Reducing the Risk of Water Scarcity by Optimizing Water Allocation: A Review

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Abstract

Many basins in arid and semi-arid area are experiencing water scarcity in the last few decades and would face even more in the coming decades. By definition, water scarcity is the shortage in the availability of freshwater relative to water demand. So, scarcity is not only due to long drought and climate change (change in supply side) but also driven by socio-economic factors, e.g. increasing the population, industrialization, inefficient agriculture, etc. (change in demand side).

Although there are different methods available to assess water scarcity, most of them concentrate only on physical aspect. The more recent studies are used integrated assessment of water scarcity risk by considering both physical and social dimensions. Furthermore, some researchers bring environmental variables beside socio-economic factors. Reallocation of water resources is the next step for reducing the risk of water scarcity. A sustainable allocation should consider ecosystem needs, as well as socio-economic requirements.

This paper is a review on the methods of assessing the risk of water scarcity and indicators that using for assessment. Also, this review included the methods of water allocation and showed how water allocation in scarcity could increasing the coping capacity in vulnerable basins.

Keywords: Risk Reduction, Water Scarcity, Resource Allocation.

Introduction

There has been unprecedented growth in human population during the last few decades, leading to increased demand for almost every natural resource. The resource that has perhaps been demanded and exploited the most across the world is fresh water. A variety of factors have contributed to create a fresh water crisis in many parts of the world – economic progress of nations, population growth in many regions of the world, increasing migration from rural to urban population centers, changes in land use, pollution of existing water bodies, and above all, climate change (Davies & Simonovic, 2011).

Increased water requirement for a variety of industrial, commercial and day-to-day activities is exerting stress on a number of ecosystems from river delta regions to water basins. This is inevitably leading to inequitable distributions of water resources and fueling economic, political and humanitarian crises from local to international levels (Haie & Keller, 2014). Projections of future water needs by various agencies seem alarming. For example the United Nations (UN) Food and Agriculture Organization (FAO) has estimated that by 2050 the world will require 70% more food compared to today and 15% of it will be supplied through expansion of cultivation area; the United States Energy Information Administration (EIA) has estimated that demand for electrical power will increase by 50% and 33% of it will be supplied by hydropower; and the UN has estimated that urban population percentage will increase from the present 50% to 69% and 2.8 billion more people will live in urban centers in 2050 compared to today (Cook et al., 2011).

The World Water Assessment Program (WWAP) has estimated that 1.1 billion people do not have access to sufficient drinking water and 2 billion people suffer from water shortages in 40 countries across the world. In addition to the causes mentioned, water shortage is also caused by uneven precipitation both geographically and over time (Wang, et al, 2008). Estimates for global water supply and demand over the next 30 years, using a river basin approach, have shown a serious mismatch. A river basin is considered as the base ecological unit, including inflows, outflows and efficient water usage, and is often analyzed in the literature concerning optimal water usage. Cai & Rosegrant (2009) assessed several sources of demand and supply: on the demand side the factors were irrigation, livestock, domestic, and industrial demand together with environmental requirements; on the supply side the factors were surface reservoirs feeding the main river as well as its tributaries. Availability of total renewable water and relevant environmental and economic policy framework were also assessed for the supply side. Even after using simplifying assumptions, the authors showed that aggregate water storage and supply will fall far short of aggregate demand in many river basins/regions across the world.

In order to alleviate this crisis, management and governance of water resources across the world is becoming increasingly vital to safeguard national interests and also ensure a more equitable future for mankind. A number of governmental panels and study groups have called for increased systemic efficiency and more optimal allocation of water resources – these include the Intergovernmental Panel on Climate Change (IPCC), the UK Secretary of State for Environment & Food and Rural Affairs (SSEFRA), the WWAP, and others (Haie & Keller, 2014).

This paper is a review on the methods of assessing the risk of water scarcity and indicators that using for assessment. Also, this review included the methods of water allocation and showed how water allocation in scarcity could increasing the coping capacity in vulnerable basins.

Water Scarcity and Water Allocation; Definitions

Water scarcity in this context has been defined in many ways. The UN defined it as the aggregate demand level supply or quality of water becomes insufficient to meet user needs (environment was explicitly included within the term “user”). It was acknowledged that scarcity is a social construct and a relative term; it was also, however, pointed out that by the year 2025 absolute water scarcity would affect at least 1.8 billion people across the world (UN-WATER, 2006). Water resource vulnerability (WRV) has been defined through formulae such as the Falkenmark Index (FI) and Criticality Ratio (CR). FI is a social indicator of water stress, defined as the average annual per person availability of water, while CR is a technical indicator, defined as the ratio of average water use to average water availability on an annual basis (Perveen & James, 2011). These two indicators were adopted by the UN as measures of water availability and indicators of water scarcity.

Water stress inevitably leads to water scarcity and to the concept of “water risk”. While water scarcity is simply a lack of water supply to meet adequate human and environmental needs, water risk has been defined in literature as the probability of occurrence of an adverse event that is related to water scarcity. Simulations by several environmental groups have shown that even a 2oC increase in average global temperature will severely increase water scarcity, and therefore water risk, for at least a fifth of the world’s population (Schiermeier, 2013). This risk will be applicable to all stakeholders of the affected population, including industrial and domestic users, and the environment. To bring issues of water scarcity into focus, Speed et al. (2013) distinguished between total available surface water, utilizable water and allocable water. They pointed out that infrastructural and technological developments would determine how much water could be utilized and how much of it could be allocated.

An inalienable part of water allocation is water rights, which was defined as the right of a user to abstract a defined volume of water from a natural water source such as river, lake, aquifer, etc. (Hodgson, 2006). Both water right and water allocations are traded in water markets, as has been noted by Lefebvre et al. (2012).

An important tool in optimal water allocation is coping capacity. It has been defined as the ability of a natural or human system from recover from a stress event or perturbation that could potentially change the system's structure or functionality (Gallopin, 2006). A related definition is that of adaptive capacity, which is associated with a longer time frame and adaptive learning of the system either before or after the occurrence of the transformational event. Adaptive capacity refers to the ability of a system to adapt itself to climate changes and moderate the effects arising from change. It can be said to be the inverse of vulnerability, which measures the extent to which the system is unable to cope with the adverse effects of climate change (IPCC Technical Summary, 2001). Coping capacity and adaptive capacity measurements are important parameters in determining water allocation in a basin. The problem of optimal water resource allocation has been addressed in literature from many different perspectives, including mathematical modeling, economic studies, socio-political framework, etc.

Water Scarcity Indicators

Since the 1990s, a number of indicators have been developed to measure water scarcity or water stress. Choosing indicators depends on basin characteristics as well as national and local policies. The indices are classified according to some criteria, including human water needs, water vulnerability, indicators that take into account ecosystem needs, water footprints and, finally, risk-based indicators. In the human water requirements indicators, the human demand and available water are the key factors, so available water for each person can use for quantity of scarcity (Rijsberman, 2006). The Falkenmark indicator is the most commonly used water stress measure. It is defined as part of the total annual runoff available for human use. According to the use of each person, a regional water situation can be characterized as: no stress, stress, scarcity and absolute scarcity. The threshold of 1,700 m3 and 1000 m3 per person per year is used as a threshold between water stress and scarce areas (Falkenmark, 1989). The Falkenmark Water Stress Index provides a method for distinguishing between climate and human-made water scarcity (Vorosmarty et al., 2005). The index is usually used for country-size valuations. Although this approach is easy to use and understand, the results cannot be extended to smaller scales. Simple thresholds omit significant changes in demand across countries due to cultural, lifestyle, climate and other factors (Rijsberman, 2006). Gleick (1996) developed a water scarcity index as a measure of all water needs to meet basic human needs: drinking water for survival, water for human hygiene, and sufficient household needs for preparing food. These water requirments to meet basic human needs result in a total demand of 50 liters per day. International organizations and water suppliers are advised to treat this basic water requirement as a new threshold to meet these basic requirements indipendent of climate, technology and culture (Gleick, 1996). Falkenmark and Gleick established a "benchmark" of 1,000 square meters per person per annum that accepted by the World Bank (Gleick, 1995; Falkenmark and Widstrand, 1992). In 2000, Ohlsson based on the

Falkenmark indicator, combined the adaptive capacity of a society to consider how economic, technological, or other means affect the total water availability in an area.

Approximately 65% of total freshwater extractions are used for agricultural purposes (FAO, 2010). Countries with limited water availability rely on importing food to compensate for the lack of food production. In 2003, Yang et al. suggested that with good correlation between the amount of available water and the quantity of imported food, and that a model can be developed to help as a water deficit index. From such models, a threshold can be established to provide regional segregation between water scarcity and water-abundant status. Areas below this threshold would lack the water needed for local food production and cereal grains must be imported to compensate for the water deficit. A threshold of 1,700 m3/ (person year) suggested by Falkenmark drops within the calculated threshold by Yang et al. (2003). However, the threshold calculated by this method is dynamic because it can vary with irrigation practices or water use efficiency, whereas the widely cited threshold developed by Falkenmark is a fixed value (Vorosmarty et al., 2005). The model developed by Yang et al. (2003) does not consider the use of nonrenewable groundwater due to lack of systematic data. Therefore, the threshold is somewhat conservative.

Table 1 Indices based on human water requirement

Index	Related Papers
The Falkenmark Indicator	• Falkenmark, 1989 • Vorosmarty et al., 2005 • Rijsberman, 2006
Basic Human Water Requirements	• Gleick, 1993 • Gleick, 1996 • Kalbermatten et al., 1982 • Falkenmark and Widstrand, 1992
The Social Water Stress Index	• Ohlsson, 2000
Water Resources Availability and Cereal Import	• FAO, 2010 • Yang and Zehnder, 2002 • Yang et al., 2003 • Vorosmarty et al., 2005

Shiklomanov and Markova published current and projected water use by regions and sectors in 1987 (Shiklomanov, 1993). Water use was divided into industrial, agricultural and domestic sectors, as well as from reservoir water loss due to evaporation. Population and economic factors were used as the main variables. Raskin et al. (1997) used Shiklomanov's water availability data and modified the approach by substituting water withdrawals in place of water demand. Since water demand varies between societies, cultures, and regions, the term is subjective (Rijsberman, 2006) and using it as a variable can lead to inaccurate assessments. The Water Resources Vulnerability Index, sometimes referred to as the WTA ratio, is then formulated as the ratio of the total annual withdrawals to available water resources. If the annual withdrawal is between 20% and 40% of the annual supply, then a country is considered to be under water scarce and if it exceeds 40%, it is severely scarce (Raskin, et al., 1997). This method and a threshold of 40% are commonly used for water analysis and are called "criticality ratio" - the ratio of water withdrawals by humans to the total amount of renewable water resources (Alcamo et al., 2000). Chavez and Alipaz (2007) proposed that Watershed

Sustainability Index (WSI), which includes hydrology, environment, life and policy, each have parameters pressure, state and response. McNulty et al. (2010) suggested a new hydrological term for the quantitative assessment of the relative magnitude of water supply and demand for the 8-digit USGS Hydrologic Unit Code (HUC) level. The new term is the Water Supply Stress Index (WaSSI), similar to the WTA approach. WaSSI is unique from other water availability measurement tools in that factors in anthropogenic water demand. Thus, areas that may have high annual precipitation levels have high WaSSI values. The International Water Management Institute (IWMI) uses a similar assessment of water scarcity, albeit on a global scale. They led a study that considered the portion of renewable freshwater resources available for human requirements (accounting for existing water infrastructure), with respect to the main water supply. The analysis considered countries as “physically water scarce” when more than 75 percent of river flows are withdrawn for agriculture, industry, and domestic uses. This means that dry areas are not necessarily water scarcity. Indicators of physical water scarcity include: acute environmental degradation, diminishing groundwater, and water allocations that support some sectors over others (Molden 2007). Countries that have sufficient renewable resources and have less than 25 percent of the water from rivers withdrawn for human purposes, but needing to make significant improvements in existing water infrastructure to make such resources available for use, are considered “economically water scarce” (Seckler et al., 1998).

Table 2 Indices based on water resources vulnerability

Index	Related Papers
The Index of Local Relative Water Use and Reuse	• Vorosmarty, et al. 2005
The Watershed Sustainability Index	• Chavez and Alipaz, 2007
The Water Supply Stress Index	• McNulty et al., 2010 • Sun, et al., 2008
Physical and Economical Water Scarcity	• Molden, 2007 • Seckler et al., 1998 • IWMI, 2008

The Dublin Conference in 1991 concluded that “since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems” (ICWE, 1992). Sullivan (2002) noted that depleted freshwater resources are linked to ecosystem degradation, and therefore, any index of water poverty should include the condition of ecosystems that maintain sustainable levels of water availability. The proposed water poverty index incorporates ecosystem productivity, community, human health, and economic welfare (Vorosmartyet al., 2005). However, this approach is critically dependent on the development of standardized weights to be applied to each of the variables previously mentioned. The problem therein lies with the basis of these weights as well as the assumption that the weights hold true for all ecosystems, communities, economies, and cultures. Asheesh (2003) developed a scarcity index that measures the change in the water availability of an area. Population growth rate, water availability, domestic, industrial and ecological water usage, are all incorporated in the water scarcity index (Wsci). A Water Stress Indicator (WSI) developed by Smakhtin, et al. (2005) recognizes environmental water requirements as an important parameter of available freshwater. Mean annual runoff (MAR) is used as a proxy for total water availability, and estimated environmental water requirements (EWR) are expressed as a percentage of long-term mean annual river runoff that should be reserved for environmental purposes.

Table 3 Indices incorporating environmental water requirements

Index	Related Papers
Population Growth Impacts on Water Resource Availability	• Asheesh, 2003
Assessing Water Resource Supplies Using the Water Stress Indicator	• Smakhtin, et al., 2005

Hoekstra (2003) introduced the water footprint concept as an indicator of freshwater use. The indicator parameters include both direct water use by consumer and producers, as well as indirect water use. The water footprint of a product is defined as “the volume of freshwater used to produce the product, measured over the full supply chain.” Hoekstra et al. (2009) developed a method of calculating water scarcity by incorporating green, blue and grey water footprints. Water scarcity is evaluated in terms of green water scarcity and blue water scarcity as well as grey water production. The green water scarcity in a region is calculated as the ratio of the green water footprint in the region and the green water availability. Likewise, the blue water scarcity is the ratio or the blue water footprint to the blue water availability. The new concept of „water pollution level‟ is an indicator of the magnitude of water flow pollution using grey water. Polluted water is considered unusable water and is not included when calculating water resource availability. The overall assessment of water scarcity can be obtained by adding all of the water footprints. The water scarcity can be evaluated at local, river basin, and global levels while incorporating ecological, socio-economical, policy, and human impacts by using this water foot printing method. Ridoutt et al. (2010) compare the carbon and water footprint concepts and suggest the improvement of the water foot printing methodology in order to make it a more useful tool for sustainable analysis. The major impacts of incorporating water consumption into product life cycles were evaluated. It is suggested that the potential damage to freshwater ecosystem quality through reduced environmental flows be the primary focus. Carbon foot printing is acknowledged as an overall simplistic concept, as the emissions from all major greenhouse gasses are additive and expressed as a single figure in the units of carbon dioxide equivalents. Many water footprints are expressed as a single figure (Hoekstra et al., 2009); however, they are not configured using a standardization process (Ridoutt et al., 2010). Furthermore, many published water footprints are a raw collective of all forms of water consumption: blue, green, and even dilution of water (Hoekstra et al., 2009). The authors argue that different kinds of water consumption should not be simply added to produce a total water footprint because the opportunity cost and the impacts associated with each form of freshwater consumption differ. Carbon footprints are also useful tools because they are comparable with the „global warming potential midpoint indicator‟ used in life cycle assessment. In this way, carbon foot printing is a modernized form of LCA. On the other hand, water footprints of different products are not comparable since they vary in social and/or environmental impacts from life cycle water consumption (Ridoutt et al., 2009). Freshwater scarcity is a localized characteristic and the state of water availability for an area cannot be assumed as the overall condition of a larger encompassing region. With carbon foot printing, multiple greenhouse gases combine to form a resulting contribution to global warming regardless of the location where they are produce. However, water foot printing requires regional impact factors. Obviously, the impact of water consumed in a region of water abundance is in no way comparable to water use where scarcity exists.

Table 4 Life cycle assessment (LCA) and water foot print

Index	Related Papers
Water Foot printing	• Hoekstra, 2003 • Hoekstra et al., 2009
A Revised Approach to Water Foot printing	• Ridoutt et al., 2010 • Hoekstra et al., 2009 • Pfister et al., 2009

Babel and Wahid (2008) developed a method for assessing the risk of water scarcity based of DPSIR framework (Driver, Pressure, State, Impact and Response). The risk of the water resources in some river basin in south Asia assessed based on four components of water risk: resource stresses, development pressure, ecological insecurity and management challenges. They used some indicator for each components and normalized them to calculate the risk in the river basins. Gain and Giupponi (2015) assessed the risk of water scarcity in the lower Brahmaputra river basin. They developed a method for assessing risk based on two popular approaches of risk: Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR). In their study they divided component of risk to hazard, exposure and social vulnerability and given some indicators for each components.

Table 5 Water scarcity risk indices

Index	Related Papers
Assessed the risk of Water Scarcity Risk Assessment based on DPSIR framework in four components: (i) resource stresses; (ii) development pressure; (iii) ecological insecurity; (iv) management challenges	• Babel and Wahid, 2008
Water Scarcity Dynamic Risk Assessment	• Gain and Giupponi, 2015

Water Allocation

Perhaps one of the earliest useful models for efficient allocation of water resource was created by Stephenson (1969) when he applied transportation theory to develop a least cost water distribution principle. The model assigned costs to the conveying of water from sources to consumers and expressed infrastructure costs as cost indices. Optimized allocation of water among a large population living in a river basin or similar area and using different transportation methods (such as pipelines, canals, conduits etc.) was shown to be possible. A variant of this treatment is using a linear programing method to optimize several variables subject to real life constraints. This approach was taken by Tingsanchali and Singh (1996) who studied an irrigation area of almost 7000 km2 created by the Mekong-Chi-Mun Trans basin irrigation project in Thailand. Some of the variables considered were soil type, area in each allocated block, dry season cultivation area, etc.; the constraints included reservoir operation policies, minimum storage areas, turbine operation restrictions, etc.; and the objective function was maximization of net benefits to farmers within the irrigation area. Different linear programing models were also investigated by Sethi et al. (2006) in order to determine optimum allocation in a coastal groundwater basin in India. They tried to assess water needs during both the monsoon season, when water is over-abundant, and the winter season, when there is a scarcity of water. The model addressed water collection from several sources, including aquifers, a rain fed area, river water lift systems and surface drain water. A sensitivity analysis of their maximized benefit solution showed that the basin geo-hydrological basin could be sustained for up to 40% deviations from existing water use patterns.

A more realistic, albeit somewhat complicated, modeling technique is the application of multi-scaling methods to the study of resource allocation in basins that have irrigation water uses. This mode is in fact more effective in cases where there is intense competition between agricultural and non-agricultural water requirements, for example in hinterlands with large water bodies, or when water becomes scarce due to poor rainfall patterns or other reasons. Victoria et al. applied such a model to study water management using several water usage requirements – cropping techniques, soil demand, irrigation practices and regulatory restrictions on water usage were considered as agricultural usages and urban, industrial and recreational purposes were considered as non-agricultural usages (2005). The authors attempted to integrate an agricultural field water use model with a river basin water management model in order to create a decision support tool for resource planners. The combined model created by them could not only calculate an effective soil water balance but also had features such as: performing irrigation scheduling to maximize yields; simulate minimum water supply constraints subject to minimum water availability; prepare a water balance schedule without irrigation; and calculate overall irrigation water requirements (Victoria, 2005). One of the strengths of this model was that it could be used to control the risk of variations in rainfall and climatic changes that usually lead to uneven water supply.

Babel et al. (2005) developed an integrated allocation model for decision makers in optimal allocation of limited water from a reservoir to different stockholders considered socio-economic, environmental and technical aspects. The model includes three modules: a reservoir operation module (ROM), an economic analysis module (EAM) and a water allocation module (WAM). The model used some techniques to convert multi-objective problem to single-objective function and optimized it with linear programming.

Neural fuzzy models have been used to simulate many non-linear and dynamic systems, from weather patterns to social phenomena. The optimal water allocation problem was tackled using this model by Abolpour et al. (2007). The authors used an Adaptive Neural Fuzzy Reinforcement Learning (ANFRL) to investigate the impact of various uncertainties in a large lake basin with both inflows and outflows. A number of hydrological factors were considered that might affect water supply and these were given individual weights (reliability of annual water supply, for example, had a weight of 0.42 since the basin was situated in a low rainfall area). Solutions of the model showed an increase of up to 100% in reliability of water supply from the system if certain conditions were met.

An economic and engineering optimization model that had a number of hydrological and management constraints was used to analyze conjunctive use of groundwater and surface water (Khare et al., 2007). The problem studied was actually a part of the river linking project in India, which aims to bring river water to drought prone areas through interlinking canals. The project has diverse stakeholders, from water intensive industries to urban water supplies to meeting agricultural requirements in the study area to a vulnerable ecosystem along the proposed canal route that requires protection. Cost and benefit analysis was performed on the total cost of ownership (capital investment, maintenance and operational costs) while a capital recovery factor (CRF) was used to computed annual cost of water supply per unit. The conjunctive use model developed by the authors was implemented in commercially available optimization software, LINDO 6.1, using a one year planning horizon and a monthly planning period. The study showed that supplementing groundwater with a canal system can drastically improve water allocation even in normally drought prone areas. Similar results for conjunctive water usage including surface and ground water were also obtained by Montazar et al. (2010). The authors studied water allocation for irrigation usage in a semi-arid area having deficit water supply. Using LINGO 10.0 to model a non-linear optimization model with economic benefits and efficiency criteria, the authors were able to find optimal monthly water allocation plans for several different scenarios. The conjunctive water use plans combined several agricultural areas through the use of link canals.

An important aspect of usage of a scarce resource such as fresh water is that conflicts often arise between different stakeholders – water users and the environment itself. To minimize this conflict and achieve sustainable development, agencies such as the UNESCAP have proposed three parameters – equity (fair distribution among all stakeholders, including the environment); efficiency (economic usage that minimizes costs and maximizes benefits); and sustainability (economic usage at present time as well as in the future without harming the environment) (UNESCAP, 2000). A model that incorporates these three parameters is the cooperative water allocation model (CWAM), and this was discussed by Wang et al. (2008). The model proposed by the authors could be applied to a river basin network or a watershed area and consisted of several elements – aquifers, reservoirs, natural or man-made dams, lakes, water inflows and outflows, etc. Pollution of one or more water streams and water treatment plants were also considered, and using a graph theory framework the authors developed scenarios that accounted for the three parameters. The authors successfully applied their model to a real life complex river basin and developed an optimal water allocation plan.

Yang et al. (2011) studied a very large, shallow lake that has recently come under threat in terms of its hydrological character and local ecosystem due to construction of upstream dams and reservoirs as well as large scale withdrawal of water. They prepared a water allocation model to sustain environmental flows into the lake and used genetic adaptive algorithms to optimize the model. They were able to create a management policy for optimal release of water from the lake and calculated monthly water levels that would restore water balance in the area and preserve the lake.

A stochastic programming model to create optimum water allocation for multiple regions from a lake basin was studied by Xie et al. (2013). Uncertainties in water availability were simulated by using probability values and different inflow rates. The authors created several allocation plans based on these inflow rates that corresponded to different benefit levels and system failure risks. They observed that the model could be used to provide economic benefits to sensible water users as well as penalize those that violate allocation policies. The model developed by the authors can be used to create allocation schemes in a complicated scenario with uncertain water supplies.

Table 6 List of publications on optimum water allocation

	Name of Article	Author	Published	Name of Journal	Used Tools	Emphasis
1	Optimum Allocation of Water Resources by Mathematical Programming	Stephenson, D.	1969	Journal of Hydrology	Transportation theory,	Least cost for water distribution
2	Optimum Water Resources Allocation for Mekong-Chi-Mun Trans-basin Irrigation Project	Tingsanchali, T. & Singh, P. R.	1996	Water International	Linear programing method	Maximization of net benefit to farmers within the irrigation area
3	Principles and Practices of Water Allocation among Water-Use Sectors. Water Resources Series.	UNESCAP	2000	Unites Nations	Cooperative Water Allocation Models (CWAM)	Proposed three parameters (equity, efficiency and sustainability) to minimizing conflict and achieve sustainable development
4	Multi-scale modeling for water resources planning and management in rural basins	Victoria, F. B. et al.	2005	Agricultural Water Management	Multi-scaling method; decision support tool	Water allocation competition between agri and non-agri sectors; water scare due to poor rainfall patterns.

						Control the risk of variation in rainfall and climate changes.
5	A model for optimal allocation of water to competing demands.	Babel, M. S., Das Gupata, A, & Nayak, D. K.	2005	Water Resources Management	Linear programing;	Integrated allocation model including three modules: ROM, EAM and WAM
6	Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India	Sethi, L. N., Panda, S. N., & Nayak, M. N.	2006	Agricultural Water Management	Linear programing method	To access water needs during both dry and wet season; maximized benefit
7	Water allocation improvement in river basin using Adaptive Neural Fuzzy Reinforcement Learning approach.	Abolpour, B., Javan, M., & Karamouz, M.	2007	Applied Soft Computing	Adaptive Neural Fuzzy Reinforcement Learning (ANFRL)	Impact of various uncertainties in a large lake basin with both inflows and outflows.
8	Assessment of water resources allocation options: Conjunctive use planning in a link canal command.	Khare D, Jat MK, Deva Sunder V	2007	Resour Conserv Recycl	Cost/benefit analysis; Capital Recovery Factor (CRF) to compute annual cost. Used LINDO 6.1 for optimization.	It analyzed conjunctive use of ground and surface water and considered various stockholders include urban, agriculture and ecosystem
9	Basin-wide cooperative water resources allocation.	Wang, L., Fang, L., & Hipel, K. W.	2008	European Journal of Operational Research	Cooperative Water Allocation Models (CWAM)	Model a complex system with several elements in river network and basin include pollution analysis.
10	Conjunctive Water Use Planning in an Irrigation Command Area.	Montazar, A., Riazi, H., & Behbahani, S. M.	2010	Water Resour. Manage.	Non-linear optimization model, LINGO 10.0	Conjunctive water use plan to combine agricultural area through canals in the semi-arid region.
11	An optimization approach for sustainable release of e-flows for lake restoration and preservation: Model development and a case study of Baiyangdian Lake, China.	Yang, W., Yang, Z., & Qin, Y.	2011	Ecological Modeling	Genetic adaptive algorithms	Preserve the lake by calculating monthly water level and optimizing resources.
12	An inexact two-stage stochastic programming model for water resources management in Nansihu Lake Basin, China.	Xie, Y. L. et al.	2013	Journal of Environmental Management	Stochastic programming model	Uncertainties in water availability; system failure risk

Water Allocation During Scarcity

Optimal allocation of water during conditions of drought was examined by Zhang et al. (2010). The region they studied had 60% or more chances of occurrences of droughts, due to spatial and temporal variations in rainfall as well as poor water holding capacity of the soil. After analyzing land use pattern and crop evapotranspiration, the authors analyzed water balance on the basis of precipitation on the supply side, and water run-off and agricultural requirements on the demand side. They proposed a demand oriented management approach, or water demand management (WDM), that led to higher social benefits. They found that using small storage areas such as pools or bunds and local water allocation plans could greatly mitigate effects of recurring droughts. They also observed that soil water storage was influenced by land use pattern as well as topsoil thickness.

Another study involving frequent, cyclical droughts and flooding suggested a number of mitigation, prevention and adapting strategies (Yan et al., 2012). The authors stressed on collective management of crises, in fact making it the basis of their planning strategies – unification of normal and emergency management as well as shifting from crisis management to collective management to mitigate the effects of droughts. They also suggested zoning of land according to usage and optimizing water conservancy projects. They proposed dynamic control of reservoir water levels and rational allocation of water units for normal usage as well as high value usage. Another water allocation scheme during periods of drought was developed by Chang & Wang (2013). Using the ANFIS model earlier developed by Abolpour et al. (2007), Chang & Wang (2013) analyzed historical hydrological data to simulate inputs to and outputs from the model. They analyzed four reservoir threshold levels corresponding to draught situations designated as precautionary, preliminary, moderate and severe. They observed that these situations where most affected by the reservoir water level, and accordingly formulated optimal allocation plans that would allow managers to maintain corresponding water threshold levels. The drought mitigation plan developed by the authors had three stages – data collection for statistical analysis; identification of drought thresholds and obtaining input-output patterns; and establishment of an inference plan.

The conjunctive use of water was recommended by Daneshmand et al. (2014) as a policy measure for optimum water allocation during periods of drought and also to mitigate other socio-economic factors. The authors considered both water quality and water source (reservoir-aquifer and river-aquifer); while environmental value of the water and socio-economic indices of users were evaluated through net income and employment rate. They were able to create optimal water withdrawal (from river) and release (from reservoir) schedules that would lower soil salinity by 50% and reduce irrigation water availability by only 10% even during a drought.

A drought risk evaluation and analysis of adaptive strategy was carried out by Yan et al. (2014). They observed that drought events are influenced by several factors: natural variations in climate; climate change caused by anthropogenic factors; changes in underlying conditions; and hydraulic engineering regulations brought in by a government. Using these factors, they were able to create drought risk maps for the river basin under study. Based on these maps they were able to identify several general adaptive strategies, including emergency water diversion and reducing water demand, which would help planners cope with the drought.

Policies for conserving ecosystems are often based on the concept of payment for ecosystem services (PES). It has been implemented in developed as well as developing countries, and they aim at creating economic incentives for individual and collective actions that protect and augment natural systems. A PES program was used in an African lake basin by Mulatu et al. (2014) to evaluate a collective action (reforestation) and two individual actions (sustainable agriculture and restoration of land near the lake shores). The authors noted that householders had divergent preferences for the collective and individual programs and that they were more willing to accept compensations for reforestation than to adopt sustainable agricultural practices.

Reduced vulnerability to drought, particularly in dryland regions, requires improved soil and water management (Falkenmark & Rockstrom, 2008; Stringer, 2008). The regulation of water flows in dryland regions have been strongly linked to the proportion of land covered by forest, grassland, and wetland, and maintaining vegetation cover can assist in adaptation to drought (Falkenmark and Rockstrom, 2008). Upland watersheds play a vital role in water regulation. Run-off from mountainous areas in SIDS is often the major supply of water (Mata and Budhooram, 2007), and in the Philippines, watersheds are a critical part of the national economy (Lasco et al., 2008). Often these watersheds are degraded, and their rehabilitation is one adaptation option (MacKinnon, 2007). Planting trees on slope fields, mini-terracing for soil and moisture conservation, and improved pasture management can also complement actions such as building of small-scale infrastructure in water resources management (World Bank, 2008). Natural resource management has been included in the NAPA of the Niger, where water stress is the major issue, and the reduction of pressure on freshwater resources is receiving attention in Brazil where the use of pesticides has impacted water quality in many areas (Hedger and Cacouris, 2008). Soil erosion measures such as conservation tillage can be coupled with rain water harvesting and are activities that can be undertaken by communities (Paavola, 2008). Water management is cross-sectoral, and is particularly relevant to agricultural adaptation.

Coping capacity and adaptive capacity in the social and economic context have been studied by many authors. For example, Yohe and Tol (2002) devised a method to improve coping capacity of a system by focusing on its underlying adaptive capacity determinants. They applied the methodology to the construction of a dam across a river and established two threshold values – the upper threshold was defined as water flow that would result in unacceptable levels of flooding, and the lower threshold was defined as water flow that would disrupt existing irrigation practices. They showed that construction of a series of levees would reduce the frequency of flooding and increase the upper threshold value of the coping range (Yohe and Tol, 2002). They also showed that construction of a dam in most cases allows more uniform water flows in periods of high as well as low rainfall, but it might fail if there is a sudden, significant increase in upstream volume.

Construction of upstream dams to divert water and consequent coping mechanisms and downstream environmental effects in the Ganges River delta ecosystem was examined by Mirza (2005). The author observed that upstream diversion of water resulted in several adverse impacts on the river basin, including downstream water scarcity, increased salinity, deforestation, degradation in agricultural lands and threats to the fishery industry. Areas near the dam construction site were exposed to increased flood threats and erosion of soil. The author noted several adaptation and coping mechanisms in the agricultural and industrial sectors. In case of agriculture, since alternative water sources such as groundwater and seasonal rainfalls were limited, the coping mechanisms were adoption of ground water pumping and sinking of deep-tube wells – this in turn lowered the water table and introduced Arsenic contamination to water. In case of industry, water was either imported on a limited basis or deep-tube wells were sunk, further lowering the water table in the region. One of the most important aspects of the study was observation of adaption by the fragile mangrove ecosystem of the area. The author noted significant deforestation due to increase deposit of silt and also increase in salinity of the soil. Some of the forest areas were replaced by bare or brassy soils.

A practical insight into adaptive capacity was offered by Pahl-Wostl (2009), who stated that governance failures were a main cause of failure in management of scarce resources such as water. The author proposed that a more diversified and dynamic governance approach, which includes different formal and informal institutions as well as state and non-state level actors, can increase adaptive capacity. She also developed a conceptual framework involving a multi-level learning process for better allocation of scarce resources. In the context of water allocation, the author suggested changes in regulatory framework (reframing loop) as well as incorporation of principles of risk management (transforming loop).

In order to minimize government failure, Berman et al. (2012) proposed that institutions can offer critical support while transforming coping capacity to adaptive capacity. They identified four key challenges to the transformation process: lack of empirical data; lack of focus on rural communities; trade-off between coping and adaptive capacities over time; and existence of concealed adaptive capacities in the system. A vulnerability analysis of residents of Mekong Delta, Vietnam, to water hazards showed that it is essential to link disaster risk reduction strategies to climate change adaptation policies especially when there is a creeping change (Birkmann et al., 2012). The authors used a series of feedback loops to create the

MOVE framework to include societal, economic, environmental and institutional vulnerabilities. The framework underlined the fact that different parts of a system under stress may have different coping and adaptive capacities and, therefore, might require different degrees of frequencies of intervention.

Just as Mirza (2005) had earlier witnessed several adaptive mechanisms to hazards such as increasing salinity of soil, Birkmann et al. also noted a number of strategies adopted by the governments as well as residents: construction of dykes and sluice gates; adjustments in crop planting schedules; changes in crops; creation of water reservoirs and increased exploitation of groundwater; migration from affected areas; etc.

Table 7 List of publications on water allocation during scarcity

	Name of Article	Author	Published	Name of Journal	Emphasis
1	Optimal Allocation of Rainfall in the Sichuan Basin, Southwest China.	Zhang, W., Wei, C., & Zhou, J.	2010	Water Resour. Manage.	Water Demand Management (WDM); Optimal allocation of water during conditions of drought in the drought prone area.
2	General framework and key issues concerning integrated strategies for coping with drought and flood in China in a changing environment.	Yan, D.-H., et al.	2012	Nat. Hazards	Dynamic control of reservoir water levels and rational allocation of water; Shift from crisis management to collective management to mitigate the effect of drought.
3	A systematical water allocation scheme for drought mitigation.	Chang, F.-J. & Wang, K.-W.	2013	Journal of Hydrology	Formulate optimal allocation plans that would allow managers to maintain corresponding water threshold levels. The drought mitigation plan include– data collection; identification of drought thresholds and obtaining input-output patterns
4	Mitigating Socio-Economic-Environmental Impacts During Drought Periods by Optimizing the Conjunctive Management of Water Resources.	Daneshmand, F. et al.	2014	Water Resour. Manage.	Optimal water withdrawal and release schedules that would lower soil salinity and reduce irrigation water availability by only 10% even during a drought.
5	Theoretical framework of generalized watershed drought risk evaluation and adaptive strategy based on water resources system.	Yan, D.	2014	Nat. Hazards	Create drought risk maps for the river basin; Identify several adaptive strategies to reducing water demand to cope with the drought.
6	Farm households' preferences for collective and individual actions to improve water-related ecosystem services: The Lake Naivasha basin, Kenya.	Mulatu, D. W., Veen, A. v. d., & Oel, P. R. v.	2014	Ecosystem Services	Apply the concept of payment for Ecosystem Service (PES) to protect natural systems.

Conclusion

Water scarcity is the shortage in the available water relative to water demand. Scarcity occurs due to unfavorable trends of water supply or demand that could have several causes, including climate change, population, and groundwater extraction (Immerzeel and Bierkens, 2012). Water availability changes significantly due to its characteristic nature of high variability in time and space (Postel et al., 1996). Climate change is one of the main driving forces, already affecting the temporal and spatial variability of water availability (Bates et al., 2008, IPCC, 2014, and Stocker et al., 2013). In other hand, many factors including population growth, economic development and land use change affect the changes in water demand (Sophocleous, 2004). The growing demand could make the water resources more scarce, which may affect food security, access to safe drinking water and public health (Taylor, 2009). Many basins are expected to experience water scarcity over the future decades (Beck and Bernauer, 2011). Besides the physical water scarcity, there are also social factors e.g., water management methods, inability to arrange for water facilities, unsustainable economic policies, inequality and poverty that intensify scarcity, which are referred as social scarcity (UNDP, 2006). The valuation of risks related to water scarcity is therefore not limited to physical water supply and demand only. It needs reflection of many socio-economic-environmental factors as well.

Most of previous studies about water scarcity focus only on physical side. The demand-driven scarcity is measured by calculating the ratio of estimated annual freshwater demand to availability. (Vörösmarty et al., 2005). The supply-driven scarcity is instead measured by calculating per person availability of renewable water resources. (Falkenmark et al., 1989). Many of the previous studies (Vörösmarty et al., 2000, Alcamo and Henrichs, 2002, Oki and Kanae, 2006, Islam et al., 2007 and Kummu et al., 2010) used these concepts of water scarcity for their macro-scale assessment comparing water availability and water demand at a yearly time scale. Recently, a few macro-scale studies were carried out at a monthly-scale on past records (van Beek et al., 2011, Hoekstra et al., 2012). Some of recent studies (Beck and Bernauer, 2011 and Gain and Wada, 2014) examine both the effects of climate change and the impacts of water demand on river basins, and provide geographically and seasonally detailed results for water distribution within the watershed. These watershed-scale valuations deliver dynamic information since water management decisions are very often determined by the watershed management authorities.

The combined assessment of water scarcity risk is a need in water resources management and allocation of water resources (Biswas, 2005, WWAP, 2009 and Varis et al., 2012). For measuring watershed-scale water scarcity risks, integration of both physical and social dimensions is required Recently, a few researches considered social, economic and environmental concerns when evaluating water scarcity, but they were limited to the investigation of spatial variations of vulnerability among the basins or sub-basins in a static manner e.g., Babel and Wahid, 2008, Pandey et al., 2009, Pandey et al., 2010, Pandey et al., 2011 and Varis et al., 2012.

It seems that due to the climate changes along with socio-economic rapid changes, a risk-based and dynamic model for projecting future water scarcity and optimal allocation of water resources to cope with scarcity and minimize the risk of it, is required.

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