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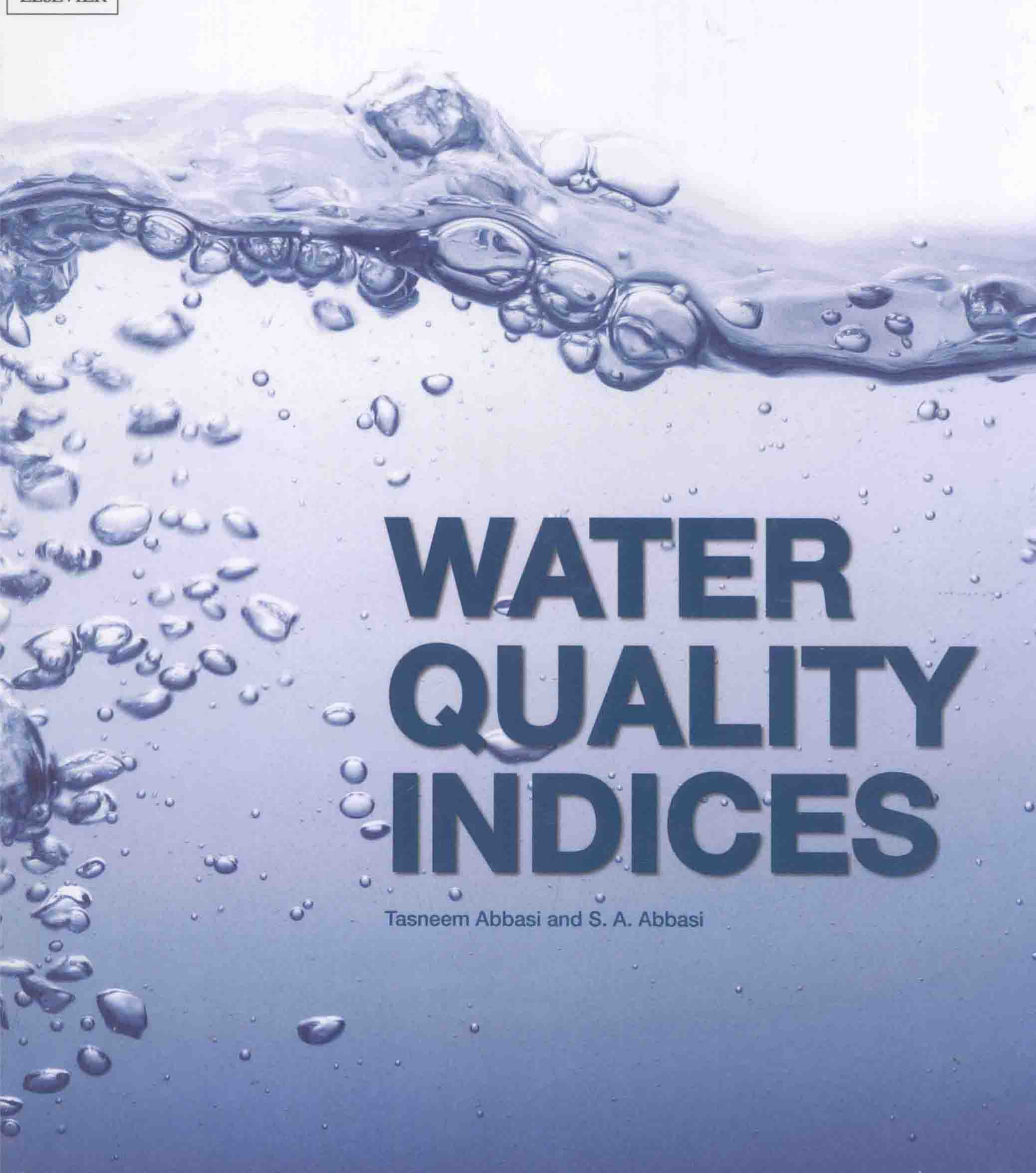

WATER QUALITY INDICES

Tasneem Abbasi and S. A. Abbasi

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Dedicated to

Neelu Aunty, Sophia Aunty, Rubi Aunty, and the memory of Daada - Daadi

-TA

Aapa, Didi, Rubi Behen, and the memory of Daddy and Mummy

-SAA

Foreword

Till as late as the beginning of the current millennium, environmental education was largely confined to postgraduate and doctoral programmes, with only a few undergraduate programmes offering specialisation in environmental studies. But, in recent years, environmental education is increasingly featuring not only in collegiate education but preparatory school level as well. The exceedingly desirable consequence of this happening is that lay persons all over the world are developing familiarity with terms such as air quality, water quality and ecorestoration. Weather reports are no longer confined to temperature, humidity and air speeds but are beginning to speak of levels of particulate matter, NO_x and SO_x.

Given the pivotal role of water in supporting and shaping our existence, it is expected that sooner than later everyone would like to know, in quantifiable terms, how good or bad is the water one uses. One would like to know whether the piped water one gets is turning for better or worse and, all aspects considered, whether Brand A of bottled drinking water is *quantifiably* superior to Brand B. Awareness towards the overall water-quality situation of a town, a city, a region or a country will also increase. This emerging scenario would necessitate widespread use of water-quality indices (WQIs) because WQIs are the only medium by which the highly multi-attribute and multi-variate concept of water quality can be conveyed to lay persons in the form of a single score.

As has been brought out by the authors in their introductory chapter, WQIs indicate water quality much in the same manner as the Sensex reflects the level of the Mumbai Stock Market and the Dow Jones Index reflects the status of the New York Stock Market. Even a person with no acquaintance with the intricacies of stock prices and economics can get an idea of the state of economy by these index values. Likewise, the simple figure of the per cent by which a share price index has risen or fallen on a day gives an idea of how thousands of different companies have fared *vis a vis* market capitalisation on that day. WQIs will perform the task of 'measuring' water quality and communicating it to the water users in a similar fashion. We will hear sentences like, "the water quality of our river at the water supply station had fallen to 35 last year; now it has improved to 45 but we are trying to improve it beyond 60 so it goes into the 'very good' class". Or a bottled drinking water supplier announcing, "our water always has a score well above 75 on the National Drinking Water Index".

Given the importance of water in the life of every single living being, not to speak of the veritable 'life-and-death' impact it has on human beings, the importance of this book cannot be overemphasised. That it is the first-ever book on the subject makes its publication an important global event. I congratulate *Elsevier* for their initiative in publishing this book and wish it great success.

Prof J. A. K. Tareen
Vice Chancellor,
Pondicherry University

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PART I

WATER QUALITY INDICES BASED PREDOMINANTLY ON PHYSICO-CHEMICAL CHARACTERISTICS

CHAPTER

1

Why Water-Quality Indices

OUTLINE

1.1. INTRODUCTION

1.1.1. Water Quantity and Water Quality

Of all natural resources, water is unarguably the most essential and precious. Life began in water, and life is nurtured with water. There are organisms, such as anaerobes, which can survive without oxygen. But no organism can survive for any length of time without water.

The crucial role of water as the trigger and sustainer of civilizations has been witnessed throughout human history. But, until as late as the 1960s, the overriding interest in water has been *vis a vis* its quantity. Except in manifestly undersirable situations, the available water was automatically deemed utilisable water. Only during the last three decades of the twentieth century the concern for water *quality* has been exceedingly felt so that, by now, water quality has acquired as much importance as water quantity.

What is water quality? This question is immensely more complex than the question: *What is water quantity?*

We can say: this reservoir contains 2 million m^3 of water or the present flow in this river is 15 m^3 sec^{-1}. Expressing water *quantity* is as simple as this.

But how do we express water quality of the same stream? The quality may be good enough for drinking but not suitable for use as a coolant in an industry. It may be good for irrigating some crops but not good for irrigating some other crops. It may be suitable for livestock but not for fish culture. Whereas water *quantity* is determined by a single parameter − the water mass − water quality is a function of anything

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and everything the water might have picked up during its journey from the clouds to the earth to the water body: in dissolved, colloidal, or suspended form. Given the fact that water is a 'universal solvent', it picks up a lot!

One way to describe the quality of a given water sample is to list out the concentrations of everything that the sample contained. Such a list would be as long as the number of constituents analyzed and that may be anything from the 20-odd common constituents to hundreds! Moreover, such a list will make little sense to anyone except well-trained water-quality experts.

How to compare the quality of different water sources? It can't be done easily by comparing the list of constituents each sample contains. For example, a water sample which contains six components in 5% higher-than-permissible (hence objectionable) levels: pH, hardness, chloride, sulphate, iron and sodium may not be as bad for drinking as another sample with just one constituent – mercury – at 5% higher-than-permissible.

Water-quality indices seek to address this vexing problem.

1.2. WATER-QUALITY INDICES (WQIs)

Water-quality indices aim at giving a single value to the water quality of a source on the basis of one or the other system which translates the list of constituents and their concentrations present in a sample into a single value. One can then compare different samples for quality on the basis of the index value of each sample.

1.2.1. A Novel Idea?

The concept of using an index to represent in a single value the status of several variables is not a novel idea; it has been well-entrenched in economics and commerce (Fisher, 1922; Diewert and Nakamura, 1993). Most countries have their 'consumer price index' in which, on the basis of an integration of the prices of certain commodities, a single value is obtained to determine whether the market is, overall, cheaper or costlier at any given instant compared to any other past instant.

The commodities for such indices are selected on the basis of their 'driver power' – in other words, the 'power' or the 'reach' of the commodity vis a vis influencing the prices of several other commodities. If a shampoo becomes costlier or cheaper, it will not affect the prices of other commodities significantly, whereas any change in the price of cement or petroleum would.

Then we have share-market indices such as the Dow Jones Index of the New York stock exchange and the Sensex of Mumbai's stock exchange. These indices are also composed of the prices of certain shares of high driver power (such as cement). In time these indices have become measures not merely of the stock traded at the respective exchanges but also of the economies of the respective countries. When indices of economically advanced countries such as the Dow Jones Index suffer a slump, it impacts the stock exchanges of most other countries as well, often taking their indices down with it.

Indices have also been used in ecology to represent species richness, evenness, diversity etc. Accordingly, we have the Shannon Index, the Simpson Index, and so on. In numerous other fields – such as of medicine, sociology, process safety, etc – indices are extensively used.

It can be said that indices (the singular of *indices* is *index*) are composite representations of a condition or situation derived from a combination, done in certain ways, of several relevant but noncommensurate observed facts/measurements. The combination leads to a single ordinal number that facilitates understanding and interpretation of the overall import of the facts that have contributed to that number.

Environmental indices – of which water-quality indices form a major component – are used as communication tools by regulatory agencies to describe the 'quality' or 'health' of a specific environmental system (e.g., air, water, soil and sediments) and to evaluate the impact of regulatory policies on various environmental management practices (Song and Kim, 2009; Pusatli et al., 2009; Sadiq et al., 2010). Environmental indices have also been used in life-cycle assessment (Weiss et al., 2007; Khan et al., 2004) and to characterise different types of environmental damages, including global warming potential (Goedkoop and Spriensma, 2000).

1.3. BACK TO WATER-QUALITY INDICES (WQIs)

WQIs may have gained currency during the last 3 decades but the concept in its rudimentary form was first introduced more than 150 years ago – in 1848 – in Germany where the presence or absence of certain organisms in water was used as indicator of the fitness or otherwise of a water source.

Since then various European countries have developed and applied different systems to classify the quality of the waters within their regions. These water classification systems usually are of two types:

1. those concerned with the amount of pollution present and
2. those concerned with living communities of macroscopic or microscopic organisms.

Rather than assigning a numerical value to represent water quality, these classification systems categorised water bodies into one of several pollution classes or levels. By contrast, indices that use a numerical scale to represent gradations in water-quality levels are a recent phenomenon, beginning with Horton's index in 1965, detailed below.

1.4. THE FIRST MODERN WQI: HORTON'S INDEX

Horton (1965) set for himself the following criteria when developing the first-ever modern WQI:

1. The number of variables to be handled by the index should be limited to avoid making the index unwidely.
2. The variables should be of significance in most areas.
3. Only such variables of which reliable data are available, or obtainable, should be included.

Horton selected 10 most commonly measured water-quality variables for his index, including dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, and chloride. Specific conductance was intended to serve as an approximate measure of total dissolved solids (TDSs), and carbon chloroform extract (CCE) was included to reflect the influence of organic matter. One of the variables, sewage treatment (percentage of population served), was designed to reflect the effectiveness of abatement activities on the premise that chemical and biological measures of quality are of little significance until substantial progress has been made in eliminating discharges of raw sewage. The index weight ranges from 1 to 4. Notably, Horton's index did not include any toxic chemicals.

The index score is obtained with a linear sum aggregation function. The function consists of the weighted sum of the subindices I_i divided by the sum of the weights W_i and multiplied by two coefficients M_1 and M_2, which reflect temperature and obvious pollution, respectively:

$$QI = \frac{\sum_{i=1}^{n} W_i I_i}{\sum_{i=1} W_i} M_1 M_2$$

Horton's index is easy to compute, even though the coefficients M_1 and M_2 require some tailoring to fit individual situations. The index structure, its weights, and rating scale are highly subjective as they are based on the judgement of the author and a few of his associates.

Horton's pioneering effort has been followed up by several workers who have striven to develop less and less subjective but more and more sensitive and useful water-quality indices.

1.5. MORE ON THE BENEFITS OF WQI

The formulation and use of indices have been strongly advocated by agencies responsible for water supply and control of water pollution. Once the water-quality data have been collected through sampling and analysis, a need arises to translate it into a form that is easily understood. Once the WQIs are developed and applied, they serve as a convenient tool to examine trends, to highlight specific environmental conditions, and to help governmental decision-makers in evaluating the effectiveness of regulatory programmes.

WQIs, of course, are not the only source of information that is brought to bear on water-related decisions. Many other factors are considered besides indices and the monitoring data on which the indices are based.

Indeed, nearly all the purposes for which one monitors water quality – assessment, utilisation, treatment, resource allocation, public information, R&D and environmental planning – are all served by indices as well. In addition, indices make the transfer and utilisation of water-quality data enormously easier and lucid. To wit, water-quality indices help in:

1. Resource allocation
   Indices may be applied in water-related decisions to assist managers in allocating funds and determining priorities.
2. Ranking of allocations
   Indices may be applied to assist in comparing water quality at different locations or geographical areas.
3. Enforcement of standards
   Indices may be applied to specific locations to determine the extent to which legislative standards and existing criteria are being met or exceeded.
4. Trend analysis
   Indices may be applied to water-quality data at different points in time to determine the changes in the quality (degradation or improvement) which have occurred over the period.
5. Public information
   Index score being an easy-to-understand measure of water-quality level, indices can be used to keep the public informed of the overall water quality of any source, or of different alternative sources, on a day-to-day basis just as Sensex score tells in one word whether the stocks, by and large, went up or down.
6. Scientific research
   The inherent quality of an index – which translates a large quantity of data to a single score – is immensely valuable in scientific research, for example, in determining the efficacy of different ecorestoration measures or water-treatment strategies with reference to a water body, the impact of developmental activities on water quality, etc.

1.6. WQIS BASED ON BIOASSESSMENT

On the basis of parameters that are incorporated in an index to judge water quality, the WQIs can be loosely classified into 'indices predominantly based on physcio-chemical characteristics' and 'indices based on bioassessment'. The first modern WQI, the Horton's index, described in Section 1.4, belonged to the first category, so are all the indices described in *Part I* of this book. Just as Horton's index has one parameter (out of 10 chosen by him) which requires bioassessment – coliforms – several other indices described in *Part I* have one or more 'biological' parameters but they are all predominantly based on physico-chemical parameters. In contrast, the WQIs based on bio-assessment, described in *Part II*, are predominantly based on sampling, identification, and enumeration of biological organisms.

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