software to receive data from sensor, database management system to store that data, software to make necessary analysis on that data and so on. Below some proposed system are discussed which are using above software in their implementation;

- F. Camacho et al. [17] has proposed a prototype to assess the water deficits over the irrigated crops, which estimates the deficits from remote sensing and agrometeorological information. Main ICT hardware used by this prototype are; Landsat TM5 sensor used for remote sensing, agrometeorological stations used to collect rainfall (Pr) & ET0 data and satellite to produce images. In this system to monitor and determine irrigation demand is using ICT like; image processing module which is used to process remote images collected from Landsat, WEB 2.0 standards for web display, AJAX used as a tool for development and integration, Google maps API used to visualize GIS information, and online analysis & visualization tools are used for delivery to the users in real time.
- G. Papadavid et al. [18] proposed system for management, irrigation demand monitoring and optimization of the water resources in irrigated agriculture through the use of remote sensing. This system is using ICT software like; WaterWare irrigation software, ERDAS Imagine software for pre-processing and processing of images taken from satellite.

B. Operational management support

It is already mentioned in section IV that this layer concern with front line managers those define low range planning for system. All the hardware and software which are discussed in water operations & action layer will be managed in this layer of our proposed model. Operational management decisions taken in this layer can be classified into structured, semi-structured and unstructured that those may need one or more technology support such as management information system (MIS), management science (MS), operational research (OR), knowledge management systems (KMS) etc [19], also choice of technology depends upon the type of decision. As an example Supervisory control and data acquisition (SCADA) is a remote monitoring and control system which normally consists of the field instruments, communications, hardware and software, water stakeholder management, soil water contents etc. It involves the use of ICT in water scheduling, monitoring, maintenance, water pollution detection, blockage detection and leakage detection. Developed countries are already using ICT facilities in; irrigation network design, irrigation scheduling, water budgeting, water supply systems, automation in mechanized irrigation and automation in surface irrigation.

C. Tactical management support

Generally tactical management is a way that organizations choose a maneuver that will render a better result. The basic objective of tactical management is to make policies in such a way that organization can get returns on investment for information system. [21]

Tactical management can be facilitated by one or more ICT technology support such as decision support system (DSS), operational research(OR), knowledge management system (KMS), supply chain management (SCM) etc. We can take DSS as an example that can use ICT to perform stated operations. In decision making process, DSS takes help from its three main components i.e. database, model and user interface. Use of ICT technologies in tactical management layer can be beneficial in term of improve quality of decision, improve communication, cost reduction, time saving, etc.

Currently we have different examples of DSS that are already proposed and/or implemented on this issue e.g. DSS for water management in Thomson Reservoir [22], DSS for regional water management in irrigated agriculture [23], water management DSS tool on localized area of watershed scales [24], etc.

D. Strategic management support

As it is discussed in section IV that water strategic management layer of our proposed model is concerns with top management of any water organization; those are responsible for making policies, plan,, specify goals, financial management, building new plants, new product planning, merging and acquit ions, research & development, quality assurance planning etc. [19]

Strategic management can be beneficiated by using ICT technologies which inherit smart and intelligence. These could include intelligent decision support system (IDSS), expert system (ES), Neural Nets, genetic algorithms, constraint problem solving, etc. are used in decision making process.

Some researchers already have proposed some decision making system that can be helpful for top management to make organizational decisions, e.g. Sajjad Ahmed et al. [25] proposed an intelligent decision support system that can be a helpful tool for top management during the different phases of flood management, Sandeep kulshrestha et all. [26] has proposed an expert system for management of water distribution network. This system based on ICT such as artificial intelligence tools, MATLAB, open source GIS and relational database management system, R.M. Faye et al. [27] has proposed an intelligent DSS for irrigation system management, etc.

VI. CONCLUSION

With the motivation of water crises in arid and semi-arid regions of world, we have presented a four layered ICT based model that can be a helpful tool during the decision making process (i.e. structured decision, semi-structured decision, and unstructured decision). ICT is providing it's support in different level of decision making like operational management support, tactical management support and strategic management support. It is concluded that quality of decision can be improved on water challenge or issues if ICT techniques are used during the different phases of managerial decision making.

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