
WORKING PAPER 201/2020

**UNDERSTANDING THE WATER CRISIS IN INDIA:
APPLICATION OF CAUSAL LOOP MODELLING TO
EXAMINE THE ENVIRONMENT-ECONOMY
INTERLINKAGE ACROSS SECTORS**

**Ashwin Ram Sridharan
Zareena Begum Irfan**



MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

August 2020

*Understanding the Water Crisis in India:
Application of Causal Loop Modelling to
Examine the Environment-Economy
Interlinkage across Sectors*

Ashwin Ram Sridharan
Madras School of Economics

and

Zareena Begum Irfan
(Corresponding author)
Madras School of Economics
zareena@mse.ac.in

WORKING PAPER 201/2020

**MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India**

August 2020

Phone: 2230 0304/2230 0307/2235 2157

Fax: 2235 4847/2235 2155

Email : info@mse.ac.in

Price : Rs. 35

Website: www.mse.ac.in

Understanding the Water Crisis in India: Application of Causal Loop Modelling to Examine the Environment-Economy Interlinkage across Sectors

Ashwin Ram Sridharan and Zareena Begum Irfan

Abstract

Water is considered as a wicked problem and hence relying on a linear and reductionist approach may no longer seems relevant in solving such complex systems. This paper adopts a system thinking principle to understand various water economy and environment challenges across sectors. System thinking has been evolving and increasingly being used to understand Complex Dynamic Systems. Based on a systematic review of literature, the present study has developed a Causal Loop Diagram (CLD) capturing key variables pertaining to quality aspects of water crisis. CLD are believed to create a broader and holistic understanding of the water management challenges by clearly exhibiting the relationship between the key variables. The CLD highlight the existing water pollution related challenges in India and proposes a pathway for sustainable management of water resources across agriculture, industry and domestic sectors. Though this paper discusses CLD based on Indian scenario, it holds good for any developing countries context.

Key words: *Water Security, Water Scarcity, Water Use Efficiency, System Thinking, Causal Loop Diagrams*

JEL Codes: *Q20, Q25, Q28, Q51, Q53*

Acknowledgement

The present paper is a part of the PhD thesis of the first author. The authors are grateful to the host institute for providing the infrastructure facilities to carry out the research. The present research study was conducted using the fund provided by the "Dr. A.C. Muthiah and Dr. Devaki Muthiah Research Fellowship" awarded by the parent institute to the research scholar. We would also like to thank the participants and the committee of the International Conference on Sustainable Urban Development, Resource Conservation, Food Security (August 6 to 8, 2020) at Bearys Institute of Technology, Mangalore in association with Bearys Enviro-Architecture Design School, Mangalore for their valuable feedback at the conference.

**Ashwin Ram Sridharan
Zareena Begum Irfan**

INTRODUCTION

Wicked problems are complex issues that are interdependent and are based on various interconnected factors which are primarily difficult to entangle and solve. The term wicked problem was first used by design theorists Horst Rittel and Melvin Webber in 1973 to define and address complex social policy problems. For instance, most of the environment related issues including the present global water crisis is considered to be a wicked problem that seeks immediate attention of government across all levels (FitzGibbon and Mensah, 2012; Streefland and Krozer, 2018). As wicked problems are very complex there are no single policies that can effectively address such issues (Rittel and Webber, 1973). Therefore, system dynamics principles have been widely used to understand and address wicked problems and influence public policies to a large extent.

System thinking has its roots in mental models and has been evolving and increasingly being used to understand Complex Dynamic Systems (CDS) since 1960s (Haraldsson, 2004). The concept evolved taking cognizance of the fact that many of the challenges across different spectrum of the real world are non linear having significant feedback process and time delays. As the real world problems are highly dynamic and complex with greater degree of uncertainty relying on traditional linear and reductionist approach seems no longer relevant to understand CDS (Kotir *et. al.*, 2017). System thinking can be viewed as a language of communicating the various processes and interrelationship of complex system in a nutshell so as to aid effective decision making process.

METHODOLOGY

Based on a systematic review of literature the present study has developed a Causal Loop Diagram (CLD) capturing the key variables pertaining to quality aspects of water sector. The CLD is believed to create a broader and holistic understanding of the water management challenges by clearly exhibiting the relationship between key variables.

The CLD understands the water quality and pollution aspects of water crisis and is broadly termed as water economy and environment model. The proposed CLD serve as a decision making tool to understand the challenges of Integrated Water Resources Management (IWRM). The CLD highlights the existing water related challenges in India and proposes a pathway for sustainable management of water resources across agriculture, industry and domestic sectors.

CLD is the one of the most important and widely used tool of system dynamics to understand the relation between different variables which affects the system behavior (Kim, 1994). CLDs are connected by nodes and edges and are unique as they explicitly take into account the feedback process and time delays of variables. If a variable changes in direct proportion in relation to another variable, it is indicated by s/+ representing a reinforcing process and if a variable changes in inverse proportion in relation to another variable, it is indicated by o/- representing a balancing process. Reinforcing process multiplies and amplifies the change in one direction while balancing process breaks the chain and acts as a counterproductive to move in opposite direction which is mostly goal seeking. Generally, there are two kinds of feedback loop in CLD; reinforcing loop and balancing loop. Depending on the problem and narrative, a particular CLD can either have only balancing loop or reinforcing loop. It is also possible for a particular CLD to have n number of reinforcing and balancing loops. Therefore, a system behavior is influenced by the complex interactions of the variables between these loops.

DISCUSSION

Water Economy and Environment Model

Water is an integral part of the ecosystem for both economic and non economic activities to flourish in a rapidly changing global economy. Despite water being an important source for economic development, climate change variability exacerbated by exponential population growth,

urbanization and industrialization are the major drivers of deteriorating water quality and freshwater availability and thus water pollution is one of the complex environmental challenges facing LDCs like India. The present water crisis in India is not only restricted to the lack of adequate water but more of failure to provide access to clean water of acceptable quality leaving India rank 120 among 122 nations in terms of poor water quality (NITI AAYOG, 2018). Access to adequate clean water of minimum standard is essential for sustainable economic growth but with increasing level of water pollution across major water bodies, poor water quality is hampering economic development, sustainable agriculture production and public health and wellbeing.

Cities across India are densely populated with growing number of residential and commercial complexes generating huge amount of sewage and wastewater affecting the environment and quality of groundwater and surface water bodies (Murthy and Kumar, 2011). In addition to domestic sewage, a large number of small scale industrial clusters and hospitals in cities discharge wastes directly to nearby water bodies (Murthy and Kumar, 2011). Large scale industries and nuclear and thermal power plants release toxic waste and other heavy metals leading to environmental degradation and harmful effects on public health (Adejumoke *et. al.*, 2018) (*Figure 1, Loops B1 and B3*). About 21 percent of diseases in India are water related, with rising levels of pollution, it is estimated that health costs will rise with increase in out of pocket health expenditure affecting the poor the most (Agapitova *et. al.*, 2017). This will further create pressure on the government to expand health infrastructure which possess significant challenges. It will be rational and cost effective for the government to penalize polluters through stringent enforcements of law and regulations than continue investing in health infrastructure.

Similarly, rural areas face water quality issues as a result of increased level of effluents from agriculture, domestic and industrial activities (Hemamalini *et. al.*, 2017). Inefficient agriculture practices

encouraged by poor policies are the major causes of water crisis both in terms of quantity and quality (*Figure 1, Loop B4*). Water availability is also crucially linked with pollution and in countries like India where a majority of the population is dependent on groundwater for drinking and agricultural purposes groundwater is getting contaminated with high levels of arsenic and other chemical substances indirectly reducing the availability (*Figure 1, Loops B6 and B7*).

Water in its natural form has certain essentials minerals and nutrients for humans and other aquatic species to survive. It is important to prevent water pollution as the potential impacts of poor water quality have irreversible effects on the functioning of the ecosystem and natural environment. Ecosystem valuation has demonstrated that benefits exceed costs of water related investments in ecosystem conservation (Costanza *et. al.*, 2014). However, water is taken for granted across the globe as it is not attached with a strong economic good status and thus does not have specialized market. As such natural water systems are increasingly being threatened and exploited with unmindful abstraction and pollution. There are multiple ways through which various water sources get contaminated and as such it becomes very complex to identify all types of water pollution.

Climate change effects through increased global warming have profound effects on water quality which greatly damages the biodiversity and marine ecosystem (*Figure 1, Loop B5*). Cities across the coastal regions greatly suffer from salinity and therefore increase the chances of seawater and saltwater intrusion. This is triggered by natural process and increased level of groundwater extraction (*Figure 1, Loops B6 & B7*) (Alfarrah and Walraevens, 2018). Though water pollution is caused by certain natural process and climate change variability, pollution caused by anthropogenic activities is the major driver and needs urgent attention (Khatri and Tyagi, 2014) (*Figure 1, Loop B5*). Addressing water quality issues and protecting the diverse water sources is very much solvable with the aid of efficient public policies and technological solutions.

Unplanned urbanization, inadequate sewage collection and lack of wastewater treatment capacity are the major drivers of water pollution (NITI AAYOG, 2018). While developed countries treat 70 percent of wastewater, developing countries like India treats only about 30 percent of its wastewater as the huge upfront investment in wastewater and sewage treatment plants and limited technical capacities are critical barriers for increased adoption (NITI AAYOG, 2018). Apart from the technical and financial barriers, there is strong stigma about reuse of treated and recycled wastewater across most of the LDCs including India. As India is highly vulnerable to water stress and water pollution, investment in STP and WTP facilitates the potential reuse of wastewater through proper treatment and recycling for non potable use thereby increasing the available water resources and reducing demand (*Figure 1, Loops B2 and B3*). Moreover, with increasing urbanization and population growth there is a huge scope for investing in water recycling technologies for sustainable management of water.

In order to address the various aspects of water security, the notion of water as a free and infinite resources first need to be changed. There is an urgent need for a complete overhaul of water governance structure and debureaucratization of water institutions (Shah *et. al.*, 2016). Economics started to play a prominent role ever since the Dublin statement regarded water should be considered as an economic good. Water pollution caused by domestic and industrial sectors can be significantly reduced through applications of economic instruments such as pollution tax and effluent fee (Irfan, 2012) (*Figure 1, Loops B2 and B3*). As water quality is affected by discharges of various pollutants from municipal, industrial and agriculture sector there is a strong need to impose strict penalties and pollution tax which acts as a disincentive for the polluters. It is also equally important to reward and recognize those users who minimize the discharge and move towards net zero discharge.

Water pollution is an acute problem across India because there is a serious lack of environmental awareness. Nudges in isolation without

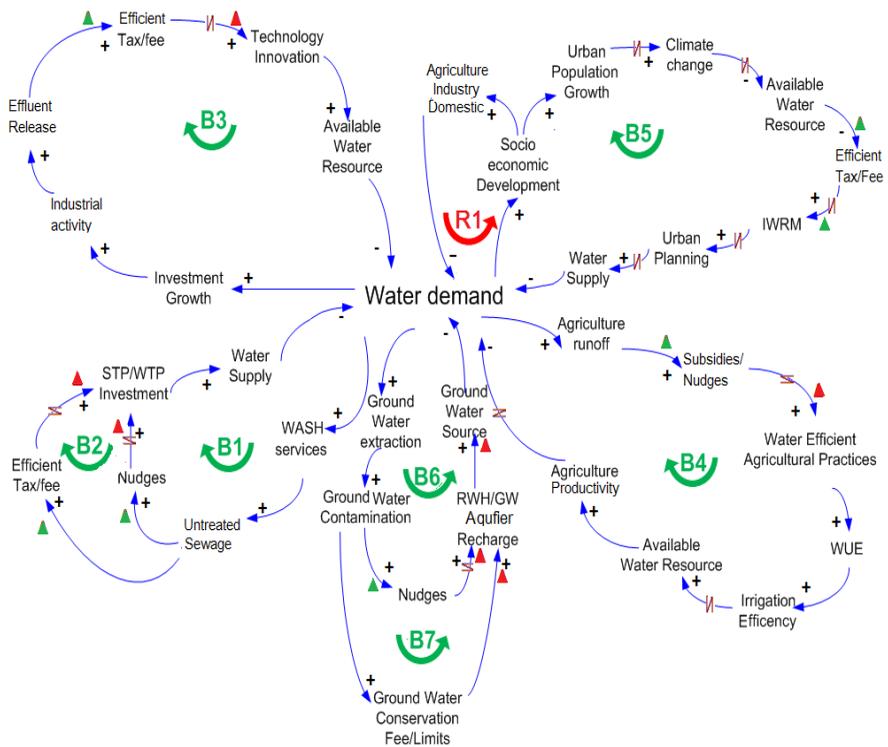
any incentives may be ineffective in reducing pollution in a large country like India with a heterogeneous population characterized by differential attitudes and understanding of civic and environmental issues. Therefore, it is important for the government to simultaneously introduce both nudges such as awareness programs and training capacity as well as pollution tax to effectively curtail pollution (*Figure 1, Loops B1 and B4*). As domestic sewage and industrial effluents are the major cause of water pollution, these sectors are to be charged with high water pollution tax and effluent fee so as to disincentivize these users to reduce discharges. On the other hand, a higher pollution tax encourages these sectors to invest in on site STP and WTP and hence move towards recycle and reuse of treated water (*Figure 1, Loops B1, B2 and B3*).

Groundwater is an important source for irrigation and drinking water in India with 60 percent irrigation needs and 85 percent of drinking water needs are fulfilled by groundwater in the absence of reliable 24x7 water supply services from public utilities. India is the third largest exporter groundwater through exports of agriculture commodities (WaterAid, 2019) and proper estimation and measurement of water footprint and virtual water trade is important to regulate the use of groundwater resources. A majority of groundwater blocks are already categorized as critical (CGWB, 2019) and hence there is an urgent need for policy and technological interventions to increase aquifer recharge through mandating rainwater harvesting and thereby reducing pollution (*Figure 1, Loops B6 and B7*). On average, India receive above normal rainfall but only about 20 percent of the rainfall is actually saved and the rest goes back to the sea and result in runoff with the lack of adequate storage facilities.

Similarly, agriculture input subsidies need to be drastically curtailed and government should create awareness about the harmful effects of water pollution and give farmers income support to use natural manure and invest in efficient, modern and innovative agricultural practices such as micro irrigation, hydroponics and aquaponics which

minimizes water use, agriculture run off and improve groundwater resources (Gulati *et. al.*, 2018; Bahinipati and Viswanathan, 2019) (*Figure 1, Loop B4*). The revenue generated from all the polluting sectors can be used for protecting and maintaining the natural water systems. The revenue from pollution tax can also be diverted to R and D activities which enables investment in advanced technologies that can minimize water pollution and increase supply.

Figure 1: Water Economy and Environment Causal Loop Diagram



Ri -Reinforcing Loop	▲ Policy Interventions
Bj -Balancing Loop	▲ Technology Interventions
	 Time Delay

CONCLUSION

In a rapidly changing global economy compounded by explosive population growth and climate change, water will be the single most important natural resource essential for survival of both humans and environmental ecosystems. Water transcends and cuts across administrative boundaries and hence it becomes very important to consider a holistic and integrated approach to water management. In this context, there is a greater need and shift in focus to develop an Integrated Water Resources Management (IWRM) strategy.

Water management and decision making in India and across most of the LDCs are ineffective as they work in silos and lack an integrated approach. This paper adopts a system thinking approach using CLD to understand the complex and integrated nature of water by identifying the key variables that affect which affect the quality aspects of water management. Therefore, the proposed CLD serve as a decision making tool for a sustainable integrated water resources management for India. The CLD proposes a pathway for sustainable use of water across sectors.

The CLD is developed keeping in mind the different values and use associated with water as a both economic and environmental good. Though the application of system dynamics has a wide range of applications across various fields, its application in environmental studies is gaining momentum only over the last two decade. The present study takes a simple and holistic approach to understand the complexities and dynamic nature of water system across agriculture, industry and domestic sectors. The balancing and reinforcing loops which drives the system behavior needs careful attention for effective policymaking.

It is quite evident that a larger part of water management decisions and policies fail as a result of narrow focus on a single sector and over emphasizing on the partial equilibrium analysis. Unlike other

natural resources, water is a special kind of renewable resource as different stakeholders associate unique values for water. Moreover, water use by one sector has multiple spillover effects on other sectors. Hence for these reasons, this paper has taken a broader view of the challenges associated with water management across agriculture, industry and domestic sectors. Though the definition of IWRM is certainly unclear and ambiguous and faces practical difficulties in actual implementation, the future of sustainable water management is crucially depended on how well government across LDCs understand and put the principles of IWRM and circular economy into practical use. Land and water are the two most important and closely associated natural resources that have to be properly harnessed and managed for a progressive and sustainable development.

REFERENCES

- Adejumoke, I. A., A. O. Babatunde, O. P. Abimbola, A. A. A. Tabitha, D. O. Adewumi and O. A. Toyin (2018), "Water Pollution: Effects, Prevention, and Climate Impact", *Water Challenges of an Urbanizing World*, 33.
- Agapitova, N., C. Navarrete Moreno and R. Barkataky (2017) "Waterlife: Improving Access to Safe Drinking Water in India", *World Bank*
- Alfarrah, N. and K. Walraevens (2018), "Groundwater Overexploitation and Seawater Intrusion in Coastal Areas of Arid and Semi-Arid Regions", *Water*, 10(2), 143.
- Bahinipati, C. S. and P. K. Viswanathan (2019), "Incentivizing Resource Efficient Technologies in India: Evidence from Diffusion of Micro Irrigation in the Dark Zone Regions of Gujarat", *Land use Policy*, 86, 253-260.
- Costanza, R., R. De Groot, P. Sutton, S. Van der Ploeg, S. J. Anderson, I. Kubiszewski, S. Farber and R. K. Turner (2014), "Changes in the Global Value of Ecosystem Services", *Global Environmental Change*, 26, 152-158.

- Central Ground Water Board (CGWB) (2019), "National Compilation on Dynamic Groundwater Resources of India", *Ministry of Jal Shakti, Department of Water Resources, River Development, Ganga Rejuvenation, Government of India*.
- Costanza, R., R. De Groot, P. Sutton, S. Van der Ploeg, S. J. Anderson, I. Kubiszewski, S. Farber and R. K. Turner (2014), "Changes in the Global Value of Ecosystem Services", *Global Environmental Change*, 26, 152-158.
- FitzGibbon, J. and K. O. Mensah (2012), "Climate Change as a Wicked Problem: An Evaluation of the Institutional Context for Rural Water Management in Ghana", *Sage Open* 2(2).
- Haraldsson, H. V. (2004), "Introduction to System Thinking and Causal Loop Diagrams", *Department of Chemical Engineering, Lund University*.
- Hemamalini, J. and B. Mudgal and J. D. Sophia (2017), "Effects of Domestic and Industrial Effluent Discharges into the Lake and their Impact on the Drinking Water in Pandravedu Village, Tamil Nadu, India", *Global Nest Journal*, 19(2), 225-231.
- Irfan, Z. B. (2012), "Arsenic Contamination in Water: A Conceptual Framework of Policy Options with Particular Reference to Bengal Delta Basin", *International Journal of Hydrology Science and Technology*, 2(4), 391-401.
- Khatri, N. and S. Tyagi (2014) "Influences of Natural and Anthropogenic Factors on Surface and Groundwater Quality in Rural and Urban Areas", *Frontiers in Life Science*, 8(1), 23-39.
- Kim, D. H. (1994), "Systems Thinking Tools: A User's Reference Guide", *Pegasus Communications*.
- Kotir, J. H., G. Brown, N. Marshall and R. Johnstone (2017), "Systemic Feedback Modelling for Sustainable Water Resources Management and Agricultural Development: An Application of Participatory Modelling Approach in the Volta River Basin", *Environmental Modelling and Software*, 88, 106 – 118.

- Murthy, M. N. and S. Kumar (2011), "Water Pollution in India: An Economic Appraisal", *India Infrastructure Report*, 19, 285-298.
- National Institution for Transforming India (NITI) Aayog (2018) "Composite Water Management Index: A Tool for Water Management"
- Rittel, H. W. J. and M. M. Webber (1973), "Dilemmas in a General Theory of Planning", *Policy Sciences*, 4 (2), 155 – 169.
- Shah, M., B. Gopal, V. Tare, K. T. Bhal, T. Shah, H. Kulkarni and B. Rajendra (2016), "A 21st Century Institutional Architecture for India's Water Reforms", *Report submitted by the Committee on Restructuring the CWC and CGWB*.
- Streefland, T. A. and Y. Krozer (2018), "Wicked Water Systems: A Review of Challenges and Opportunities", In *Urban Agglomeration, IntechOpen*
- WaterAid (2019), "Beneath the Surface: The State of the World's Water".

MSE Monographs

- * Monograph 34/2015
Farm Production Diversity, Household Dietary Diversity and Women's BMI: A Study of Rural Indian Farm Households
Brinda Viswanathan
- * Monograph 35/2016
Valuation of Coastal and Marine Ecosystem Services in India: Macro Assessment
K. S. Kavi Kumar, Lavanya Ravikanth Anneboina, Ramachandra Bhatta, P. Naren, Megha Nath, Abhijit Sharan, Pranab Mukhopadhyay, Santadas Ghosh, Vanessa da Costa and Sulochana Pednekar
- * Monograph 36/2017
Underlying Drivers of India's Potential Growth
C.Rangarajan and D.K. Srivastava
- * Monograph 37/2018
India: The Need for Good Macro Policies (*4th Dr. Raja J. Chelliah Memorial Lecture*)
Ashok K. Lahiri
- * Monograph 38/2018
Finances of Tamil Nadu Government
K R Shanmugam
- * Monograph 39/2018
Growth Dynamics of Tamil Nadu Economy
K R Shanmugam
- * Monograph 40/2018
Goods and Services Tax: Revenue Implications and RNR for Tamil Nadu
D.K. Srivastava, K.R. Shanmugam
- * Monograph 41/2018
Medium Term Macro Econometric Model of the Indian Economy
D.K. Srivastava, K.R. Shanmugam
- * Monograph 42/2018
A Macro-Econometric Model of the Indian Economy Based on Quarterly Data
D.K. Srivastava
- * Monograph 43/2019
The Evolving GST
Indira Rajaraman

MSE Working Papers

Recent Issues

- * Working Paper 192/2020
If Monetary Aggregates, then Divisia
Naveen Srinivasan and Parush Arora
- * Working Paper 193/2020
Institutional Design and Credibility
Jyotsana Kala and Naveen Srinivasan
- * Working Paper 194/2020
A Constant Gain Learning Framework to understand the behaviour of US Inflation and Unemployment in the 2nd half of 20th century
M.Venkata Raamasrinivas and Naveen Srinivasan
- * Working Paper 195/2020
Information Theoretic Ranking of Extreme Value Returns
Parthajit Kayal, Sumanjay Dutta, Vipul Khandelwal and Rakesh Nigam
- * Working Paper 196/2020
Inflation Targeting in the United Kingdom: Is there evidence for Asymmetric Preferences?
Pranjal Rawat, Naveen Srinivasan
- * Working Paper 197/2020
The Oil Story: Is it Still the Same?
Swati Singh and Naveen Srinivasan
- * Working Paper 198/2020
Inventory Cycles and Business Cycles – Has the relationship lost its importance over the years: A Time-Varying Parameter Approach using U.S. Data
Parijat Maitra and Naveen Srinivasan
- * Working Paper 199/2020
From Income to Household Welfare : Lessons from Refrigerator Ownership in India
Sowmya Dhanaraj, Vidya Mahambare and Poonam Munjal
- * Working Paper 200/2020
Double Burden of Malnutrition in India : Decadal Changes among Adult Men and Women
Brinda Viswanathan and Archana Agnihotri

* Working papers are downloadable from MSE website <http://www.mse.ac.in>
\$ Restricted circulation