ISSN 2348-3156 (Print)
International Journal of Social Science and Humanities Research ISSN 2348-3164 (online)
Vol. 7, Issue 4, pp: (450-457), Month: October - December 2019, Available at: www.researchpublish.com

GLOBAL WATER CRISIS: AN OPERATIONS RESEARCH PERSPECTIVE

[1]SIDDHIKA AGRAWAL, [2]SOHIL JAIN, [3]SOMYA DENGRE, [4]TANISH VYAS, [5]TATHAGATA BAYA

[1,2,3,4,5]Student NMIMS, Anil Surendra Modi School of Commerce, Mumbai Campus

Abstract: **Water usage across the globe is growing at an unprecedented rate which is more than twice the growth rate of Human population. Hence, making conservation of water a necessity for survival. Despite the wide availability of water; its cost, requirement and supply over developed, developing and under-developed nations differs. Seeing the potential and urgent requirement of developing sustainable solutions for the global water crisis, we've tried to integrate this concern with Operations Research. Using various methods of OR like IWMF, LPP and Simplex, we've tried to find ways that ensure efficient storage capacities, optimal allocation, increasing irrigation efficiency, cost of development of new facilities, etc.**

Keywords: **Water Crisis, Operations Research, Linear Programming, IWMF, optimal allocation.**

1. INTRODUCTION

Also known as "Blue Gold", water is the most valuable commodity we have on Earth. It is a resource that distinguishes our planet from all the others we know about

"Water is essential for existence and the well-being of humans. It is the key to sustainable development. Water supports all aspects of human society such as agriculture and industry and simultaneously, is an integral part of the ecosystem." (Cosgrove and Loucks 2015)

Our actions have impaired our environment in irrecoverable ways which in turn had affected the amount, distribution and supply of water. We depend on water not only for life, but also for our economic well-being. Water plays a role in the creation of everything that we produce. It has no substitutes and even though it is renewable in nature there is only a limited amount of it.

70% of Earth is covered with water which is approximately 1400 million km^3. However, 97.5% of this is sea water which is salty leaving us with only 35 million km^3 of fresh water. Of the total amount of fresh water available, around 69% is in the form of ice caps, 30% is underground water reserves and only a percent is present on the surface of the earth.(Guppy & Anderson, 2017)

It is estimated that by 2030 there will be a 40% gap between water demand and water availability. The factors leading to these differences are:

- Global Climate Change
- Increasing Agricultural Waste Demand
- Polluting the available Water Bodies
- High water wastage in households
- Uncontrolled use of bore-wells.
- Degraded eco-systems.

To meet with these challenges and threats, we have made decisions and taken steps to manage our water resources. But these steps and actions have not always helped us become more secure or sustainable. The challenges of our current decade are resource constraints, financial instability, religious conflict, inequalities within and between countries, environmental degradation, successful water management will be a base for ensuring availability and management of water and sanitation for every individual.

In this research paper, we've tried to analyze, focus and suggest various ways in which Operations Research can help fight against a problem that is essential for sustaining human existence.

2. OVERVIEW OF THE INDUSTRY

There are three types of economies in the world: developed, developing and underdeveloped. Water is managed and priced very differently in every one of them. In the following text, one example will be taken from each of the economies to analyse the water industry in every one of the various contexts.

Two of India's most utilized sources of water are surface water and ground water. The availability from surface water and groundwater is 1,869 cubic km. Out of this only 60% can be put to positive uses. (ncert, n.d.)The four major sources of surface water in the country include rivers, lakes, tanks, and ponds. The total replenishable groundwater resources in India are about 432 cubic km. (Studyadda, n.d.) On average a 1 litre water bottle costs $0.20 in India. (Numbeo, n.d.) Due, to these cheap prices, waste of this scarce resource is high in the country.

The US will be taken as an example of a developed economy. Sources of water in the states range from lakes, rivers, aquifers, aqueducts, and reservoirs. The country depends on both surface and underground und water sources. America has over 100,000 lakes, 250,000 rivers and hundreds of reservoirs which are the primary sources wherever they are located. Some cities like Chicago and Detroit rely 100% on rivers and lakes for their freshwater needs. (World Atlas, n.d.) Other cities like Philadelphia get only a percentage of their drinking water from a specific source. Surface sources account for 74% of all water demand in the country. (Umich, n.d.) Allocation of water in the US depends mostly on the location of the household. Whatever source is nearby probably supplies the water to the house. A single bottle of water costs approximately $1.45 in the US.

Ethiopia is one of Africa's and the world's poorest countries. Access to safe drinking water there is amongst the lowest in Africa and the world. Ethiopia has 12 river basins and an estimated average of 1575m per person per year. However, due to large variations in the rainfall and lack of storage, water is not available where and when needed. (Down to Earth, n.d.)The major river in the country is the Blue Nile. But, most of the drinking water comes from ground water sources and not rivers. On average, a 1 litre water bottle costs $0.36 in Ethiopia. (Numbeo, n.d.)This proves that the price of water does not depend on the availability but more on the market forces and the economic condition of the country.

Present Solutions to the Water Crisis:

Pollution is a major contributor to water scarcity in the world today. Water pollution, which is the dumping of harmful substances into clean water systems, is playing a major part in reducing the amount of water available for consumption. Adopting correct sewage management systems, green agricultural practices, industrial waste water treatment processes and implementing sufficient anti-pollution laws and policies are slowly being adapted globally (more in developed economies) and can hugely help curb water pollution.

Artificial groundwater recharging has proven to be one of the most successful methods of solving water scarcity in many areas. The process can be human induced or a natural process including injection wells or spreading basins.

Recent breakthroughs in research and technology have come up with techniques that have made it possible for water considered unfit for consumption, to be made clean and safe for consumption. Some of the most frequently used techniques include Reverse Osmosis, Electrodialysis Reversal (EDR), Desalinization, Nanofiltration, and Solar and UV Filtration.

Rainwater harvesting and water catchment basins are one of the major water sources, specially in the African region due to its low cost and easy implementation process. " A major advantage of this method is that it allows for the conservation of safe drinking water while the harvested rainwater is used to take care of daily chores. This method is also useful in areas where the natural landscape acts as a natural water catchment and favors the collection of rainwater. This makes it possible for rainwater to be harvested in large quantities."

3. RESEARCH OBJECTIVES

1) To understand the importance of Operations Research in Global Water Crisis.

2) To obtain some indication of the extent to which application of these techniques are made to tackle Global Water Crisis.

3) To analyse the milestones achieved in dealing with Global Water Crisis in terms of technology and data science.

4) To identify the limitations of the techniques used in this research paper.

5) To identify and outline the future trends of Operations research in Global Water Crisis.

4. RESEARCH METHODOLOGY

"Operational Research can also be regarded as a scientific approach to the analysis and solution of management problem." (Lyeme 2012).

The development and allocation of water resources includes a long sequence of crucial decisions to take. The water planners face the problem of identifying optimal plans in order to make optimal utilization of the scarce water resources. For our research paper, we have done a secondary research. This research paper is based on the evaluation and understanding of various previously published papers, news articles, and journals.

Some of the techniques highlighted in our research paper include, Linear Programming Model and The Simplex Model. We have also analysed the situation with the help of qualitative measures such as the IWMF (Integrated Water Markets Framework) and water allocation systems (administered/market).

FINDINGS & ANALYSIS

The solution to the Linear programming problem consists of several parts including objective function, the values of real and slack variables, and the solution to the problem of dual LPP.

1) Optimum value of the objective function

"The optimum value of the objective function is used primarily to compare one optimum solution with another." In the project applied, the optimal value gives the minimum annual cost of development of new facilities which in turn will meet the specific demands of water.

2) Optimal allocation

"For a given set of water requirements and constraints, the minimum cost allocation of water in the state is given by the activity levels or values of the variables in the optimal solution."

The reason for this is the storage problems. They are underutilised due to inadequate allocation and needs to be utilised up to two thirds a year.

Other Results

1) Effect of changing irrigation efficiency

This effect can be seen by observing the changing agricultural return flow. These changes occur due to practices such as land levelling, canal and ditch lining, pipeline installations, sprinkler irrigation, and trickier irrigation.

2) Effect of changing groundwater policy

"There are two rather obvious groundwater policy changes which might be investigated: 1) no groundwater recharge allowed, and 2) no further development of the groundwater allowed."

3) Effect of changing growth projections

"The effect of changing the growth projections to those of the earlier estimate can be determined by changing the increments used in parameterizing."

Our objective here is to display the true potential of what water markets can do and how they operate in different environments/legal frameworks. To come up with a *qualitative, ordinal rank of the institutional foundations of water* *markets and their performance in terms of integrated water resource management.* This framework is designed to provide subjective rankings and evidence to back the hypotheses. *The integrated water markets framework (IWMF) we develop is based on a four-point scale in three categories: institutional foundations, economic efficiency, and environmental sustainability.* Qualitative criteria are derived from secondary/primary data, however there are also economic efficiency criteria are quantitative.

An ideal water allocation model includes 2 types of systems – Administered System (AS) & Market-Based System (MS). Transparency of information and distribution of resources is needed to fulfil the optimization goals. We have used linear programming to spark the water market to maximise net returns and minimise *amount of energy to be globally generated and firm power to be globally guaranteed, minimize the total cost* subject to continuity, reservoir, irrigation, hydro-electrical, artificial effluents and navigation constraints. We have also derived the per user maximum water benefit and designed an allocation model to maximise the minimum ratio for each stakeholder's profit to its highest possible benefit.

Alternative trends and demand levels for water are the source data. Additional surface and groundwater is not being used currently and the projected demands were then minimized by solving a simplex model of the economic hydrologic-physical system. "The constraints in the model include the following categories: groundwater and surface water availabilities in the various areas, water requirements of all kinds (including municipal and industrial, wetlands, and agriculture), present and potential reservoir storage, evaporation losses from storage, return flows, free groundwater for wetlands, groundwater recharge limits, inter-basin water transfer limits, required outflows and other physical limits on the system." (Clyde, 1971) This method is now all inclusive and all the content has been included in the analysis.

Simplex method allows the full cost structure to be considered instead of just portions of the development cost. The objective function's cost coefficient and appropriate constraints can be made as thorough as possible with the given time and scarce resources. The final objective here was to develop a water planning related methodology over performing a specific plan and little focus was spent on defining costs precisely.

MS approach takes complete account of the process for each water user under specific trading rules in the water market, unless AS approach. As a result, a major influential factor for water allocation is transaction rules. Forces of demand supply ultimately determine the tradeable rights and transaction prices. Developing these water market mechanisms to make sure that this reallocation process is as efficient as possible is of utmost importance. Bulletin boards and sealed double auctions are the 2 techniques used by water exchanges under MS. The first method is a comparatively logical transaction method as all traders are required to make decisions on incomplete information. Buyers/sellers are required to post offers and requests like on a digital platform. Just like a stock market, trade transactions are executed by finding suitable and matching offers with the right price and quantity by individuals.

Both qualitative and quantitative frameworks can be used to compare different water markets. There are three main categories, institutional foundations, economic efficiency and environmental sustainability. This framework would help show which markets could presently contribute to integrated water resource management, criteria that helps pin these markets, and which areas could use some development.

The framework is used to identify strengths/limitations in five water markets: Australia‘s Murray-Darling Basin, Chile, China, South Africa, and the western United States. All these locations are semi-arid and face, to a greater or lesser extent, an expectation of reduced water availability associated with climate change. All countries, however, differ substantially in terms of their history of water use and reform and in terms of their legal and institutional frameworks. In general, it's presently believed that water rights transaction is effective to solve problem of water resource distribution in context of scarcity.

5. LITERATURE REVIEW

With the growing population and rising demands for water, researchers have expressed a number of challenges that economies and environment will face in future. Lisa Guppy in her paper states that 'This limited resource will need to support a projected population of 9.7 billion in 2050 and an estimated 3.9 billion will live in severely water-stressed river basins.' It is also suggested that more than 3 times of the current capital investment is required to achieve the SDGs on WASH. Similar concerns have been raised by the UN Water in their WWDR4 which also highlighted the need for proper infrastructure at the least possible cost. In his paper, Prashant Mehta has written about Southern Asia and Sub Saharan

Africa as areas with high water scarcity due to underdeveloped water infrastructure, high vulnerability to drought, and difficult access to reliable water supplies.

Characteristics of Operation Research:

I. **System Orientation of Operation Research** - One of the most characteristics is that it is concerned with the problem as a whole. This implies that an activity by any part of the organisation has an underlying impact on the activity of every organisation.

II. **Application of Scientific Method -** Some problems in Operations research require the use of scientific methods. It refers to real life experiments rather than laboratory experiments like physics or biology. (No company can risk failure in order to be successful).

III. **Human Factor -** Human aspect is one of the most if not the most important aspect of Operations research. Without the help of human resources Operations research study is incomplete.

The rise of water crisis awareness in the recent times has been framed by narratives about 'The End of 'Free and Cheap' Water'. Curmi believes that two of the most important solutions are investing in well-needed infrastructure and water pricing. Martina Ricato and Tara Lohan wrote on similar lines as Curmi. In his paper, Sjödin, J. has analyzed the impact of water pricing policy adopted by Australia and South Africa. Lizhen Wang in his research article used the administered and market-based system to build a multi-agent and multi-objective optimal allocation model, to direct the distribution of water resources under an AS in the Shiyang River Basin.

In response to this popular discourse of water scarcity, a number of researchers have devised ways to minimize the problem using OR. P.M. Jacovkis formulated a LP model for the use of analysis and planning of a multiobjective water resources system. This model has been used integrated with other models for two real cases in Argentina and has shown positive results. Calvin G Cylde (1971) developed a model for optimal allocation of water in the state of Utah using LP. Cylde set the objective function to minimize the cost and identified 204 constraints with 338 variables. The model generated the optimum solution including both the optimal allocation of water resources and the shadow prices of these resources for Utah. Uri Shamif in his paper mentions about a similar model of LP developed by M Chayat to develop a policy of water allocation under conditions of scarcity. The objective function was set to maximize total income attributable to water and constraints reflected the availability of water and of other resources. The results were viewed as a policy for minimizing the damages due to curtailment of supplies. Dr. Prakash Chandra Swain worked along the similar lines in his research paper and used LPP and Simplex method to devise a solution. The CALVIN model was developed to examine integrated water management and water markets for California. It is an economic-engineering optimization model based on generalized network flow programming using the HEC-PRM reservoir system optimization software

6. FINDINGS

Evaluation of the methods

It is clear that the first objective of the study is a mathematical model with appropriate constraints which has been formulated for a least cost allocation of water model. It is comprehensive and inclusive of areas and sources of water.

In the second objective, the linear programming model was solved with an appropriate algorithm which is used to determine the optimal water allocation. While this study was good initially, it was not inclusive of the investigation which can be used to determine the optimal allocation under many other sets of conditions.

The third objective of the study was to demonstrate how various operational rules, legal policies and how political and social objectives might have an impact on the water allocation.

From a qualitative perspective, when you implement an integrated water markets framework, it provides 4 ordinal rankings:

1. The highest (three drops) – criteria to be nearly or fully operational
2. Two drops – criteria is most likely satisfied but some additional development might be needed
3. One drop – criteria is partially satisfied and significant development is needed

4. The lowest (X) – criteria is missing or is not operational

The IWMF model is designed to:

1. Benchmark different water markets
2. Track the performance of water markets over time
3. Identify ways in which water markets might be reformed to achieve desired goals

The criteria needs to be carefully specified and streamlined such that the correlation between criteria does not give rise to inter-related issues of water governance.

This integrated water market framework model has been applied in 5 markets:

1. Australia‘s Murray-Darling Basin
2. Chile (the Limarí Valley)
3. China
4. South Africa
5. The western United States

Australia‘s Murray-Darling Basin has developed considerably well since factors such as volume traded has increased by over 20% in both Murray and Darling inclusive of temporary and permanent water rights. Historically, water markets have well developed in terms of the volume traded as a proportion of the entitlements available. *Total volume of trade in the Murray-Darling Basin worth over $1.8 billion in 2009 and estimated gains from trade in a dry year around $495 million.* Prices are fairly consistent in this market too.

7. CONCLUSIONS

The root of the problem here is not a lack of water, it's non-optimal management of the water we have. Humans have a history of constructing concrete jungles, irrigating fields, designing infrastructure and generating energy on the assumption that we have access to unlimited water.

Now, billions face water shortages every year, millions suffer diseases due to lack of sanitation. Surface water is clogged with industrial waste and groundwater availability has been dropping at a rate faster than ever.

There are several independent solutions in the industry, however the ideal scenario would consist of several solutions being integrated simultaneously to account for both qualitative and quantitative factors at the same time and ensure that the problem is being addressed.

First, charge the true price of water instead of selling it at highly undervalued prices due to its essential nature. This can be done with water markets, where water rights for specific volumes of water are sold/leased to facilitate water reallocation and conservation. For example, in a developed economy, if price of water is low, a farmer might tend to waste some of it, however if a market exists, the farmer would choose to save and resell the resource. This would then be bought for industrial uses and applications and move higher up in the value chain. It also forms part of the Market-Based System (MS) for water allocation.

Secondly, there is a desperate need for better governance of water bodies and optimal allocation of resources. By implementing more integrated water management systems, like Australia's Murray-Darling River basin, it's allowed for much better monitoring and management of water resources. Operations research techniques like Simplex and Linear Programming are tools which aid in implementing optimal allocation when all quantitative factors can be factored in as constraints to the objective function. This can also be considered as the Administered System (AS).

Third, a revamp in water treatment and sanitation infrastructure of a country. A better pricing scheme would involve two important components, he explains. The first is a fixed charge for all users to cover operational costs of the system; the second is a tiered rate structure in which users pay more when they use more. Several analysis and economic surveys show that a better pricing model for water encourages users to conserve more water and manage demand for water, rather than directly restricting supply/usage of water.

LIMITATIONS

- As research was secondary, specific data could not be collected which is directly related to the topic.
- There was a time limit set for the research to be done.
- Lack of quantity and quality of data available for the team to analyse.
- The number of team members was low.
- Lack of free online articles available for the topic.

REFERENCES

[1] Bessadi, S. Y. (2019, July 19). *How technology can help end the global water crisis*. Retrieved from World Economic Forum: https://www.weforum.org/agenda/2019/07/how-technology-can-help-end-the-global-water-crisis

[2] Clyde, C. G. (1971). *Application of Operations Research Techniques for Allocation of Water Resources in Utah.* Utah: Utah State University Digital Commons @USU.

[3] Cosgrove, W. J., & Loucks, D. P. (2015). Water management: Current and future challenges andresearch directions. *AGU Publications*, 4823-4839.

[4] Curmi, E., Morse, E. L., Buiter, W., Doshi, A., Fenner, D. R., Knatchbull-Hugessen, A., . . . Yuen, A. (2017, April 1). *Solutions for a Global Water Crisis*. Retrieved from Citi Global Perspectives & Solutions: https://www.citivelocity.com/citigps/solutions-global-water-crisis/

[5] Giraldo, L., Cortignani, R., & Dono, G. (2014). Simulating Volumetric Pricing for Irrigation Water Operational Cost Recovery under Complete and Perfect Information. *MDPI*, 1204-1221.

[6] Guppy, L., & Anderson, K. (2017). *Global Water Crisis: The Facts.* Hamilton: United Nations University - Institute for Water, Environment and Health.

[7] Jacovkis, P. M., Gradowczyk, H., Freisztav, A. M., & Tabak, E. G. (1989). *A Linear Programming Approach to Water-Resources Optimization* . Buenos Aires: ZOR.

[8] Kondili, E., & Kaldellis, J. K. (2009). *OPERATIONS RESEARCH METHODS IN WATER SYSTEMS.* Athens: TEI of Piraeus.

[9] Lund, J. R. (2008). *Optimization Modelling in Water Resource Systems and Markets* . Davis: University of California - Davis.

[10] Mehta, P. (2012). *Impending water crisis in India and comparing clean water standards among developing and developed nations.* Jodhpur: Scholars Research Library .

[11] R. Quentin Grafton, G. L. (2011). *An Integrated Assessment of Water Markets: A Cross-Country Comparison.* Acton: ANU.

[12] Revelator, T. (2019, March 11). *The Global Water Crisis May Have a Surprising Solution*. Retrieved from EcoWatch: https://www.ecowatch.com/global-water-crisis-2631317903.html

[13] Ricato, M. (2019). *Water Pricing - General.*

[14] Rinaudo, J.-D. (2015). *Long-Term Water Demand Forecasting.* Montpellier: HAL Archives-Ouvertes.

[15] Roozbahani, R. (2014). *USE OF ADVANCED OPERATIONS RESEARCH METHODS FOR OPTIMAL WATER ALLOCATION MODELLING.* Melbourne: RMIT University.

[16] Sawe, B. E. (2017, April 25). *Where Does Most Of The Drinking Water In The US Come From?* Retrieved from World Atlas: https://www.worldatlas.com/articles/where-does-most-of-the-drinking-water-in-the-us-come-from.html

[17] Shamir, U. (1980). *Application of operations research in Israel's water sector.* Haifa: Technion-lsrael institute of Technology.

[18] Sjödin, J., Zaeske, A., & Joyce, J. (2016). *Pricing instruments for sustainable water management.* Retrieved from SIWI: https://www.siwi.org/wp-content/uploads/2016/07/Pricing-instruments-for-sustainable-water-management-DIGITAL-Final-1.pdf

[19] Swain, D. P. (2016). *WATER RESOURCES SYSTEMS PLANNING & MANAGEMENT.* Burla: Veer Surendra Sai University of Technology.

[20] Wang, L., Zhao, Y., Huang, Y., Wang, J., Li, H., Zha, J., . . . Jiang, S. (2019). *Optimal Water Allocation Based on Water Rights Transaction Models with Administered and Market-Based Systems: A Case Study of Shiyang River Basin, China.* Shanghai: MDPI.

[21] Water Resources. (2015).

[22] Werft, M. (2016, 9 2). *Could Fighting Over Water Actually Cause WWIII?* Retrieved from Global Citizen: https://www.globalcitizen.org/en/content/water-scarcity-wwiii-war/

[23] Werft, M. (2016, 9 1). *Is Desalination the Answer to Water Shortages?* Retrieved from Global Citizen: https://www.globalcitizen.org/en/content/is-desalination-the-answer-to-water-shortages/

[24] Wright, J. D. (2015). Water Wars. In J. D. Wright, *International Encyclopedia of the Social & Behavioral Sciences* (pp. 443-447). Oxford: Elsevier.

[25] Zilberman, D., & Schoengold, K. (n.d.). *The Use of Pricing and Markets for Water Allocation.*