Impact of Industrialization on Environment and Sustainable Solutions – Reflections from a South Indian Region

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Abstract. Industrialization has brought economic prosperity; additionally it has resulted in more population, urbanization, obvious stress on the basic life supporting systems while pushing the environmental impacts closer to the threshold limits of tolerance. With booming industrial growth and relatively low land mass, environmental sustainability is now becoming a significant deciding factor in industrial development process. Accumulating evidences constantly indicate that the transition of the existing industries into eco-industrial network through successful implementation of green approaches provides a viable solution to preserve the natural resources of the region while concurrently enhances the regional economy on a sustainable basis. It calls for an appropriate planning and integrated framework in harmony with the environment, after careful assessment of past and prevailing conditions. The empirical knowledge on affected area helps understanding the local context and developing further course of action based on ground realities. With this aim, a study was conducted on the current industrial pollution and environmental setting of Puducherry. A causal chain analysis indicated severe impacts of industrialization on local environment while highlighting its immediate and root causes. The findings form a base for suggesting sustainable solutions to curb rampant pollution in Puducherry region and similar scenarios found across the world.

1. Introduction
Since ages, industrial growth has started to affect environment with severe downside problems. It causes tremendous stress on the entire bioweb and natural system components like water, air, soil, bio-diversity including surrounding eco-system. Realizing the severity of the problem, impacts of industrialization on the environment need to be analyzed with more intensity and feeling [1]. Industrial effluents contain numerous essential nutrients or possess properties which can easily be utilized for many value-added purposes with commendable benefits to society and environment. Application of green approaches based on 6Rs technologies (reduce, reuse, recycle, recovery, redesign, rethink) and closed-loop systems within the integrated framework of industrial ecology (IE) provides an excellent opportunity to preserve the natural resources of the region while concurrently enhances the regional economy on a sustainable basis. It calls for an appropriate strategic planning encompassing technical, ecological, socio-cultural and economic driving factors that can affect the industrialization process. Prior to evolving a practical approach towards strategic development, it will always be indispensable to derive lessons from other similar situations. With a systematic way of looking at events occurred with identical consequences, critically analyzing the situations, policies, activities and overall scenarios related to the problem, it may help to gain a sharpened understanding of the ways the instance has happened [2]. In this backdrop, industrial profile and impacts of industrialization on environment were examined in Puducherry, which has emerged as an industrial nerve centre of South
India over past few years. Based on the lessons learned, this study indicates how a strategic green approach may be generated and applied in Puducherry region and matching context in other parts of the world.

1.1. Industrial profile and local context of Puducherry

Puducherry is a peaceful place located in a scenic location in South India with a cosmopolitan culture. The Union Territory (UT) of Puducherry covers an area of 492 km$^2$ and comprises four interspersed geographical entities, namely Puducherry, Karaikal, Mahe and Yanam. The Puducherry region is the largest of the four, which covers 293 km$^2$ (60.66% of the UT). During the last couple of years, Puducherry has attracted a large number of industries due to the easy availability of land, water, labour, power and various incentives and concessions given by the government in the form of tax concessions, power subsidies, tax holidays and soft loans that were not available in most of the neighbouring states.

With annual industrial growth varied from 1.86‒12.28%, by mid-2016 the UT of Puducherry had an impressive establishment of 8562 industries representing a cross-section of diverse industries. Almost 80% of the total industries are located in the Puducherry region followed by 13% in Karaikal, 4% in Yanam and 3% in Mahe. Currently, seven well-established industrial estates are propelling the industrial growth of the UT of Puducherry. Out of these, six industrial estates, namely Thatanchavadi, Mettupalayam, Sedarapet, Kirumambakkam, Kattukupam and Thiruvuvanai are located inside the Puducherry region. Due to the industrial friendly climate, new industrial estates are also being planned while many large industrial companies of national repute and several renowned multinational corporations are showing keen interest to establish their factories in Puducherry in the near future [3], [4].

This rampant industrialization, alongside economic prosperity, has resulted in sudden increase of population, urbanization, obvious stress on the basic life supporting systems, pushing the environmental impacts closer to the threshold limits of tolerance. Based on the nature and severity of the pollution, industries in Puducherry have been categorized as Red, Orange and Green, referring to high, medium and low pollution potential, respectively. At present, 19% of the total industries are grouped in the red category, 21% orange and 60% green [5]. By mid-2016, the estimated generation of hazardous waste in the UT of Puducherry was approximately 36,768 tonnes per annum (TPA), of which Puducherry alone generated 33,305.63 TPA[4]. Except only one hazardous waste recycling unit and no secured landfill site to take adequate care of industrial waste, some industries are selling their waste to other regions, while in most of the units waste disposal is being done in an improper manner, exerting a significant level of environmental burden. Uncontrolled, inadequate and unsystematic handling of this waste poses a great risk towards the environmental health of this region [4-8].

During the years 1890 -1900, the Puducherry region received only 98.4 tons of total pollution load, while during the period 1960-1970, the total pollution load reached 1794.2 tons, an eighteen fold increase which continuously escalated in subsequent years. According to a preliminary study by Ramesh (2005), this may be directly attributed to the rapid pace of industrialization during the same period [9].

2. Methodology

The nature of the study needs the collection and analysis of primary and secondary data on environmental, technological, economic, and policy aspects of industrial pollution. Hence, to obtain first hand information, it requires direct interactions with the Government as well as local non-governmental organisations, closely working and actively involved in the field of environmental pollution.

Causal chain analysis is an ideal apparatus to study the impacts of industrialization on a region and its causes. It is a step-by-step process that identifies the most important causal links between the environmental and socio-economic impacts resulting from the issues and concerns related to the field, their immediate causes, the factors responsible and finally the root causes that determine the behaviour of the concerned sector [10]. In a nutshell, it looks at the overall scenario related to the concerned
problem with a view to identifying underlying roots and driving factors that can stimulate sustainable growth in line with green approaches.

Application of this analytical approach (adapted from GIWA methodology, 2002) in Puducherry region not only provided a holistic overview of impacts of industrialization on environment, but also it helped immensely to identify the underlying causes of industrial pollution prevalent in this area.

In the first phase work, after obtaining the necessary permission from Puducherry Pollution Control Committee and Department of Science, Technology & Environment, the study initiated a situational analysis with the collection of required data from primary as well as secondary sources, such as libraries, journals, feature articles, magazines and publications from relevant government departments, NGOs, academic & research institutes and business associations. Impacts of industrialization on Puducherry ecosystem, water, air, biodiversity and its causes were analyzed comprehensively and the results were documented through a causal-chain diagram (figure 1). Information on the driving forces, such as actors and institutions, physical environment, policy support, management options, market forces, trade and legal requirements, challenges and infrastructure facility available for the formation of an eco-industrial network were also collected for a better understanding to formulate a strategic planning and to develop sustainable solutions for the pollution problems.

3. Results and discussions
Causal chain analysis in Puducherry portrayed a detailed picture of environmental and allied socio-economic impacts arising out of rapid and unplanned industrialization and tried to find out its major immediate causes as well as route causes. Attempts have been made to find out key drivers which have an effect on the industrialization process starting from industrial evolution era to present period.

3.1. Impacts of industrialization on Puducherry environment

3.1.1. Impacts on water - A detailed analysis of the environmental impacts of industrialization revealed that industries set up before the 1990s included mostly textiles, sugars and distilleries that were water intensive and had a higher pollution potential, exerting enormous pressure on the environment. The indiscriminate discharge of industrial effluent along with municipal solid waste disposal is the principal source for surface water contamination [11], [12]. The heavy metals, salts and fluoride effluents from the industries of chemicals production, metal processing and paper manufacturing from the Mettupalayam Industrial Estate, established during 1979 on the fringe of Puducherry, were found to have contaminated the surrounding groundwater[4]. This polluted groundwater is moving at an average velocity of approximately 30m a year, migrating to the Mettupalayam well field which houses the main wells for Puducherry’s drinking water supply. By comparing the groundwater quality over the past 20 years, i.e. from 1981 to 2001, Ramesh (2005) noted that there was an alarming drop in the water level from 6 m to 26 m. The study by Sivasankaran (1997) on the status of pollutants in groundwater of the Puducherry region highlighted the presence of pesticides and heavy metals. The study on heavy metal concentrations in the industrial area of Puducherry by Aruna Devy (2002) indicated that cadmium and lead were present at higher levels beyond the prescribed standards in various industrial areas. Several studies have found that the accumulation of these metals in the food chain had become an enormous environmental hazard [13-15].

Various studies carried out to assess the physico-chemical characteristics of water indicated that the values of conductivity, total dissolved solids, calcium, magnesium, hardness and sulphate in groundwater have increased twenty fold since past few years, the values of chloride and sodium have increased fifty fold and potassium by six fold [16]. Based on the Linear Regression Forecasting by Ramesh(2005), it is estimated that by the year 2020 the discharge of the total suspended solid (TSS) load will reach 592.18 TPA, the Biological Oxygen Demand (BOD) load will be 1958.93 TPA, and the Chemical Oxygen Demand (COD) load will be 4667.27 TPA. Discharge of oil and grease load will reach 66.65 TPA during this period. The projected annual groundwater utilisation by the industrial sector will reach 5727715.75 KL (5.727 mcm). However, the annual replenishment would remain at 155 million cubic metres (mcm). Thus the deficiency will increase to 3.6 mcm by 2020. It will lead to
further depletion of the groundwater table in the north western part and salt-water intrusion in the south eastern part of Puducherry [9]. In view of this situation, stringent action has to be taken by the government for the sustainable use of water resources for future industrialization.

3.1.2. Impacts on air - The air quality is equally affected by industrialization. By the end of the eighteenth century, Puducherry received 499 tons of suspended particulate matter (SPM), 2.88 tons of sulphur dioxide (SO\textsubscript{2}) and 1.99 tons of nitrogen dioxides (NO\textsubscript{x}) per year. At the end of the nineteenth century, several air pollution potential facilities such as M.S. ingots, ferro alloys, and calcium carbide were established and the pollutant level increased nearly ten fold for SPM and NO\textsubscript{x} and fifteen fold for SO\textsubscript{2}. The total emissions from these industries are still vast, even after applying the advanced air pollution control devices such as bag filter, double way scrubber and multiple cyclone. By 2005, 65 industries were identified as ‘point source’ (Stack emission) of air pollutant releasing units in Puducherry. By 2012, pollutants such as SPM, CO, SO\textsubscript{2} and NO\textsubscript{x} were found to have either exceeded or nearly reached the limits[17], necessitating the immediate installation of a continuous monitoring and control mechanism. According to the predictions by Ramesh (2005), the emissions of SPM released by the industries in the Puducherry region will be approximately 7834 tons in 2020, while the SO\textsubscript{2} released will reach 54.7 tons and the NO\textsubscript{x} released will be 32.4 tons. Thus, air quality may deteriorate further in due course.

3.1.3. Impacts on ecosystem - This uncontrolled industrialization brought changes in community and habitat structure [18]. Forest cover of Puducherry has become very less, posing a threat to current ecosystem [8]. With this sudden boom in industries, the pattern of resource utilization in the form of energy, water usage etc increased drastically leading to the inevitable resource disturbance and imbalance. Today, the land bears no resemblance to its past, except in a few pockets of the region. It

Figure 1. Causal chain diagram illustrating the causal links for Industrial Pollution in the Puducherry region (based on Giangiobbe et al., 2002)
already affected the sedimentation patterns, the distribution of major and trace elements and rate of soil formation, which in turn brought significant changes in ecosystem stability [9].

Regular inflow of industrial effluents into the ponds disturbed their ecological equilibrium. Consequently, the water which previously could be used for domestic and agricultural purposes became exceedingly unusable. This in turn affected the cropping pattern. Though not conspicuously alarming, the slow and steady pollution by heavy metals in the environment is quite hazardous. They reach the aquatic environment and being non-degradable, remains suspended or partially dissolved in water and subsequently accumulated in organisms [13].

3.1.4. Impacts on flora and fauna - Due to the changing climate of industrialization and in the absence of forest cover in most of the areas of Puducherry, several endangered and threatened plant species such as Derris ovalifolia, Mallotus philippensis, Atlantia monophylla, Pamburus missicnsis Glycsemis pentaphylla, Lepisanthus tetraphylla, Dioxypros ebnum,Gloriosa superba Gymnema sylvestre,Combretum ovalifolium,Derris scaden and varieties of mangroves found in this region are under great threat [18]. The peri-urban estuaries where mangroves are located, receive a large quantity of untreated sewage and solid wastes that degrade the habitat and threaten the flora and fauna [19-20]. It also poses great risk to the very survival of rare and endangered species of wild animal population. Among the five species of sea turtles reported in Indian coast, leatherback (Dermochelys coriacea), loggerhead (Caretta caretta), olive ridley (Lepidochelys olivacea), hawksbill (Eretmochelys imbricata), and green olive ridley turtles (Chelonia mydas) are the common species nestling along Puducherry coastal belt. Possible adverse effects of noise on these turtles can range from behavioural modification including mild disturbances, disruption, displacement from key habitat, disorientation, capillary damage, loss of motor control, even death at some time [18].

3.2. Immediate causes

The current study identified inadequate/uncontrolled disposal of industrial wastes, discharge of untreated industrial effluent, lack of/complete absence of proper facilities for the waste treatment system, absence of secured hazardous waste landfill site, increased use of heavy metals and hazardous toxic substances, leaching of hazardous and toxic wastes as immediate causes of industrial pollution in Puducherry region (figure 1). With rapid industrialization, there has been a substantial increase in generation of various hazardous wastes, discharge of industrial effluents and emission contaminating groundwater resources [7].

The crisis of aquatic pollution and its impact on the health of organisms were an important current problem mainly because of the indiscriminate discharge of industrial effluents containing heavy metals like Iron, Chromium, Zinc and Lead etc. [11]. As the region’s industrial structure shifts into highly polluting sectors, industrial effluents contain more and more heavy metals and non-biodegradable toxic and hazardous waste, leaching of which increasingly contaminate ground water resources both chemically and microbially [12].

Currently industries such as electroplating, pharmaceuticals, chemicals, steel, textiles, electronics, distilleries are major polluting industries, mainly responsible for generating hazardous waste of diverse nature. ETP sludge, waste oil, zinc oil, dichromate waste, spent pickling acid are major wastes or pollutants of concern. Uncontrolled, inadequate and unsystematic handlings of these wastes pose a greater risk and significant environmental burden in this region.

3.3. Root causes

Various issues related to governance, law, knowledge, technology and socio-cultural aspects have been identified as major root causes of industrial pollution in this region. Such causes include lack of long-range commitment from businesses to the environmental-friendly approaches, insufficient management systems, ineffective institutional mechanism for strategic planning, development, implementation and monitoring of pollution management, lack of access to appropriate technology and know-how, a failure to understand the specific potential of green approaches, lack of time and resources, corporate conservatism and a reluctance to drastically change business practices regardless of the economic and environmental benefits. Further challenges include the corporate belief that
pollution reduction is always a cost and never a saving and a business orientation toward sales maximization rather than cost minimization.

Hence, in this alarming situation if we fail to ‘green’ the industrial activities, then industrial pollution will be much more serious in this ecologically sensitive coastal region. Puducherry now needs to refurbish its infrastructure base to meet increasing sociological, economic and environmental demands simultaneously, without any further delay.

4. Recommendations for sustainable solutions

Strategic planning is necessary to address the environmental impacts of economic development to an acceptable level. In this scenario of degrading environment and pressure for constant industrialization, eco-industrial network development provides viable solutions to move towards sustainable industrialization. However, it will require a supportive infrastructure base to make it happen. Industry will need a perfect combination of incentives, regulations, management mechanisms, information and other infrastructure facilities to provide the conditions in which industrial symbiosis (IS) can thrive [21].

A subsequent SWOT analysis by this author and her doctoral research broadly highlighted that significant potential exists for development of industrial clusters in different sectors in Puducherry. For businesses looking into inter-organisational interfaces for by-products and resources, potentials appear attractive. 5 types (one-one, one-many, many-one, many-many and one-all) and 28 total numbers of potential synergies were identified for by-product and resource exchanges during the same research. This can be supported by policy elements that emphasise and encourage the companies to move in directions aligned with IS principles [22], [23]. Regional development agencies and local Govt, which have increasingly accepted responsibility for balancing economic development with other pillars of sustainability, have a welcoming approach to the concept [24]. Industrial diversity, continuous waste production, existing motivation in work environment, willingness of the govt., industry friendly incentives/subsidies, huge investment on industrial sector, good transport access, close proximity of industrial participants, local academic skill/expertise provide promising opportunities for successful implementation of IE principles [25-28]. All these create a supportive atmosphere for creation of eco-industrial park in this region based on material and by-product exchanges.

5. Conclusion

Rampant industrialization and urbanization have been very important causes for putting pressure on natural resources and also causing various degrees of environmental degradation. Puducherry, the south Indian industrial base has been experiencing similar kind of situation since many decades. There is urgent need of initiatives that ensure that industrialization is sustainable both in terms of taking measures to prevent damage to the environment and also promoting more environmentally friendly industries. A transition of the industries into eco-industrial network has emerged as a dynamic approach to preserve the natural resources of the region. Forging strong linkages between industry and related services can accelerate this transition to a diversified, high income economy while providing a safer environment. Situational analysis of Puducherry region pointed out existence of significant potential for industrial clusters development and inter-organisational interfaces for by-product and local resources. Key lessons learnt from Puducherry may act as a good basis for the development of a strategic action for the areas with similar environmental problems. From a comprehensive analysis of local environmental settings, strategies can be evolved to overcome the problems, by modifying or introducing appropriate approaches and filling the missing aspects of the related policies for strengthening sustainable industrialization.

Nevertheless, there is no one system that will work for every case. The same framework by itself will not bring a successful eco-industrial model. In light of this, the case of the each industry needs to be analyzed separately; however, other examples of successful strategies can be used as a basis to draw inspiration. The achievement of eco-industrial network depends on the in-depth study of each industrial characteristics and driving factors. It demands a strong determination and complete
dedication of major stakeholders, especially participating companies. It is important to make the participating companies understand that eco-industrial network will undoubtedly provide them with opportunities to gain environmental and socio-economic benefits in a long term and will greatly increase the sustainability of the system.

However, we need to address a number of concerns about implementation, dissemination and uptake of new management approaches to move industries in the direction of more sustainable practices and make them ready for the acceptance of recycled products and materials. Such solutions cannot be imposed from outside and need a holistic approach that is widely understood, or at least accommodated by local industrial systems. This will further allow to be readily absorbed into the local business culture while simultaneously helping to improve overall effectiveness, and thereby possibly assisting in a benign transformation of an existing ‘business-as-usual culture’ to a ‘sustainability-based culture’[29]. All that is needed to achieve this is a logical way to approach the strategy, through binding all the essentials rooted in social, economic, environmental, technical, scientific, cultural and intellectual green components in an integrated fashion. Implementing a feasible green approach along these lines will create the much desirable integrated structure, needed for the development of sustainable industrial base in the regions with similar features.

6. References

[1] Webnote 2017 Impact of industrialization on the environment Environment Insider. http://environmentinsider.com/impact-industrialization-environment/

[2] Zucker D M 2009 How to do case study research School of Nursing Faculty Publication Series Paper 2.

[3] Directorate of Industries and Commerce 2010 Government of Puducherry

[4] Raj S 2016 Environmental issues of Puducherry UT an environmentalist’s outlook Best: [5] International Journal of Humanities, Arts, Medicine and Sciences 44 171-196

[5] Annual Environment Survey Report 2010–2011 Govt. of Puducherry

[6] Puducherry government inventory 2008. Inventory of Hazardous Waste Generation and the Hazardous Waste Generating Units in the UT of Puducherry PPCC Government of Puducherry

[7] PUDCOCAN handnote 2009 Puducherry – The gateway to success

[8] PondyCAN final report 2012 Sustainable regional planning framework for puducherry.viluppuram, auroville & cuddalore Sustainable Regional Plan Project Number 1009C0056

[9] Ramesh N 2005 Evolving an Integrated Environmental Management Plan for Sustainable Industrialization of Pondicherry Region PhD dissertation Pondicherry University

[10] Giangiobbe S, Gonzalez S and Pacheo F 2002 Causal chain analysis GIWA Regional Assessment 38 Patagonian Shelf Kalmar Sweden: University of Kalmar

[11] Murugesan A G, Baladhandayuthapani M and Sukumaran N 1999 Immuno-toxicity of lead and modulatory effect of extract of aegle marmelos to fish, cyprinus Proc of Int Wrkshp on Environmental Impacts of Metals (Coimbatore India: TNAU) 61–67

[12] Abbasi SA, Ramesh N and Chari KB 2002 Studies on environmental management of Pondicherry: The water and air resources Journal of the Institution of Public Health Engineers 3 20–24

[13] Rao U and Govindarajan S 1992 Transfer of copper and zinc through a marine food chain Acta Botanica India 2 71–75

[14] Senthil Nathan D Kumar RM Reddy SS Sivasankaran MA and Ramesh R 2012 Trace elements in groundwater of coastal aquifers of Pondicherry region India Journal of Environment 1 4 111–18

[15] Jameel AA Sirajudeen J and Vahith RA 2012 Studies on heavy metal pollution of groundwater sources between Tamilnadu and Pondicherry India Advances in Applied Science Research 3 1 424–29

[16] Ramesh NE, Ramasamy V and Kothandraman R 1994 Salinity intrusion in the coastal aquifer of Pondicherry Nat Semnr Clean Water Great Needs Greater Challenges(Puducherry India: Pondicherry University) 23-24
[17] Balashanmugam P, Ramanathan AR, and Kumar VN 2012 Ambient air quality monitoring in Puducherry International Journal of Engineering Research and Applications 2 2 300–07
[18] EIA report 2010 Design and construction of work shelters in fishing villages along the Puducherry and Karaikal coasts Emergency Tsunami Reconstruction Project _ Environment Impact Assessment Report Government of Puducherry
[19] Satheeshkumar P and Senthilkumar D 2011 Identification of heavy metals contamination by multivariate statistical analysis methods in Pondicherry mangroves India Journal of Environment and Earth Science 1 1 30–48
[20] Palanisamy S 2012 Puducherry mangroves under sewage pollution threat need conservation Current Science 102 1 13–14
[21] Cote RP, Grant J, Weller A, Zhu Y and Toews C 2006 Industrial ecology and the sustainability of Canadian cities Eco-Efficiency Centre
[22] Patnaik R and Poyyamoli G 2015 Developing an eco-industrial park in Puducherry region India – a SWOT analysis Journal of Environmental Planning and Management 58 6 976-96
[23] Patnaik R 2012 Studies on the Application of Industrial Ecology Principles in Puducherry Region PhD dissertation Pondicherry University
[24] Amurthalingam A 2016 Environmental protection through NGOs in Puducherry region International Journal of Interdisciplinary Research in Arts and Humanities
[25] Mirata Mand Pearce R2006 Industrial symbiosis in the UK. In Industrial Ecology and Spaces of Innovation, ed K Green and S Randles (Cheltenham: Edward Elgar) pp 77‒105
[26] Chiu ASF and Yong G 2004 On the industrial ecology potential in Asian developing countries Journal of Cleaner Production 12 1037–45
[27] Banerjee SB 1998 Corporate environmentalism: perspectives from organizational learning Management Learning 29 147-64
[28] Chertow M 2000 Industrial symbiosis: literature and taxonomy Annual Review of Energy and Environment 25 313–37
[29] Clayton A, Muirhead J and Reichgelt H 2002 Enabling industrial symbiosis through a webbased waste exchange Greener Management International 40 93–106

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