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Editorial

Water Resources Assessment and Management in Drylands

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Abstract: Drylands regions of the world face difficult issues in maintaining water resources to meet current demands which will intensify in the future with population increases, infrastructure development, increased agricultural water demands, and climate change impacts on the hydrologic system. New water resources evaluation and management methods will be needed to assure that water resources in drylands are optimally managed in a sustainable manner. Development of water management and conservation methods is a multi-disciplinary endeavor. Scientists and engineers must collaborate and cooperate with water managers, planners, and politicians to successfully adopt new strategies to manage water not only for humans, but to maintain all aspects of the environment. This particularly applies to drylands regions where resources are already limited and conflicts over water are occurring. Every aspect of the hydrologic cycle needs to be assessed to be able to quantify the available water resources, to monitor natural and anthropogenic changes, and to develop flexible policies and management strategies that can change as conditions dictate. Optimal, sustainable water management is achieved by cooperation and not conflict, thereby necessitating the need for high quality scientific research and input into the process.

Keywords: dryland water resources; managed aquifer recharge; monitoring water resources development; irrigated agriculture; water policies; remote sensing of water resources

1. Introduction

Population and water demand are rapidly growing in the drylands regions of the world. More than 20% of the world's population, at least 1.2 billion, currently live in areas with physical scarcity of water. Arid and semi-arid regions occur in about 30% of the total land area of the Earth and with intensification of desertification caused by global warming and poor land management practices, this percentage is increasing [1]. The future health and well-being of the populations occupying these areas are dependent upon being able to assess the status of the available water resources in real time and to develop and implement policies and management strategies to maintain and grow water supplies.

The papers contained within this Special Issue of *Water*, entitled "Water Resources Assessment and Management in Drylands", describe new methods of water resources assessment and evaluation of drylands hydrology, use of new tools in the implementation of water policies and management strategies, and strategies used to manage agricultural water use which accounts for the largest global water use at over 70% [1]. The papers cover different areas of geography and climatic conditions that highlight a variety of techniques tailored to the unique conditions occurring within regions with differing water use rates and management problems.

2. Contributors

New methods and the application of old ones are required to assess and manage water resources in drylands regions. Thomas *et al.* [2] provide a regional assessment of the impact of rainfall intensity on the recharge rate over a large area of the southwestern United States in their paper entitled "Precipitation Intensity Effects on Groundwater Recharge in the Southwestern United States". They use a combination of the water table fluctuation and master recession curve methods to assess aquifer recharge applied to water level data collected from a large number of observation wells. They apply a double mass curve graphical method to assess the consistency of hydrologic data and an intensity-duration-frequency analysis to develop recharge/precipitation ratios. The techniques applied yield intensity-duration-frequency curves for various rainfall events ranging from three to 48 h in duration. This type of analysis is critical in developing assessments of recharge rates during climate change that may bring changes in duration of rainfall events and drought periods. They emphasize the importance of "characterizing groundwater recharge behaviors over short time periods which are affected by variability in precipitation statistics" to understanding overall recharge for the development of improved groundwater management strategies.

The paper by Jadoon *et al.* [3] entitled "Anthropogenic-induced changes in the mechanism of drylands ephemeral stream recharge, western Saudi Arabia" documents how over-pumping of a shallow aquifer system in drylands can impact recharge. The authors demonstrate that a wadi system in western Saudi Arabia can no longer recharge by conventional infiltration and percolation from a channel during storm events. The natural occurrence of thin clay layers in the unsaturated zone and a pumping-induced water table position more than 10 m below surface no longer allows infiltrated water to reach the water table. Recharge can now occur only around the wadi perimeter where permeable sediments intersect with fractured rocks that receive rainfall. The only water management remedy to make the aquifer system sustainable is to curtail pumping until the water table reaches a level that can be maintained by rainfall recharge and a lesser degree of pumping.

In their paper "Predicting soil infiltration and horizon thickness for a large-scale water balance model in an arid environment", Saito *et al.* [4] use a model calibrated from double-ring infiltrator data, horizon thickness measurements, and vegetation surveys to assess infiltration over a 30 km $\times$ 50 km area of Western Australia. They developed a set of type curves relating cumulative infiltration with time and related the curves to vegetative biomass. They concluded that a strong correlation occurs that relates cumulative infiltration and horizon thickness with biomass and canopy coverage. The predictive equations developed can be used with vegetation distribution maps derived from a combination of field surveys and satellite images to make landscape-scale infiltration estimates.

Re-forestation is a method commonly used to help slow or mitigate desertification. Huang *et al.* [5], in their paper entitled "Simulation of water use dynamics by *Salix* bush in a semi-arid shallow groundwater area of the Chinese Erdos Plateau", evaluate the impacts of using this plant to develop shelterbelts and to return farmland to forest. They used the Hydrus-1D model to evaluate the contributions of groundwater and the plant to evapotranspiration (ET). This model allowed investigation of the heat flux on soil water flux and evaluation of the impact of *Salix* on evapotranspiration. They concluded that the water use of *Salix* is dependent on rainfall infiltration and, in the driest period, more groundwater is used. Also, groundwater contributions to ET were 26.9% and 40.6% with and without heat, which causes groundwater contribution to be over-estimated when thermally-driven water vapor flow is not taken into account.

A major water management strategy in drylands regions is the use of managed aquifer recharge to balance water supply imbalances [6]. In two companion papers, Lopez *et al.* [7] in their paper "Method of relating grain size distribution to hydraulic conductivity in dune sands to assist in assessing managed aquifer recharge projects: Wadi Khulays dune field, western Saudi Arabia" and Mughal *et al.* [8] in their paper "Experimental measurement of diffusive extinction depth and soil moisture gradients in a dune sand aquifer in western Saudi Arabia: Assessment of evaporation loss for design on an MAR system" deal with two important issues in assessing the feasibility and design of Managed Aquifer Recharge (MAR) systems in a hyper-arid region. The location of MAR projects in stabilized dune fields requires screening of large landscape areas to assess potentially feasible sites. Lopez *et al.* [7] developed a mathematical method using grain size distribution data to estimate hydraulic conductivity. Their research documents the changes of hydraulic conductivity and effective porosity with grain size distribution across dunes and allows the development of saturated water storage to be made without the collection of large amounts of data. This research could be coupled to remote sensing methods to allow landscape screening and assessment of potential MAR sites. A critical design aspect for MAR project development in a dune sand aquifer is the prevention of diffusive evaporative loss of water from storage during system operation. Mughal *et al.* [8] determined that the diffusive evaporative extinction depth is about 1 m in dune sands within the size range evaluated by Lopez *et al.* [7]. Therefore, if a MAR system were to be developed, a 1 m cover of sand above the water table position would be sufficient to prevent water loss. They determined that it took 56 days of soil diffusion to reach the extinction depth.

It is necessary to make improvements in water policy and management in arid and semi-arid regions, especially in consideration of natural climatic variability and anthropogenic warming. Kahil *et al.* [9], in their paper "Improving the performance of water policies: Evidence from drought in Spain", use a hydro-economic model that links hydrological, economic and environmental elements to efficiency, sustainability, and equity requirements. They conclude that water pricing and water markets in a river basin located in Spain are an economic means that work well where private markets control water, but not as well where the government controls the resources. The water pricing policy favored by the European Water Framework Directive (WFD) tends to be detrimental to farmers by increasing their losses during drought conditions, whereas stakeholder cooperation lessens the impacts to individuals by spreading losses more equitably.

Yang *et al.* [10], in their paper "Simulation of groundwater-surface water interactions under different land use scenarios in the Bulang Catchment, northwest China", evaluate the current use of water within the vegetative landscape and four proposed changes in the composition of the vegetation. The different land use scenarios were evaluated using a simple calculated water balance, a steady-state groundwater model, and a transient groundwater model. They found that within the current landscape condition, 91% of the precipitation is consumed by crops, leaving 9% to become groundwater recharge which sustains stream discharge in the observed year of record. Four scenarios were evaluated, including (1) the status quo vegetation types; (2) the previous natural state of vegetation which was desert grasses; (3) a change of crop types to dry resistant types; and (4) an optimal landscape consisting of dry resistant crops and desert grasses. The optimal scenario was found to increase groundwater recharge and increase river discharge.

Maintenance of oases is a critical issue in arid regions because these areas commonly have the only source of freshwater, a high diversity of vegetative types, and support rural human populations. Xue *et al.* [11], in their paper "Quantification of environmental flow requirements to support ecosystem services of oasis areas: A case study in Tarim Basin, northwest China", evaluate the necessary environmental flow requirements (EFRs) to maintain riverine ecosystem health, assurance of oasis-desert ecotone and riparian forest stability, and restoration of ecotone groundwater resources. They quantified the environmental flow requirements, divided the flow into those portions needed for maintenance of various ecosystem functions, and assessed the response of environmental flow requirements to natural runoff. The EFRs for maintenance of the oases ecosystem function and groundwater flow restoration were deterred as a percentage of natural river discharge.

Vegetative belts are commonly used to stabilize wind-transported sand in proximity to major highways or other infrastructure. This vegetation is maintained by using the lowest quantity and quality of water possible which can cause salinization and loss of the vegetative buffer. Huang *et al.* [12], in their paper "Spatiotemporal distribution of soil moisture and salinity in the Taklimakan Desert highway shelterbelt", assess the impact of the irrigation on plant growth to prevent salinization and maintenance of the vegetation buffer for the future. They found that the soil texture played an important role in controlling the plant growth and concluded that the currently designed drip irrigation system would allow the contained growth of the plants within the shelterbelt.

Since agriculture is the largest percentage user of water in the world, new irrigation management techniques are quite important in conserving and managing water. Al-Bakri *et al.* [13], in their paper "Geospatial techniques for improved water management in Jordon", used groundwater pumping data, estimated crop consumption data, and Landsat data to develop an irrigation water auditing technique. They applied the method in three water basins in Jordan to assess if the pumping schemes being used are sustainable. Overall, pumping was found to be in excess of sustainable yields by between 144% and 360%. Also, it was found that the monitoring technique could be used to reveal violations of water use practices and could be incorporated into changes in water law in Jordan.

In arid regions crop ET losses consume a considerable amount of irrigation water. Tian *et al.* [14], in their paper "Partitioning of cotton field evapotranspiration under mulched drip irrigation based on a dual crop coefficient model", used the dual crop model SIMDualKC to estimate actual crop ET and basal crop coefficients over a cotton field located in northwestern China. They found that the model used is capable of providing accurate estimates for the cotton crop ET and could be used to establish efficient irrigation schedules. Also, they found that plastic mulch had a positive effect on reducing irrigation water use.

Development of an efficient irrigation schedule can have significant benefits in terms of reducing crop irrigation water use requirements. Yang *et al.* [15], in their paper "Winter irrigation effects in cotton fields in arid inland irrigated areas in the north of the Tarim Basin, China", investigated the use of winter irrigation to assess water and salt management practices. Their research resulted in the development of a specific range of irrigation applications per unit area and a recommendation to delay application to early December. Irrigation application by using several stages, along with the change in time of application delivery, improved salt control.

3. Conclusions

From the information found in this collection of papers, it is apparent that new evaluation methods will be needed to manage water sustainably in drylands regions. The 14 papers contained herein incorporate a diverse group of technologies and methods including field measurements, modeling, and remote sensing to evaluate water resources to resolve regional and local issues in drylands regions. Policies and management strategies that reduce water use, control salinization, maintain ecosystems, and maintain sustainable water use for public water supply, crop irrigation, and industrial use are developed from the types of research information herein presented. The diverse technologies and global geography of applications will be useful to all entities involved in drylands water management.

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