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A Critical Evaluation of the Adaptation of the Right Scientific Method in the Chemical Analysis of Pollution in a Waterbody

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Abstract

In-adequate and in-comprehensive chemical investigations on the pollution impacts of natural ecosystems such as waterbodies fail to produce fruitful solutions as they do not systemically approach the problems. As such, this review paper proposes that inductive reasoning should be effectively applied to generate hypotheses (which are developed on the basis of an in-depth understanding of the ecosystem), where systemic and comprehensive investigations are possible, thus enabling the researcher/s to find the root causes and the rightful solutions to the problems.

[***Key words****:* analytical chemistry, hypothesis, induction, waterbody, regulations]

1.0 Introduction

Science is a systematic and controlled method of knowing. Enquiry (generally referred to as **scientific enquiry**) in science involves the following five steps:

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i. Use of a conceptual scheme,
ii. Finding out the relationships between the variables (system components),
iii. Empirical tests of hypotheses (proving or disproving them),
iv. Leaving out what can not be explained (dealing with testable prepositions only) and,
v. Developing theories (or comprehensive understandings of the problem/s of concern).

The reasoning used to develop the scientific enquiry is always expected to be *inductive* – with the objective of contributing to the development of the scientific knowledge base. This is contradictory to the system of *deductive reasoning* – which is *non-ampliative*, creates no new findings and does not contribute to the development of new knowledge/understandings.

Pollution of waterbodies and wetlands is a major problem in Sri Lanka. For example, Vavuniya is no exception to this and, at present; almost all the waterbodies within the town limits are in different stages of eutrophication and deterioration. With the initiative to conserve and protect the wetlands/waterbodies started up internationally from 25th of January 2002 (The Ramsar Convention on Wetlands, 2002), the need for rehabilitating them is paramount. This necessitates the critical evaluation of the present states of the water quality of the waterbodies using analytical chemistry.

In these regards, most of the investigations conducted so far in this country have not produced any solutions to the problem of pollution in water bodies. All these exercises have been costly – but were designed in the lines of deductive reasoning (e.g. Sugirtharan *et al.*, 2004, Fardeepha and Thiruchelvam, 2005), thus producing no valuable information as to the root causes of the problem. A common criticism of this work by the scientific world is that: '*these are merely pollution monitoring exercises and, can not be considered as research which merits scholarship*'.

In this paper, we present an idea as to how *inductive reasoning* could be effectively applied to develop scientific enquiry (and eventually a scientific methodology) that enables betterment to the understandings of water body pollution in Sri Lanka.

We begin by posing the question: 'Why is chemical analysis important in assessing the impact of water body pollution and how can it be conducted in the right scientific manner?

To be able to find answer to this question the first step will be to understand the waterbody system and map the relationships between the components/ processes within. For this analysis, we consider a water body as an area (of relatively smaller size than a lake) of fresh water where the ponding effect has occurred i.e. a pond.

2.0 Ecosystem of a Waterbody:

An ecosystem is a functional self-supporting system that includes the organisms in a natural community and their environment. A *pond* is a small body of standing water. Shallow that rooted plants can grow over most of the bottom. Pond ecosystems maintain themselves in a characteristic dynamic state. They are kept going by the energy that flow through their biotic components and by the circulation of materials like N, C, H_2O within and outside the system. Ecological kinship in the final analysis is energy oriented. Ultimate source of energy is the sun. Solar energy is trapped by the autotrophs, it moves to heterotrophs producer-consumer, or producer-herbivore-carnivore relationship. It means that energy is transferred from one trophic level to the other in succession in the form of a chain as food chain.

2.1 Zonation of Waterbody Ecosystems:

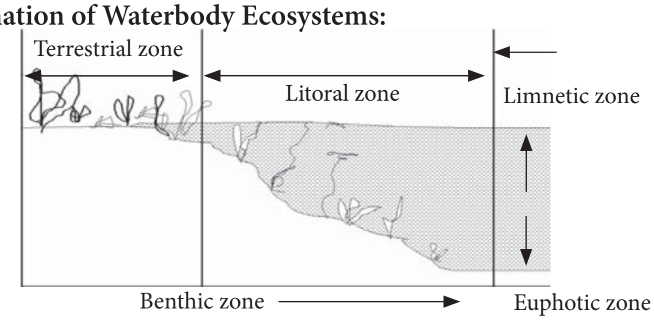

Fig 1: Tank zonation based on photosynthetic activity and proximity to bottom

This tank ecosystem can be classified into the following zones based on the depth and the spread of organisms.

- Littoral zone – This is the shallow water region where light can reach up to the bottom. Rooted plants chiefly occupy it.
- Limnetic zone – This is the open water zone up to the depth of effective light penetration. The community of this zone comprises plankton, nekton and sometimes neustons. Total illuminated stratum including littoral and limnetic zones is called as euphotic zone.
- Profundal zone – The bottom and deep-water area where light does not penetrate is called as profundal zone. This zone is often absent in ponds.
- Benthic zone - the bottom sediment.

2.2 Biotic Composition:

Organisms of fresh water may be conveniently classified as producers, consumers and decomposers.

- Producers - Organisms which produces organic matter for itself and all other organisms, by photosynthesis.
- Consumers - Organisms that ingest organic food (usually particulate) or other organisms.
- Decomposers - Organisms, which obtain their nutrient by breaking down dead organic matter into simple molecules.

Those living in the bottom sediments are called as benthos, those living on projected surfaces such as stems and leaves are called as periphyton and those flying freely with the water current are called as plankton. Other smaller organisms can swim and navigate at will known as nekton. Organisms resting or swimming on the surface are called as neustons.

Thereby the ecosystem of a water body is keeping in a balance state by the interaction of biotic and abiotic components.

2.3 Usages of Waterbodies:

Storm water paths and wastewater drains discharge into many natural waterbodies. The water is cycled through the hydrological cycle for its continued availability. For example, tank water is used for irrigation through irrigation channels. Water is of the prime importance for all the human activities and so its management and conservation is most essential. In this present age, when every man is aware of the importance of sustainable environment, training the mass in environment management is the need of hours. It is necessary to change people's attitude towards the importance of water. A new environmental behaviour is necessary, in which quantitative demands and confrontation must be replaced by qualitative appreciation and co-ordination. This will hopefully lead us into a new era of human harmony, which can bring changes to the well being of life on the earth.

3.0 Pollution of Waterbodies:

Pollution is defined as addition of some exogenous substances in the environment, which are harmful for organisms including human beings.

3.1 Pollution Dynamics

The anthropogenically utilizable water resources are small in number and quantity, compared to the increasing demands. The rapid population explosion, urbanization and industrialization have posed a two-way stress on the fresh water resources. First, the increasing demand of potable water and the pollution of available water bodies. A second type of intervention occurs through deforestation. Vegetation has a significant role in the water cycle.

The quality of water in the tank is degraded due to various anthropogenic activities. These activities include rapid urbanization and agricultural practices. This increasing human activities resulted to some environemtnal impacts such as sedimentation, eutrophication etc.

Water quality problems in reservoirs are often due to cultural eutrophication* which is caused by:

- Municipal sewage discharges
- Industrial wastewater discharges
- Urban runoff
- Agricultural runoff with natural or artificial fertilizers causing high nutrient loading
- Biocides from aquaculture

Some physical parameters also affecting the water quality in water bodies, those includes,

- Wind movement
- Temperature changes
- Inflows or outflows

Usually the following processes are taking place in the ecosystem of water body.

- Reduced inflows in summer months with corresponding reduced water depths
- Increased solar radiation in the summer months with corresponding elevated water temperatures, particularly closer to the surface.
- Reduced dissolved oxygen values in the summer months, due to increased temperature and reduced depths.

Little amount of pollutant enter into the water body, the concentration of the pollutant increases, the oxygen concentration decreases while the BOD and COD increases. If the pollutants are toxic it leads to the death of the biota and thus photosynthesis decreases. The respiratory process increase and so does the activity of the micro organisms causing a further increase in the BOD load.

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* Cultural eutrophication is normally caused by human activities.

3.2 Pollution Paths

Fresh water is being polluted in many ways due to discharging wastewater without proper treatment and proper management. Pollutants have entered the water bodies in the form of silt through erosion, diverse form of wastes from industries, as organic materials from municipal sewage (effluents from rice mills, vehicle service stations, garages, petrol stations, hotels, lodges & household waste) and agricultural land, toxic chemical such as pesticides used in agriculture. Wastes are causing the accumilation of nutrient & pollution loads to tanks.

4.0 Impacts of Pollution on Waterbodies:

Pollution is any increase in the concentration of matter or energy generated by human activity, which degrades a living community or its abiotic environment. Pollutant shows persistence if it remains in the system in a form that continues to have an impact on the biota (such as non-biodegradable pollutants). Most often, a dose-response relationship is used to measure the impact of various concentrations at which some effect is observed and at which some action might be taken in the field. Pollutants rarely occur and their interaction with each other can further complicate the impact. Two pollutants whose combined impact is greater than the sum of each acting independently are said to be synergistic: their interaction enhances their toxicities. One pollutant is antagonistic to another where it ameliorates the toxicity of the second.

Even ground waters have been affected by infiltration of water from **tanks**, lakes…etc. Also important in this regard is the socio-economic aspect of unhygienic use of aquatic systems, pollution by pathogens and its impact on public health.

The widespread scarcity, gradual destruction and aggravated pollution of freshwater resources, along with the progressive encroachment of incompatible activities, demand, integrated water resources planning and management. Such integration must cover all types of interrelated freshwater bodies, including both surface water and ground water, with due consideration to both the quantitative and qualitative aspects.

Integrated water resources involve effective water pollution prevention and control programs, based on an appropriate combination of pollution reduction-at-source strategies, environmental **impact assessment** and **enforceable standards** for major point source discharges and high-risk non-point sources, commensurate with socio-economic development.

5.0 Conditions Related to Wastewater and Pollutant Standards

Pollution and water quality degradation thus interfere with vital and legitimate water uses at scales from local to regional to international levels. Water quality criteria and standards are therefore necessary to ensure that the appropriate quality of resource is available to a particular consumer process. The related legislation is used as an administrative means to manage and maintain water quality for the maximum number of users of the water body.

Water quality and standards vary and may originate in a number of possible ways; there are international standards set by the WHO and EU, regional standards set by individual states or local standards set by individual local authorities. In Sri Lanka, CEA has designed some limits for the pollutants that discharge with sewage water into fresh water bodies.

The total quantity of wastewater discharged to local Authorities to issue Environmental Protection License should be less than 3 m^3 /day. If any activity discharges more than 3 m^3 of wastewater per day, such activity comes under No. 1159/22 dated 22.11.2000 and such activities should be referred to the Central Environmental Authority.

The conditions generally used to control environmental pollution from the wastewater discharge the activities, which have discharge capacity of less than 3 m^3 of wastewater per day are as follows.

a. All wastewater discharged from the operation of the industry (inclusive of bottle washing wastewater) should be confirmed to the tolerance limits for discharge of the industrial effluents prescribed by the CEA.

b. Wastewater generated from the domestic activities should be released in to a properly constructed septic tank/soakage pit.

Depending on the discharge point and the receiving source, the tolerance limits of the wastewater has gazetted in the Gazette Notification No. 595/16 dated 02/02/1990 (Source: CEA).

General Standards for Discharge of Effluents into Inland Surface Waters (Source: CEA)

No	Determinant	Tolerance limit
1	pH value at ambient temperature	6.0-8.5
2	Total suspended solids, mg/l, max	50
3	Particle size of total suspended solids	Shall pass sieve of aperture size 850 micron
4	Temperature of discharge	Shall not exceed 40oC in any section of the stream within 15m down stream from the effluent outlet.
5	Biochemical Oxygen Demand (BOD_5), in the five days at 20^oC, mg/l, max	30
6	Cyanides as (CN), mg/l, max	0.2
7	Chemical Oxygen Demand (COD), mg/l, max	250
8	Oil and grease, mg/l, max	10.0
9	Phenolic Compounds, (as phenolic OH) mg/l, max	2.0
10	Sulphides, mg/l, max	2.0
11	Fluorides, mg/l, max	2.0
12	Total residual chlorine, mg/l, max	1.0
13	Arsenic, mg/l, max	0.2
14	Chromium total, mg/l, max	0.1
15	Copper, total, mg/l, max	3.0
16	Zinc total, mg/l, max	5.0
17	Ammonia cal nitrogen, mg/l, max	50.0
18	Total residual chlorine, mg/l, max	1.0

19	Cadmium total, mg/l, max	0.1
20	Lead, total, mg/l, max	0.1
21	Mercury total, mg/l, max	0.0005
22	Nickel total, mg/l, max	3.0
23	Selenium total, mg/l, max	0.05
24	Pesticides	Undetectable
25	Radio active material a) Alpha-emitters micro curie/ml b) Beta-emitters micro curie/ml	 10^{-7} 10^{-8}

6.0 Impact Assessment:

Impact assessment is usually done by setting standards for water quality and then assessing the various parameters in relation to such standards. However, these standards are based on the toxicity tests as well as toleration limits

There are several methods that/which are used in assessing the impacts of water quality, including Modelling, chemical analysis etc. In this regards, application of chemical analysis in assessing water quality impacts is explained in detail.

7.0 Chemical Analysis:

Analysis of water and wastewater is becoming increasingly important and necessary to examine the quality of water and wastewater. This is also an important tool to conduct treat ability studies of wastewater and to assess ill effects and health effects. Chemical analyses are used in conjunction with biological and physical parameters to characterize the quality and understand the chemical evolution of fresh water. Standardized analytical methods allow the integration of data collected on disparate water bodies, regardless of geographic location.

7.1 Importance of Chemical Analysis

Pollutant analysis provide a clear understanding of the limits of a water body's ability to assimilate (take in) some level of **pollution** without harming the water system, its aquatic plants and animals and humans who may use the water.

The analytical study should begin with an assessment of previous records of factors that might influence natural changes and of recent discharges that may have been made and then performing the necessary physico-chemical and hydro biological analyses of the water.

Chemical examination of the water is carried out on site during the field investigation and in the laboratory. Water monitoring and the chemical analysis of water require careful planning to achieve valid results. Water analysis focuses the purpose of water monitoring efforts, the currently known information about the water body and the intended use of the resulting data. Once this information is known, project managers establish specific parameters to be measured set the level of quality needed to support the intended data use and determine the detailed steps of a monitoring program.

The parameters to be measured would be as follows:

- Dissolved oxygen (DO) and **pH** (to characterize the oxygen swings/fluxes);
- Turbidity and chlorophyll (to monitor changes in algae growth); and
- Nitrate and phosphate levels (to monitor the nutrients).

In order to monitor the daily changes in DO and pH, a continuous monitoring probe would be used. Weekly **grab samples** would be taken for the other parameters.

Each method in turn specifies the sampling procedures in terms of type of container to be used to collect the sample (plastic or glass); preservation requirements once the sample is collected (acidification or refrigeration); and holding-time limits within which the sample must be analyzed.

The methods also specify the **calibration** procedures and quantization limits of the method.

All of these specifications ensure that the analytical results meet the requirements of known data quality in terms of **accuracy** and **precision**. With the decision that the data were not to be used for legal enforcement, the watershed council could forego a formal chain-of-custody record that involves documenting the exact location of the sample at all times to ensure it could not have been tampered with between the time of collection and final analysis.

The chemical analysis of water involves many steps that are closely linked: planning, sample collection, analytical chemistry, quality assurance and data management. If these steps are followed, the data can be used for short-and long-term trending, modelling and predicting and basic research.

7.2 Tools of Chemical Analysis:

7.2.1 Collection of Water Samples

In reservoirs, the places where water should be sampled and located is based on each specific situation; in some cases, the samples may have to be taken from different depths within the water column. Special sampling equipment are used to take water samples from different depths and from just above the bottom.

The samples are poured into clean 1- to 2-litre bottles. It is not recommended that bottles be filled with water taken from near the bank or shore; it is usual to take the samples from 1–2 m away from the water's edge. Water samples from near to the bottom must be taken with care in order not to include mud and other sediment. To obtain the maximum value in terms of analytical accuracy and usefulness of the data, the time between sampling and analysis must be as short as possible. Ideally, the samples should be transported in thermally insulated containers. In the laboratory, the samples should be stored in refrigerators and kept at 3–4°C. However, these procedures may not be adequate to ensure the stability of some water parameters. In such cases, the samples must be analyzed as soon as they are collected, or they may be stabilized with a small amount of preservative.

7.2.2 Preservation and Treatment of the Samples

The basic chemical analysis of the water includes the determination of the colour, odour, pH, acid capacity (alkalinity) and concentration of dissolved oxygen, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia, nitrites, nitrates, phosphates and total phosphorus. The need to analyze for any other chemicals depends on the outcome of the local investigation into possible sources of pollution; the aim is to obtain chemical data that, together with eco toxicological data, will identify the causes of the mortality or damage of the fish. When assessing the results of the physico-chemical analysis of water samples in order to identify causes of mortality, the parameters should not be evaluated in isolation; possible interactions have to be taken into account. The toxicity of the different chemicals and products to fish and aquatic invertebrates is influenced by the natural quality characteristics of the aquatic environment.

7.2.3 Chemical Concentration Units

The concentration of a substance in water is usually expressed as milligrams per litre (mg/l) or micrograms per litre (μg/l), which are more casually referred to as parts per million (ppm) or as parts per billion (ppb), respectively. It is interesting to note that owing to improvements in the chemical analysis of water, many environmental analyses are measuring well beyond the ppb range and into levels of parts per trillion and even parts per quadrillion.

7.3 Capabilities of Chemical Analysis

Analytical chemistry is the science to analyze compositions and quantities of analytical targets. These analytical results have played critical roles from the understanding of basic science to a variety of practical applications, such as biomedical applications, environmental monitoring, quality control of industrial manufacturing and forensic science, to name a few.

7.4 Failures of Chemical analysis:

Standard approaches in analytical chemistry result in failures due to:

- Instrumental errors
- Calculation errors
- Physical conditions of environment (temperature)
- Chemical errors (outdated chemicals)
- Analyst's carelessness.

Further, especially in scenarios where ecosystems are being investigated using analytical chemical methods, failures can occur if the researchers develop methodologies in a mechanical and linear manner with no appreciation for the complexity of the system of concern. This could be one of the main reasons as to why investigative studies on waterbody pollution in Sri Lanka produce no solutions to the problems. As such, the present analytical methods need to be improved.

7.5 Improving Chemical Analysis Methods:

To enable a systemic understanding of the problem that is being analysed using analytical chemistry non-linear (or systemic) approaches is needed. In this respect, it becomes necessary to employ inductive reasoning oriented hypothesis generation methods. Any investigation should have a solid theoretical underpinning in these regards and, generation of hypotheses prior to the investigation/s enable the researchers to visualise and comprehensively approach the problem of concern. Further, within the confinements of investigations of waterbodies, the findings using analytical chemistry can further be supplemented by (successful integration of):

- System/s simulation modelling approaches to test plausible management options
- Geographic Information Systems (GIS) to map and produce zonation maps for planning and chemical remediation.
- Generating environmental audit procedures for assessment of socio-economic and management aspects to the impacts of waterbody pollution.

Further, when it comes to reporting the findings of a research project in this regard, a comprehensive approach can also be developed to integrate field data, analytical chemistry data, quality control data and historical data when analysing/including results to accommodate technical and systematic analysis.

Analytical chemical data generated using such validated protocols or their equalling provides the supporting quality control information necessary to assess the quality of the data.

This knowledge is useful in planning for data gathering activities, in the design of treatment systems and in presenting site data to management, regulators and the public in an understandable, non-threatening manner. This is prescribed under the fact that two methods combined in impact assessment are greater than the sum of each acting independently (synergistic), their interaction enhances their ability to improve pollutant identification and monitoring processes.

7.6 Generating Hypotheses in Chemical Analysis:

A **hypothesis** consists either of a suggested explanation for a phenomenon or of a reasoned proposal suggesting a possible correlation between multiple phenomena. The scientific method requires that one can test a **scientific hypothesis**. Scientists generally base such hypotheses on previous observations or on extensions of scientific theories.

Any useful hypothesis will enable predictions, by reasoning (including deductive reasoning). It might predict the outcome of an experiment in a laboratory setting or the observation of a phenomenon in nature. Researchers weighing up alternative hypotheses may take into consideration:

- Testability
- Simplicity
- Scope - the apparent application of the hypothesis to multiple cases of phenomena
- Fruitfulness - the prospect that a hypothesis may explain further phenomena in the future
- Conservatism - the degree of "fit" with existing recognised knowledge-systems

Any such investigation should preferably be designed through a hypotheseis generation perspective using the inductive reasoning perspectives.

8.0 Conclusion:

Failure of chemical investigations of natural ecosystems fails to produce fruitful solution as they fail to systemic approach the problems.

As such, this review paper proposes that inductive reasoning should be effectively applied to generate hypotheses (which are developed on the basis of an in-depth understanding of the ecosystem), where systemic and comprehensive investigations are possible, thus enabling the researcher/s to find the root causes and the rightful solutions to the problems. The chemical analysis is important in scientific inquiry by using inductive reasoning as for–

- Understanding the system according to chemical changes
- Identify possible impacts in water body ecosystem by detect the pollution pathways.
- Can manage the chemical pollution in water bodies
- It can help to monitoring the ecosystems equilibrium through chemical analysis.

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