Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 28 (2020) 51-66 EISSN 2543-5426

Conceptual analysis of urban water management considering climate change scenarios

Afera Halefom[1,*], **Deepak Khare**[2], **Ermias Sisay**[1], **Asirat Teshome**[1], **Tesfa Worku**[2], **Dessalew Tadesse**[3], **Mihret Dananto**[4]

[1]Department of Hydraulic and Water Resources Engineering, Faculty of Technology,
Debre Tabor University, Ethiopia

[2]Department of Water Resources Development and Management,
Indian Institute of Technology Roorkee, Uttarakhand, India

[3]Department of Hydraulic and Water Resources Engineering, University of Gondar, Gondar, Ethiopia

[4]Department of Water Supply and Environmental Engineering, Institute of Technology,
Hawassa University, Hawassa, Ethiopia

*E-mail address: aferahalefom@gmail.com

ABSTRACT

Since the trends of adverse climate change and integrated urban water management have continued in the twenty-first century, governments and other institutions seek reliable predictions as water resource requirements arise. Although uncertainty is never cut off from the need for a probabilistic movement, through current developments in science and the technology of hydrological modeling on urban water management analysis, researchers can improve the ability to create realistic scenarios that will benefit the water sector it adapts to these changes. Model studies on the combined effects of climate change and the water sector have found that the change can be significant, depending on scenarios and the assumptions of climate change, as well as the degree of urban development. In this work, conceptual analysis of urban water management has been applied to several scenarios of climate change in order to obtain new insights and uncertainties.

Keywords**:** urban, water, management, modeling, climate change

(Received 12 November 2019; Accepted 29 November 2019; Date of Publication 01 December 2019)

1. INTRODUCTION

Water is a very important substance and covers 73% of the Earth's surface as oceans, rivers, and lakes. Water has cultural and religious significance in many parts of the globe in terms of blessings, concepts of beautiful views or recreational activities and was fundamental to the development of agriculture and thus civilizations. Water is also used for other purposes, for example, as a coolant for industrial production and power generation, and it is thus it has a wide range of business functions. The Hydro- soil environment contains a huge amount of water (about 1.388 billion cubic kilometers), but about 97% of this amount is saltwater and only 3% is fresh water. Most of this freshwater is in the form of ice and permanent snow cover in Antarctica, Greenland, in other parts of the Arctic and mountain regions. However, 30% of all fresh water is available, as, among others, groundwater, while <1% of the total amount of fresh water on Earth is concentrated in lakes, reservoirs and river systems. Therefore, <1% of the total available water is available for our economic needs, yet at the same time, it is crucial for land-based water ecosystems [1]. Water resources are, therefore, limited in nature, and scarcity is increasing day by day. Thus, optimal utilization and management are needed for sustainable development.

Integrated Urban Water Management (IUWM) describes the practice of management of drinking water, wastewater, and rainwater as components of a basin-wide management plan. It builds on the existing water supply and sanitation considerations within the urban complex part of the total current of Urban Water Management Participation [2]. In developing countries, there is still a significant proportion of the population that has no access to adequate water and sanitation. Herein, Integrated Urban Water Management (IUWM) refers to the practice of management of drinking water, wastewater, and rainwater as links in the resource management structure, within an urban area as a unit of management.

IUWM within a municipal water system be carried out by applying new intervention strategies. Among these are performance evaluation, holistic approaches, systems analysis of water supply, sewage and various system elements such as rainwater and sustainability types [3]. IUWM is commonly seen as a strategy for achieving the goals of a water-sensitive urban design. It attempts to modify the effects of urban development on the natural water cycle, based on premises that are managed through assessing the urban water cycle as a whole. Within these are the efficient use of water resources. Doing so provides not only economic benefits, but also improvements in the social and environmental spheres. One approach is to establish an inner, urban, water cycle by implementing re-use strategies. This urban water cycle loop development requires an understanding of both the natural, pre-development, water management and post-development water balance. Accounting of flows in the pre- and predicting post-development systems is an important step toward limiting the urban impact on the natural water cycle [4].

2. METHODOLOGICAL REVIEW

To evaluate the current urban water management trends under the changing climatic conditions, a review analysis was carried out from research into this new frontier. The research output is based on the relevant research paper, web pages and other related documents on urban water management. The review approach was considered and used to treat certain indicator parameters important for the analysis. Research documents were reviewed during data acquisition and thoroughly checked in the present paper. The collected data includes a summary of performance reports, scientific reviews and project completion reports and others. The specific methods used for the study were tested under each presented case study. The present paper provides a distinction among existing problems of urban water management and puts forward various options for a solution in enabling sustainable development.

2. 1. Urban Water Management

Integrated urban water management (IUWM) is described as the practice of managing freshwater, wastewater, and stormwater as components of a basin-wide management plan. It builds in considerations of the existing water supply and sanitation within an urban settlement by incorporating urban water management in an entire river basin [2]. IUWM within an urban water system can also be conducted by performance assessment of any new intervention strategies by developing a holistic approach that encompasses various system elements and criteria, including sustainability types in which integrations of water system components including water supply, wastewater, and storm-water subsystems would be advantageous [3]. In [5] a discussion is raised of the issues, challenges, and options of urban water management in New Delhi, India. IUWM is commonly seen as a strategy for achieving the goals of water sensitive urban design. Likewise, it seeks to change the impacts of urban development on the natural water cycle, based on the premise of managing the urban water cycle as a whole. Herein, more efficient use of resources can be achieved providing not only economic benefits, but also improved social and environmental outcomes.

As listed in [6], activities under the term IUWM include: the efficiency of water-based services, water supply and fuel efficiency, waste-water and storm-water management, the inclusion of rainwater harvest, the use of alternative water sources, treated water improvement operations and investments to improve and engage communities reflecting their needs and knowledge for water management, the planning and implementation of policies and strategies to facilitate the activities and ways of strengthening the capacities of the previously mentioned concerns.

Some challenges and obstacles for enhanced urban water management exist. These include strong climate fluctuations that are difficult to predict, extreme population density, uneven and scarce water resources, very rapid urbanization, food safety, the destruction of the environment, differences in economic and human development and institutional mismatches.

An interactive two-stage stochastic fuzzy programming approach for the management of water resources is found in [7]. The developed approach was applied for a case study to demonstrate a water resource allocation problem. A number of solutions under various degrees of feasibility were estimated to plan allocation based on cost-effectiveness, satisfaction and the risk of a constraint violation. They concluded that interactive two-stage stochastic fuzzy programming (ITSFP) help the decision-makers to identify desired water-allocation schemes.

A conditional value-at-risk (CVaR) was pointed out in [8] that is based on applying an inexact two-stage stochastic programming (CITSP) model to a water resource allocation problem involving a reservoir and three competing water users. They showed that the CITSP model was able to produce cost-effective decision-allocation schemes, gain insight into the depth of the impact of uncertainty and allow an analysis of the trade-offs between the cost-effectiveness of the system and risk aversion. In comparison with other methods, CITSP reflected several advantages and limitations. It might reveal uncertainty in water resource allocation systems in different formats and help to establish a meaningful link between the predefined water policy, thus establishing associated economic impact and expected loss. CITSP would encounter difficulties, however, when the right side of the model coefficients are very uncertain.

A model potential sources of demand for water resources is found in [9], this includes domestic, irrigation and industrial applications and management tools, including wastewater re-use, water potential for Tabriz SD modeling, supply resources for municipal water systems (groundwater, freshwater and treated wastewater imports) and recycling, inter-basin water transfer, water price and maintenance tools. The model sizes are groundwater volume, surface water quantity, water consumption, lack, and benefits vs. costs as an index for water management. Since this model was created for the use of EAWWC, which has no authority over industrial and agricultural water use, it examines in detail only domestic water requirements. Model Tabriz SD (Fig.1) consists of five major subsystems: (1) the water balance, (2) population, (3) ground and surface water, (4) cost-benefit index based on new legislation and the government subsidies, and (5) back water resources. The model was developed based on data acquired at monthly intervals. Water supply and demand management strategies are used in the model in an attempt to suppress an anticipated increase in water shortage. They concluded that the SD model can be used as an effective decision support system (DSS) for urban water authorities.

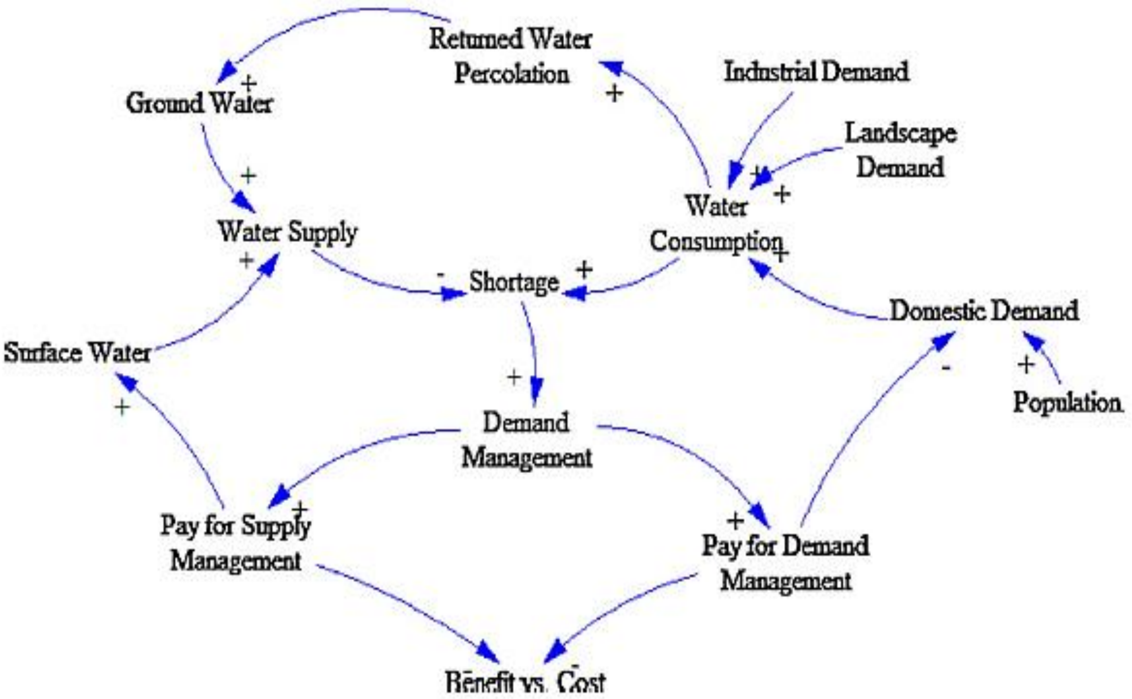

Figure 1. Causal diagram for the Tabriz SD model [9]

An interactive, multi-stage stochastic fuzzy programming approach for optimal water resources referred to as allocation strategies, was applied in [10]. This led to an interactive multi-stage stochastic programming fuzzy (IMSFP) model. They concluded that such a model can be created that allows in-depth scenario analysis of different policies that are associated with different levels of economic sanctions if the promised objectives water allocation are violated, and thus can help DMs practice desired water allocation schemes.

In [11], the read can find an applied new optimization algorithm for urban water planning resource (particle swarm optimization with mutation similarity (PSOMS)). The use of PSOMS was successfully demonstrated on a municipal water problem for Tabriz city of Iran. The problem was formulated with an objective function to maximize cost, enhance water supply and to minimize the risks for the environment. Pipeline capacity, groundwater, demand and the effects of conservation tools were considered as limitations. Use of PSOMS improved the Pareto frontier, and enabled the correct choice of optimum solutions under uncertain conditions. Finally, PSOMS Pareto was developed to obtain optimal solutions. By measuring the variety of solutions, it is shown that the PSOMS approach was useful for comparing the distribution in GA. Therefore, finally, they concluded that improved PSOMS can be applied to solve multi-objective and non-linear urban water resources problems.

The 21st century marks the first time in history that half of the global human population resides in urban areas [12]. The prediction and management of urban water demand are complicated by the close relationship that exists between human and natural systems in urban areas. This relationship results from multiple interactions between microscale (single, household, or packet level) and macroscale (local or regional) processes and patterns. For example, in complex systems, local interactions between individuals over space and time accumulate, producing mesoscale and macroscale variables which, in turn, must be addressed through individual decisions [13, 14]. This embedded nature of social and ecological systems in the area of natural resource management is a major challenge for water management. A separate analysis of these systems is not possible; the complex and often unpredictable responses to various shocks, policies and interventions remain extremely difficult [14, 15].

Currently, water manager demand estimates vary with long-term climate trends and the principle of stationarity (the idea that natural systems vary within a constant variable) [16]. However, climate change leads to uncertainties that can limit the accuracy of this method, as historical trends are no longer reliable for predicting the future climate-sensitive water requirements [16, 17].

The urban water supply is, of course, variable and is also subject to the complex interaction of social and ecological dynamics in the environment. A wide range of researchers and practitioners are, therefore, interested in gaining a better understanding of the complex spatial and temporal patterns of water consumption [18].

Urban water consumption is particularly sensitive to seasonal timescales. Peak water demand tends to occur during periods of hot, dry weather because of the increase in water consumption for the irrigation of lawns and gardens and because of the need to replace the water in swimming pools and other water games as water is lost through evaporation. Seasonal peak water demand is partly physical and partly psychological [19] since human behaviour reacts to both actual and perceived changes in the environment. Both considerations are going to determine how much water the vegetation needs to survive a dry spell.

Climate change projections represent an additional challenge for water requirement modelling due to uncertainty as to the size, timing, and even the direction of changes experienced at a particular location [20]. Therefore, there is a need to assess existing methods that are capable of detecting, isolating and quantifying sources and sizes of uncertainties in water demand analysis. Research in the fields of climate change, remote sensing and land use in changing science and hydrology has led the development and application of methods for quantifying and incorporating uncertainties in model predictions [21].

2. 2. Demand-Side of Urban Water Management

Water is the most important natural resource without which human action and life would be impossible because there is no substitute for water. It is also an integral and important part of the environment. As with water scarcity, water excess can be a danger that can lead to great harm and unhappiness. People consume and conserve water because they cannot survive without it, but at the same time, they have to maintain ecological balance and protect themselves from the dangers of water excess and water limitation. Water is needed for agriculture, industry, household, recreation and the environment. However, water requirement already exceeds the supply in many parts of the world and more and more areas are expected to experience this imbalance shortly. The demand for water for agricultural, household, recreational and environmental protection is growing rapidly due to the ever-growing population, particularly in the developing countries and due to growing awareness of environmental, health and leisure issues. Fig. 2 shows the total water consumption of non-irrigation (household, industrial and livestock) for the different regions of the world [22]. This figure shows that it is in developing countries where there will be a drastic increase in consumption.

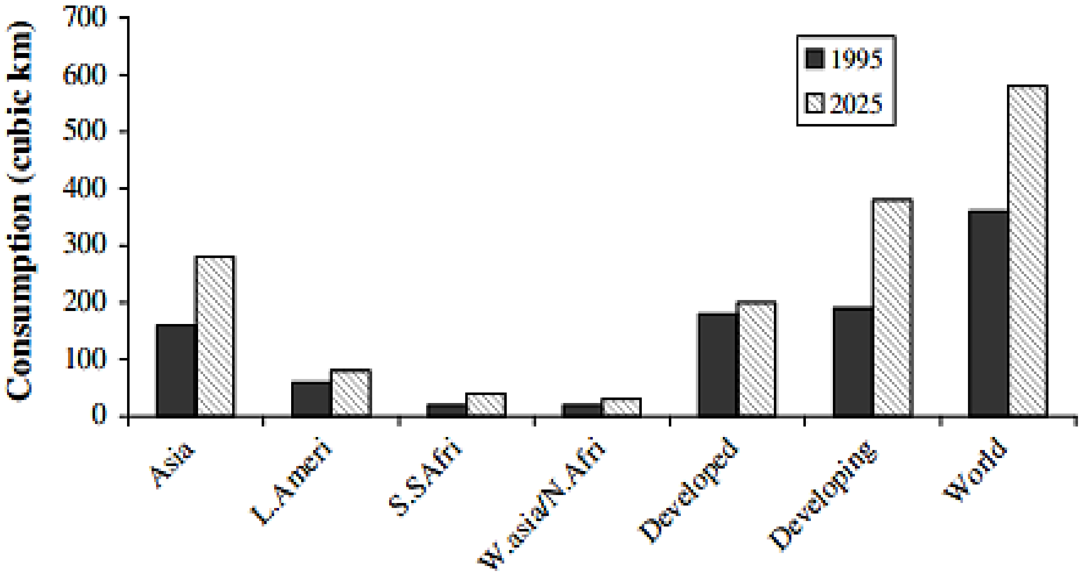

Figure 2. Total non-irrigation water consumption by region [22].

However, rapid population growth and economic expansion have increased beyond the limits of local water supply in some urban areas [23] and water providers can consider demand-side management to balance a stressed system [24, 25]. Demand-side management reduces the requirements of the utilities through implementing a range of water management measures, including promoting water efficiency, promoting indoor and outdoor conservation, setting water prices, recycling water, reusing water and identifying leakages [26].

2. 3. Supply-Side Urban Water Management

The water supply of the cities is crucial not only for the survival of the inhabitants, but also for healthy economic growth. Awareness of the lack of water is evident in many Third World cities, where poor living conditions and restricted access to adequate water and sanitation make a significant contribution to the health impact of the urban poor, which is often the case in inner cities [27]. For example, 85% of the Indian urban population has access to drinking water, but only 20% of this water meets minimum health and safety requirements. It is estimated that by 2050, half of the Indian population will live in urban areas and will face acute water problems [28]. The over-reliance of utilities in municipal water supplies to capital investments in new treatment and distribution networks has been increasingly criticized as the costs for the development of new sources or the expansion of existing sources are becoming ever higher as the most accessible water resources have already been used [27].

The management of water resources requires careful planning to adopt the requirements of human and ecological communities efficiently and sustainably to the limits of limited supply and to seasonal change in global climatic conditions. As population growth, urbanization and climate change are changing the expected timing and availability of water levels, water supply issues can be emphasized in the future [29]. Urban water management strategies have in the past been based on supply management, which increases the availability of water through activities including the development of water infrastructure systems and the acquisition of new sources [29, 30]. This cannot continue in the future.

2. 4. Climate Change

Climate is the description of the long-term pattern of weather in a particular region and period, usually for 30 and more years. It is an averaging of the patterns of weather for a particular region. With the increase in global temperatures, rising sea levels are expected, as well as changes in precipitation patterns and other local climate conditions. Changing regional climates will change forests, crop yields, and water supplies. This, in turn, will also affect human health, regional fauna, and many types of ecosystems. Climate change can be triggered by external factors. These include natural factors such as changes in the flow of energy from the sun, variations in the Earth's orbit and volcanic eruptions, and human activities such as the production of greenhouse gases and land surface modification.

Because of global warming due to the enhanced greenhouse effect, a significant impact on the water cycle is expected, as stated by the Intergovernmental Panel on Climate Change [31]. Accordingly, the water cycle will intensify, with more evaporation and precipitation, but the additional precipitation will be unevenly distributed around the globe. Thus, some parts of the world will experience a significant reduction in rainfall or major changes over time of the wet and dry seasons. Global warming would, hence, cause an increase in floods and droughts. Many aspects of the environment, economy and society are dependent on water resources and changes in water resource base have the potential to greatly affect the quality of the environment, economic development and social well-being [32].

Still, while on the global scale, climate change has potential impact on water resources, climate change is only one of the pressures affecting water resources and their management in the coming years and decades [33, 34]. Generally, there are both supply-side and demand-side pressures. The lowered pressure is climate change driven, but the destruction of the environment through pollution and clear-cutting will reduce the amount of water available for use. Demand pressures are driven by population growth and concentration. Climate change may affect the demand side of the balance sheet and the supply side.

In the paper [35], the authors applied the Integrated Quantity-Quality Model (IQQM) to simulate the effects of climate change on water resources, to simulate the output of a regional climate scenario generator of climate change and the proposed increase in forest area for 2030, to outflows in an Australian pool. Therein, the authors found that a 10% driven increase in forest areas results in a 17% decrease in outflows, while the climate scenarios only reduces runoff by 5%.

According to [16], the principle of stationarity serves as the basis for an argument regarding the central concept in Water Resources Management that climate change will enhance variability in future hydrological events. Currently, water managers make decisions based on the probability density functions that are generated with the observed data on an inverse relationship between the frequency of occurrence and their size. Since climate change is expected to change the average conditions and variability of hydrological conditions, the long-term management decisions on these functions will support highly problematic reality. This is increasingly recognized by water resource managers.

In [36], the authors develop an Integrated Urban Water Management Model of Climate Change (IUWMCC), which is suitable for deriving an optimal distribution of water from multiple sources to meet the requirements of different users. Herein, the impact of climate change has been included in the non-linear mathematical model of resource allocation on behalf of climate change factors. The formulation of this IUWM model includes the definition of objective function and constraints of the various components. The model was designed to incorporate the impact of climate change on water availability. The formulated model is a non-linear mathematical optimization problem; the standard successive linearization technique used was dissolved. The nonlinearity of groundwater pumping costs was then linearized by the successive linearization technique. Finally, they concluded that the model was suitable for use in the search for the optimal integration of different sources in the water supply system capable of enduring several changing climate scenarios. The presented model would be useful for decision-makers/authorities in urban areas in optimal water use planning.

According to [37], the Blue Mountain Water supply in Australia can be used to assess the significant environmental and community factors on water demand. Herein, it was revealed that the Community Intervention factors are the dominant drivers of demand in urban water supply. Moreover, it was found that Community intervention and price behavior combine to play an important role in the management of water demand to maintain the balance between water demand and supply. With regard to climatic factors, the results show that rainfall has little effect on water consumption, while the temperature has a certain impact on water demand. This indicates that future water needs will be affected by climate change especially if there is a rise in temperature. The overall results of the study underline the fact that the intervention of Community factors is more important than environmental factors in the water demand forecast. The results of this study will help water authorities to develop effective demand management strategies and water demand forecast models to achieve sustainable management of water resources. The methodology of this study can be adapted to other water supply systems, to identify the factors in water demand modelling.

The authors of [38] determined the impacts of climate change on water availability indicators in a semi-arid region, by modeling the downscaled output from different Atmosphere-Ocean Coupled General Circulation Models (AOGCMs).

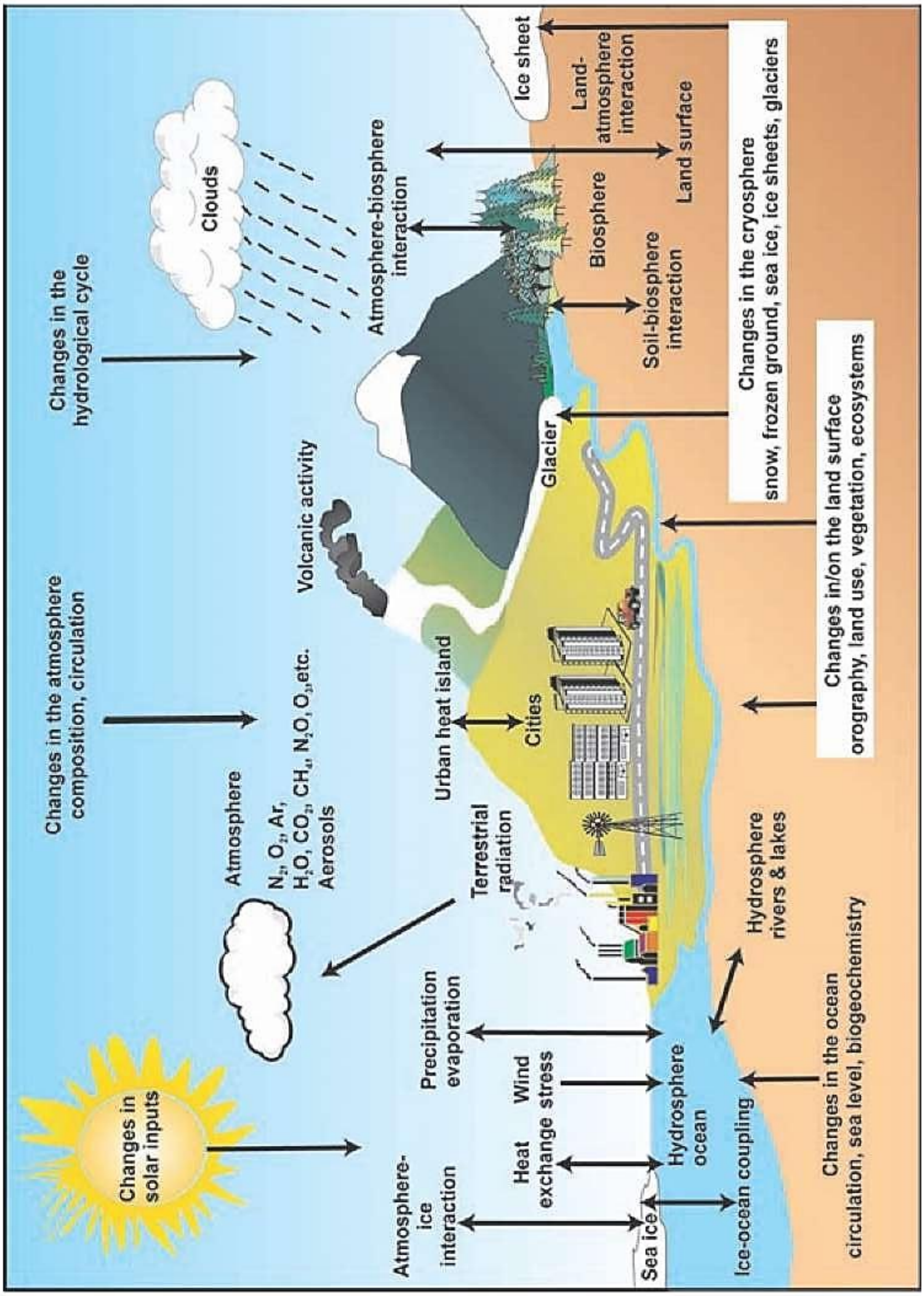

Figure 3. The global climate system, shown is the many interactions among the different components of the climate system and water resources (http://what-when-how.com/climate-change/global-climate-change-and-its-impact-on-urban-areas-urban-climate-processes-trends-and-projections/)

The case study shows that projected simulations can be used as a framework for water managers and decision-makers in the development of water resources planning and adaptation strategies under extreme climate conditions in semiarid regions. The authors describe the scenarios of climate change for the future in the Queretaro River Basin (QRB). Accordingly, it will see both dry and wet periods becoming more frequent, increasing the vulnerability of water resources and endangering its sustainability. In reviewing current water policies in this semi-arid region, the results suggest that the authorities are aware of the impact of climate change on flood risks, but strategies for dealing with scarce water resources require much more attention. The paper concludes that water managers need to review current policies and regulations with a holistic approach that considers not only the growing demand of different users for the water, but also that water resources are unreliable. Moreover, water managers must adopt flexible adaptation strategies to enable planning under various potential scenarios in the long term.

Rising global surface temperature, arctic and land ice loss, sea-level rise, irregular rainfall patterns and an increase in carbon dioxide concentration are the main indicators of climate change. The projected climate change in the upcoming century can have both positive and negative environmental impacts, but the greater the changes and the rate of change in the climate, the more negative they are [39]. The effects of climate change on the frequency and intensity of floods and droughts are likely to intensify changes in water and flood management practices in the 21st century. It is, therefore, necessary for policy-makers and decision-makers to take into account the potential impact of such fluctuations in the future climate, in the management of water resources and plans [40]. The climate of the Earth results from the interaction of many processes in the atmosphere, ocean, land surface and cryosphere. The interactions are complex and extensive (Figure 3) so that quantitative predictions of the impact on the greenhouse gas increase cannot be made simply by simple intuitive thinking. For this reason, computer models have been developed that try to mathematically simulate future climate systems, including the interactions between the system components.

2. 5. Urban Water Management And Climate Change

It is generally acknowledged that the global climate will warm up in the coming decades due to the anthropogenic release of greenhouse gases, largely by fossil fuels [41, 39]. The impact of climate change on the hydrological cycle has the potential to influence not only the natural environment, but also the human environment. To date, most studies have concentrated on the former with little regard for changes in human behavior against climate change, including adjustment and mitigation.

To this end, the Intergovernmental Panel on Climate Change [41] has investigated real impacts on the water system with regard to water resources. Innovations in drainage network technology, for example, have a greater potential to alter wastewater inflows than does climate change. While the direction of climate change is fairly certain, there is great uncertainty surrounding the magnitude of those changes and their impacts [42].

Urban areas are arguably the most modified human environments, and urbanization affects all parts of the hydrological cycle. Herein, land-use change is rapid and has a major impact on the local climate [43, 44]. The removal of the increased permeability, vegetation, and efficient drainage through buried pipes means that high flow peaks and a fast reaction to low precipitation events characterize urban hydrographs. Although there are notable real-world studies of the environmental impacts on water resources [44] For a variety of activities, such as water production and the irrigation of crops, only a few have been concerned with urban hydrology beyond the water supply.

With regard to the aforementioned, [39] notes that the costs of infrastructure for rainwater harvesting and management require long-term planning that incorporates an unknown future. To this end, they state that the best adaptation strategy is one that can be changed if technology and knowledge of climate change are improved. While maintenance and rehabilitation of water supply and drainage systems can be expected over the decades, innovation is underway, but it remains to be seen which strategies will be adopted. Most clearly, there is a current paradigm shift towards urban water use and reuse [45] this has more to do with the philosophy of sustainable development than with climate change. Nevertheless, these strategies are often in the same direction as the adaptation behavior of climate change (Table 1).

Table 1. Overview of urban water management considering climate changes

S.No	Authors	Findings	Limitation
1.	[46]	✓ Control urban microclimate by suburban design features that maximize evapotranspiration, such as vegetated roofs.	✓ Increase in weight load of the roof ✓ Require extra maintenance ✓ Climate change adaptation
2.	[47]	✓ accounts for spatial autocorrelation, ✓ forecast small area water consumption, ✓ improvement over OLS (R2 = 0.64) versus GWR (mean R2 = 0.85) ✓ calculates a set a unique regression equation for each observation defined by geographic coordinates,	✓ availability of geo-tagged data continues is lacking, ✓ each sample has its unique regression, difficult to interpret results for a large sample, ✓ computationally and data-intensive, ✓ a model demonstrates spatial variation
3.	[48]	✓ high ranked intervention strategies in the integrated UWS are those supporting both water supply and stormwater/wastewater subsystems (e.g. rainwater harvesting and greywater recycling schemes)	✓ Stakeholder participation ✓ Sanitation and re-use of wastewater
4.	[18]	✓ model individual household-level consumption data, ✓ visualize and quantify water use patterns at fine spatial scales, ✓ correct for heterogeneity due to spatial autocorrelation, which otherwise causes biased parameter estimation	✓ data usually must be aggregated to protect customer privacy, ✓ water provider service areas do not match administrative boundaries

			✓ no consistency between water providers regarding the collection of water use data
5.	[42]	✓ innovations in drainage network technology have a greater potential to alter wastewater inflows than climate change and that, while the direction of climate change is fairly certain,	✓ Policy response ✓ Ecosystem services consideration

3. CONCLUSIONS

The challenges that will be encountered in the water sector in the upcoming decades is to integrate cross-sectoral cooperation between different actors with regard to water supply management. The intent is to maintain crucial water supply to urban areas whilst also providing the maintenance and / or the high water services for urban residents. This will necessitate rainwater harvesting and management, inter communicating of water engineers with local planners, and meeting residents and taking in their input. The growing implementation of local solutions in rainwater harvesting and management will lead to changes in the city. Thus, the integration of rainwater management at all spatial and temporal scales of urban and rural planning throughout a river basin is required.

Water requirement already exceeds the supply in many parts of the world, and more countries are expected to experience this imbalance shortly. The demand for water for agricultural, household, recreational and environmental protection is growing rapidly due to the ever-growing population, particularly in the developing countries. Such demand goes hand in hand with growing awareness of environmental, health and leisure issues. The new challenge is to develop methods to call for applications such as in toilet flushing or the irrigation of parks and local agriculture that involve the recycling and the use of rainwater in less quality. This process should, together with new sanitary fixture types, lead to new standards in new construction.

Consistent application of all source control options in the management of rainwater will improve the ecological integrity of rivers and streams, reduce flooding in the city and downstream areas, minimize sediment transport and reduce the need for erosion mitigation. Urban hydrology and urban water managers, but as designers of water intake, pipelines and treatment plants, should be key players in a team looking for integrated efforts in sustainable water management, not only in a city or in a catchment area, but also in the entire human environment. The existing vital connections between the water sector and the environmental and economic future of many regions in the developed and developing countries bring the need for increased efforts to enhance the number of hydrologists and water engineers specialized in urban hydrology and trained as integrated water managers. Moreover, the need for research and training for field-level applications in urban water management must be fulfilled and this training must incorporate climate change aspects. Further adaptation policy needs to be evolved for urban water management, thus technical universities around the world should adapt their curricula accordingly – and technical issues cannot be divorced from social, political and economic factors.

References

[1] Duda, A.M. and El-Ashry, M.T., 2000. Addressing the global water and environment crises through integrated approaches to the management of land, water and ecological resources. *Water International,* 25(1), 115-126.

[2] Parkinson, J.N., Goldenfum, J.A. and Tucci, C., 2010. Integrated Urban Water Management: Humid Tropics: UNESCO-IHP. CRC Press.

[3] Behzadian, K; Kapelan, Z (2015). Advantages of integrated and sustainability based assessment for metabolism-based strategic planning of urban water systems. *The science of the Total Environment.* 527-528: 220–231.

[4] Barton, A.B. (2009). Advancing IUWM through an understanding of the urban water balance. Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Retrieved 2009-09-14.

[5] Biswas, R., Khare, D., & Shankar, R. (2007). Water management in Delhi: Issues, challenges and options. *Journal of Indian Water Works Association,* 39*(*2), 89–96.

[6] Integrated urban water management United Nations Environment Programme (UNEP). 2009. pp. 1–2. Retrieved 2009-09-14

[7] Wang S, Huang GH. Interactive two-stage stochastic fuzzy programming for water resources management. *Journal of Environmental Management* 2011; 92: 1986–95.

[8] Shao L. G. X. S. Qin Y. Xu, (2011). A Conditional Value-at-Risk Based Inexact Water Allocation Model. *Water Resour Manage* 25: 2125–2145. DOI 10.1007/s11269-011-9799-9

[9] Zarghami M, Akbariyeh S. System dynamics modeling for complex urban water systems: application to the city of Tabriz, Iran. *Resources, Conservation and Recycling* 2012; 60: 99–106.

[10] Wang S, Huang GH. Identifying optimal water resources allocation strategies through an interactive multi-stage stochastic fuzzy programming approach. *Water Resource Management* 2012; 26: 2015–38.

[11] Zarghami M, Hajykazemian H. Urban water resources planning by using a modified particle swarm optimization algorithm. *Resources, Conservation and Recycling* 2013; 70: 1–8.

[12] United Nations Population Fund (2007), State of the world population 2007: Unleashing the potential of urban growth, report, New York.

[13] Liu, J. (2007), Complexity of coupled human and natural systems, *Ambio*, 317, 1513–1516.

[14] Irwin, E. G., C. Jayaprakash, and D. K. Munroe (2009), Towards a comprehensive framework for modeling urban spatial dynamics, *Landscape Ecol.* 24, 1223–1236, DOI:10.1007/s10980-009-9353-9.

[15] Berkes, F., and C. Folke (2001), Back to the future: Ecosystem dynamics and local knowledge, in Panarchy, edited by L. H. Gunderson and C. S. Holling, pp. 121–146, Island Press, Washington, D. C

[16] Milly, P. C. D., J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D. P. Lettenmaier, and R. J. Stouffer (2008), Stationarity is dead: Whither water management? *Science* 319, 573–574, DOI:10.1126/science.1151915

[17] Gober, P., C. W. Kirkwood, R. C. Balling Jr., A. W. Ellis, and S. Dietrick (2010), Water planning under climatic uncertainty in Phoenix: Why we need a new paradigm, *Ann. Assoc. Am. Geogr.* 100(2), 356–372, DOI: 10.1080/00045601003595420

[18] Lee, S.-J. and E. A. Wentz (2008), Applying Bayesian maximum entropy to extrapolating local-scale water consumption in Maricopa County, Arizona. *Water Resour. Res. 44*, W01401, DOI: 10.1029/2007WR006101.

[19] Zhou, S. L., T. A. McMahon, A. Walton, and J. Lewis (2000), Forecasting daily urban water demand: A case study of Melbourne, *J. Hydrol.* 236, 153–164, DOI:10.1016/S0022-1694(00)00287-0.

[20] Frederick, K. D. (1997), Adapting to climate impacts on the supply and demand for water, *Clim. Change*, 37(1), 141–156, https://doi.org/10.1023/A:1005320504436

[21] Beven, K. (2009), Environmental Modelling: An Uncertain Future? Routledge, New York.

[22] Rosegrant, M.W., Cai, X., Cline, S.A., 2002. Averting an Impending Crisis, Global Water Outlook to 2025, Food Policy Report, International Water Management Institute (IWMI), Colombo, Sri Lanka

[23] Hardberger, A. (2008). From policy to reality: Maximizing urban water conservation in Texas, Environmental Defense Fund, Washington, DC, 1–35.

[24] Brooks, D. B. (2006). An operational definition of water demand management. *Water Resour. Dev.* 22(4), 521–528.

[25] Haarhoff, J and Jacobs, H. (2004b). Application of a residential end-use model for estimating cold and hot water demand, wastewater flow, and salinity. *Water SA*, 30(3), 305–316.

[26] Stiles. G. (1996). Demand-side management, conservation, and efficiency in the use of Africa's water resources. Water Management in Africa and the Middle East: Challenges and opportunities, IDRC, Ottawa

[27] UNESCO, 2003, Water for People Water for Life – The United Nations World Development Report, United Nations Educational, Scientific and Cultural Organisation, New York, USA.

[28] Singh, N., 2000. Tapping traditional systems of resource management, Habitat Debate, UNCHS 6 (3)

[29] Marvin, S., Graham, S., and Guy, S. (1999). Cities, regions and privatized utilities. *Prog Plann.* 51(2), 91-169

[30] Galán, J., Lopez-Paredes, A., and del Olmo, R. (2009). An agent-based model for domestic water management in Valladolid metropolitan area. *Water Resour. Res.* 45(5), 1–17.

[31] IPCC: 1996, Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the IPCC Second Assessment Report.

[32] Alcamo, J., Doyle, P., Kaspar, F., Siebert, S. 1997. Global Change and Global Scenarios of Water Use and Availability: An Application of WaterGAP1.0. University of Kassel, Germany.

[33] Gleick, P.H., 1998. The World's Water: The Biennial Report on Freshwater Resources 1998}1999. Island Press, San Francisco.

[34] Kundu, S., Khare, D., Mondal, A. and Mishra, P.K., 2015. Analysis of spatial and temporal variation in the rainfall trend of Madhya Pradesh, India (1901–2011). *Environmental Earth Sciences*, 73(12), 8197-8216.

[35] Herron, N., Davis, R., and Jones, R. 2002: The effects of large-scale afforestation and climate change on water allocation on the Macquarie River catchment, NSW, Australia. *Journal of Environmental Management* 65, 369–81.

[36] Santosh M. Pingale Mahesh K. Jat and Deepak Khare, Integrated urban water management modeling under climate change scenarios. *Resources Conservation and Recycling* 83: 176-189

[37] Md Mahmudul Haque, Prasanna Egodawatta, Ataur Rahman Ashantha Goonetilleke. Assessing the significance of climate and community factors on urban water demand. *International Journal of Sustainable Built Environment* Volume 4, Issue 2, December 2015, Pages 222-230

[38] M. Herrera-Pantoja, K.M. Hiscock. Projected impacts of climate change on water availability indicators in a semi-arid region of central Mexico. *Environmental Science & Policy* Volume 54, December 2015, Pages 81-89

[39] IPCC: 2001a, Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the IPCC Third Assessment Report.

[40] IPCC: 2001b, Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the IPCC Third Assessment Report.

[41] Annette Semadeni-Davies (2004), urban water management. climate change: impacts on colder wastewater inflows. *Climatic Change* 64: 103–126,

[42] Meena, P.K., Khare, D., Shukla, R. and Mishra, P.K., 2015. Long term trend analysis of megacities in Northern India using rainfall data. Indian Journal of Science and Technology, 8(3), pp.247-253.

[43] Kundu, S., Khare, D., Mondal, A. and Mishra, P.K., 2014. Long term rainfall trend analysis (1871–2011) for the whole of India. In Climate Change and Biodiversity (pp. 45-60). Springer Japan.

[44] Lettenmaier, D. P., Wood, A. W., Palmer, R. N., Wood, E. F., and Stakhiv, E. Z. (1999). Water Resources Implications of Global Warming: A U.S. Regional Perspective. *Clim. Change* 43, 537–579.

[45] Matsui, S., Henze, M., Ho, G., and Otterpohl, R.: 2001, ‘Emerging Paradigms in Water Supply and Sanitation’, in Maksimovi´c, ˇ C. and Tejada-Guibert, J. (eds.), Frontiers in Urban Water Management, IWA Publishing, London.

[46] Mitchell VG, Cleugh HA, Grimmond CSB, Xu J. Linking urban water balance and energy models to analyze urban design options. *Hydrological Processes* Volume 22, Issue 16, 30 July 2008, Pages 2891-2900

[47] Wang S, Huang GH. An interval-parameter two-stage stochastic fuzzy program with type-2 membership functions: an application to water resources management. *Stochastic Environmental Research and Risk Assessment* 2013; 27: 1493–506.

[48] Behzadian, K; Kapelan, Z (2015). Advantages of integrated and sustainability based assessment for metabolism-based strategic planning of urban water systems. *The Science of the Total Environment.* 527-528: 220–231.