AN INVESTIGATION INTO OPTIMISING WATER FLOW OF INDUSTRIAL SYMBIOSIS: DEVELOPMENT AND APPLICATION OF A MODEL

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Name of the Student: B.H. Mallawaarachchi

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The above candidate has carried out research for the PhD thesis under my supervision. I confirm that the declaration made above by the student is true and correct.

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Date: 19.10.2022

ABSTRACT

An investigation into optimising water flow of industrial symbiosis: Development and application of a model

The concept of Industrial Symbiosis (IS) has obtained world concern as a new initiative for achieving collaborative benefits through exchange of resources between industries including water. Even though, these initiatives became prominent as successful projects in the early stages, many of them have resulted in failures in the long term without achieving the expected results due to deficiencies in IS planning. In the current process, no prior evaluation and optimisation are taking place before implementing the identified water synergies. There is therefore a need to have a standardised method to assess the optimum water flow of IS. Accordingly, the current study aimed to develop a model to assess the optimum water flow of IS. In order to achieve the aim, the research stands within the pragmatism philosophical stance. The abductive approach was applied as the appropriate research approach. Sequential exploratory research design was adopted consisting three phases: Phase I: Desk study; Phase II: Interviews with industry experts; and Phase III: Case study. Phase I - Desk study was conducted to collect and review the data from reliable published sources to identify water inputs and outputs of industrial entities. Based on the key literature reviewed, the conceptual model was developed by integrating mathematical formulae. In Phase II, sixteen interviews were conducted with industry experts in Sri Lanka to collect the data. The collected data were analysed using the code-based content analysis technique with the application of QSR International's NVivo. 12. As key findings derived from analysis, current methods & issues of industrial water management and enablers & barriers for initiating water exchange networks in Sri Lanka were identified. Furthermore, the conceptual model and mathematical formulae were also refined to the selected context. The applicability and feasibility of the model were evaluated during Phase III. An IS network in an export processing zone (EPZ) in Sri Lanka, comprising three geographically co-located industrial entities, was selected as a suitable case study. Seven semi-structured interviews were conducted with professionals within the selected case to collect the data, which were analysed using the mixed integer linear programming (MILP) approach. The assessment model was developed and tested using SageMath software. Finally, environmental, economic and social feasibility of the developed model were also determined. The developed model forms a unique foundation for assessing the optimum water flow of IS, applying in any context subject to context-specific enhancements. The novelty of the current research is its objective of reducing freshwater consumption of the IS network through maximum wastewater recovery in assessing the optimum water flow of IS. Thus, the research outcomes provide a role model for all developed and developing countries for reducing the environmental impact of industrialisation through optimum water sharing between industrial entities.

Key Words: Industrial Symbiosis, Mathematical Programming, Optimisation Modelling, Optimum Water Flow, Water Network

DEDICATION

I dedicate this piece of work to my beloved family who encouraged me, with emotional and spiritual effort in this endeavour…

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADB	Asian Development Bank
BOD	Biological Oxygen Demand
BOI	Board of Investment
CE	Circular Economy
CE-EIP	Circular Economy Eco-Industrial Park
CEA	Central Environmental Authority
CKD	Chronic Kidney Disease
CLD	Casual Loop Diagram
COD	Chemical Oxygen Demand
CPI	Consumer Price Index
CSR	Corporate Social Responsibility
CWWT	Common Wastewater Treatment
DGM	Deputy General Manager
EIP	Eco-Industrial Park
ENA	Ecological Network Analysis
EPZ	Export Processing Zone
FTZ	Free Trade Zone
FW	Freshwater
GPL	General Public License
GWP	Global Water Partnership
HR	Human Resource
IE	Industrial Ecology
IS	Industrial Symbiosis
IWM	Industrial Water Management
IWRM	Integrated Water Resource Management
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LCCA	Life Cycle Cost Analysis
LP	Linear Programming
MILP	Mixed Integer Linear Programming
MINLP	Mixed Integer Non-Linear Programming
MRQ	Main Research Question
NASL	National Audit Office Sri Lanka
NISP	National Industrial Symbiosis Programme
NWSDB	National Water Supply and Drainage Board
PEIP	Planned Eco-Industrial Park
PLS	Plain Language Statement
PPI	Producer Price Index
PV	Present Value
RIP	Retrofit Industrial Park
SDGs	Sustainable Development Goals
SLSI	Sri Lanka Standards Institute
SNA	Social Network Analysis

SOS	Self-Organising Symbiosis
TAC	Technical Advisory Committee
TDS	Total Dissolved Solid
TOC	Total Organic Carbon
TSS	Total Suspended Solid
TWW	Treated Wastewater
UN	United Nations
USA	United State of America
UWW	Untreated Wastewater
WHO	World Health Organisation
WW	Wastewater
ZLP	Zero Liquid Discharge

LIST OF APPENDICES