Trends in Environmental Analytical Chemistry 3 (2014) 7–13

Contents lists available at ScienceDirect

Trends in Environmental Analytical Chemistry

journal homepage: www.elsevier.com/locate/teac

Review

The social responsibility of environmental analysis

Miguel de la Guardia *, Salvador Garrigues

Department of Analytical Chemistry, University of Valencia, Research Building "Jeroni Muñoz", Dr. Moliner str., 46100 Burjassot, Valencia, Spain

ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form 9 September 2014
Accepted 9 September 2014

Keywords:
Social responsibility
Green analytical chemistry
Environmental studies

ABSTRACT

A literature updated has been made on the academical studies focused on the social impact of environmental studies, paying attention to both, the quality of the information provided and the side effects of the methodology employed, also considering the importance of the analytical methodologies in the development of remediation processes and the key subject of the transmission of the environmental information to the policy makers and the general society.

Contents

1. Introduction

Environmental analysis is nowadays one of the main fields of application of analytical methods and it covers from private to public studies, focused to evaluate the effect of human activities and their impact on the quality of air, water, soil or biota. Proper analytical environmental data provide evidences about bad industrial practices and offer the prime matter to develop mathematical models suitable to evaluate the sustainability of our life style [1–3].

The North American Environmental Protection Agency (EPA) has insisted many times on the need of deep analytical studies to correctly evaluate the risks of technological processes and to alert about environmental side effects of human activities and, in this frame, the interest of greening both, chemistry and analytical chemistry, has been extensively influenced the political activities and attract academic interest [4–8].

The main objective of this paper is to discuss the state-of-the-art of the ethical involvement of academic and social institutions in order to evaluate aspects regarding both, the side effects of methodologies used, and the intrinsic aspects of the environmental analytical studies concerning both, the subject of study and the transmission of the information to the policy makers and the society in general.

2. Man and the biosphere

The presence of man in the earth planet creates tremendous changes, difficult to be interpreted without taking into account the capability of humans to build new tools and to change dramatically the natural equilibrium on the earth [9]. Because of that, from the last century many voices claimed about the risks of an increasing population and the limits of growth in all the different aspects of the life.

As Fig. 1 shows, the presence of humans completely modifies the natural chemical cycles between air–water–soil and biota and new chemicals and processes are incorporated by anthropogenic activities in both, industrial and habitation sites covering from

* Corresponding author. Tel.: +34 96 3544838; fax: +34 96 3544845.

2214-1588/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.teac.2014.09.001

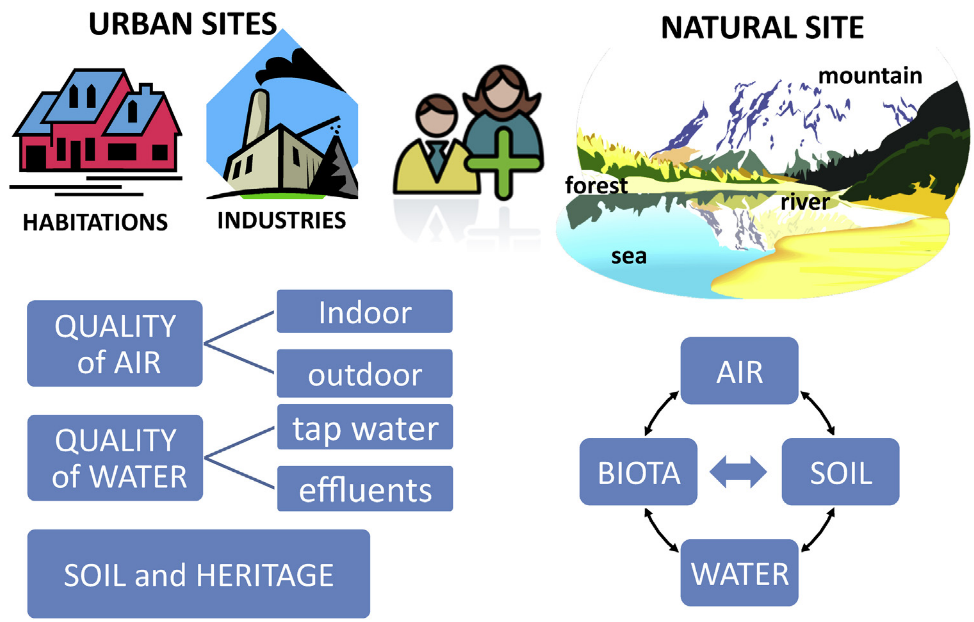

Fig. 1. Man and the biosphere. A complex relationship.

remote practically isolated environments to our big cities, thus establishing really complex relationships which dramatically influence the quality of air and water also providing long term changes in the earth crust [10]. Because of that, special care must be taken in order to well focus environmental studies, considering all the factors influencing the quality of air, soil and water and providing data about as much as possible elements and molecules in order to correctly evaluate the present state of both, natural and polluted sites, and to prevent their future evolution.

On the other hand, the social demands on complete informations about any kind of samples increase year after year and to be able to create significant models to evaluate the environment we need to process data from different compounds and different kind of samples. All that increases the analytical efforts and could increase the side effects and collateral damages involved on the use of chemicals. So, this is a kind of paradox than the increasing of environmental studies could be one of the reasons of environmental pollution, thus affecting in a negative way the quality of our air, water and land. However, it must be also considered that analytical methodologies could be of a great value for the development and control of remediation processes.

Because of the social demand of analysis and the potential negative impact of this activity, Green Analytical Chemistry (GAC) becomes a solution for the challenge to extend the advantages of the chemical knowledge in many aspects of the life without deleterious environmental effects. Additionally, in the last five years Green Analytical Chemistry has been evidenced its importance in the scientific literature through the publication of many special issues of analytical journals devoted to this fact [11–14] and by the publication of several books covering many aspects of the fundaments and applications of that [6–8,15].

3. Evolution of environmental conscience on analytical chemistry

Taking into consideration that accuracy is the main analytical characteristics in all kind of analysis and representativeness is the main problem in environmental analysis to obtain a correct picture of problems, in former times the basic analytical features as sensitivity, selectivity and precision were in the focus of the analytical practice and every effort to search for highly selective and sensitive methodologies was justified in order to move from molar concentration to parts per million or parts per billion, looking for the development of specific methods suitable to determine quantitatively a single molecules in a complex sample, being the rest of method features considered just as practical aspects.

So, every kind of sophisticated instrumental and complex methodologies were deeply explored in former years to look for the improvement of the analytical properties in spite of their actual needs. That was a clear reflect of the chemiurgical paradigm in terms of Malissa interpretation of the Analytical Chemistry development [16] and thus environmental and safety side effects of the use of new toxic reagents and tremendously big amounts of energy and consumables was totally out of consideration by method makers.

We must recognize that the chemiurgical analytical chemistry provided a tremendous development in both, instrumentation and methods, moving from the availability of tools for major and minor sample components to new possibilities to evaluate the target analytes at trace and ultra trace levels, thus providing a good knowledge about sample composition and accurate data for earlier diagnostic of problems found in the long term use of industrial products. From the environmental point of view we are nowadays able to speak about emerging pollutants because of the improved sensitivity of our methods to make visible very low amounts of chemicals used from the past but which remain unappreciable in environmental matrices till the possibility to measure these compounds with an enhanced sensitivity [17,18].

However the increase of the number of analysis made at all the chemical activity levels, from the industrial to the health and environmental fields, has created economic problems including a high demand of reagents and solvents and the need of waste management of hazardous materials, thus increasing dramatically the cost and risks of analytical practices and, because of that, a new relationship between method developers and method users with the social community must be explored in deep in the frame of social responsibility.

Green Analytical Chemistry (GAC), as a difference of other ecological mentality movements, does not implies the increase of costs of operation. On the contrary, in some cases the search for simplified and direct methods and the minimization of these methodologies imposed by the need of a drastic reduction of environmental side effects creates also a reduction of costs. So, probably one of the main reasons of the success of GAC could be that it combines the interest of both, the environment and the economy adding economic reasons to the environmental ethics and thus improving the sustainability of our daily practices.

As it can be seen in Fig. 2 the evolution from the chemiurgical use of analytical chemistry to the ecological paradigm has been compressive [19] without renouncing to the main analytical features of the methods but incorporating to it the so called green parameters. These figures are focused on the replacement of toxic reagents, the reduction of the use of energy, solvents and reagents, especially those coming from non-renewable origin, through the development of direct analytical methods suitable to be applied to untreated samples, the miniaturization and automation of all the steps of the analytical process, together with the on-line waste treatment, incorporating to the routine methodologies as a final step after measurements, and the development of portable apparatus and instrumentation suitable to avoid the sample transport and thus avoiding analyte loses or contaminations and environmental risks.

Nowadays the Green Analytical Chemistry seems to be the best way to provide a correct answer to the increasing social demands of analysis, from the mineral composition of samples to the presence of organic compounds, including organometallic ones and biochemical molecules and also incorporating information about chemical species of elements and discriminating metabolites from the original molecules.

The aforementioned demand covers environmental samples of all types from air, water and soils till biota. Nowadays special attention must be do in order to assure that the social needs of an increasing number of analysis do not involve serious risks for both, method operators and the environment. Because of that, additionally to incorporate the ultimate advanced techniques as rearguard confirmation methods, it must be mandatory to impulse vanguard screening alternative ones, suitable to be employed on remote sensing, in-field analysis or at least in-field sampling and analyte pre-concentration and on-line elution in the laboratory (see Fig. 3) to obtain as fast as possible information with the lowest consume of energy and reagents and all the suggested items must be adapted in order to balance the advantages of an increase of our knowledge about environmental pollution and the deleterious environmental effects of an increasing use of reagents and solvents together with energy consumption and waste generation.

4. The side effects of environmental analysis

It seems clear that the main purpose of the environmental analysis is to provide information about the way that natural causes and human impact affect ecosystems and thus, data and, especially models suitable to explain the presence and evolution of natural components and pollutants, is the challenge of environmental studies. However we cannot forget that a lot of energy and labor, reagents and solvents must be used and so, a correct balance of both, input and output of the analytical methods must be done to evaluate their side effects which, in our opinion, could be condensate in the consume of energy and materials together with the waste and residue generations in front of the information obtained (see Fig. 4).

On the other hand, when we evaluate the different steps of an analytical procedure, not only sample pretreatment, analytes extraction or sample dissolution, analyte separation and their determination must be considered, apparently innocuous steps, like sampling and sample transport can affect negatively the environment, being also some of the reasons that damage the accuracy of determinations, thus affecting the value of the analytical data through problems concerning sample representativity and sample changes from the field to the laboratory.

In order to minimize the aforementioned troubles, to move from off-line analysis to in-situ ones seems the best option and probably it is the reason for the strong development in portable instrumentation [20] and portable sample treatments together with the use of different methods of analysis [21,22].

Another subject of importance in the development of new analytical tools is the exponential growing of nanotechnologies and the impressive production and use of nanoparticles which will create new challenges in the environmental field during the next years, and because of that it seems of a great importance the compromise of the analytical chemists with the development and use of the so called green nanotechnology [23] which involves a sustainable nanotechnology in order to equilibrate the advantages offered by scaling down the size of materials and the environmental extra costs and side effects involved, thus being required a careful consideration of the toxic nature of nanomaterials

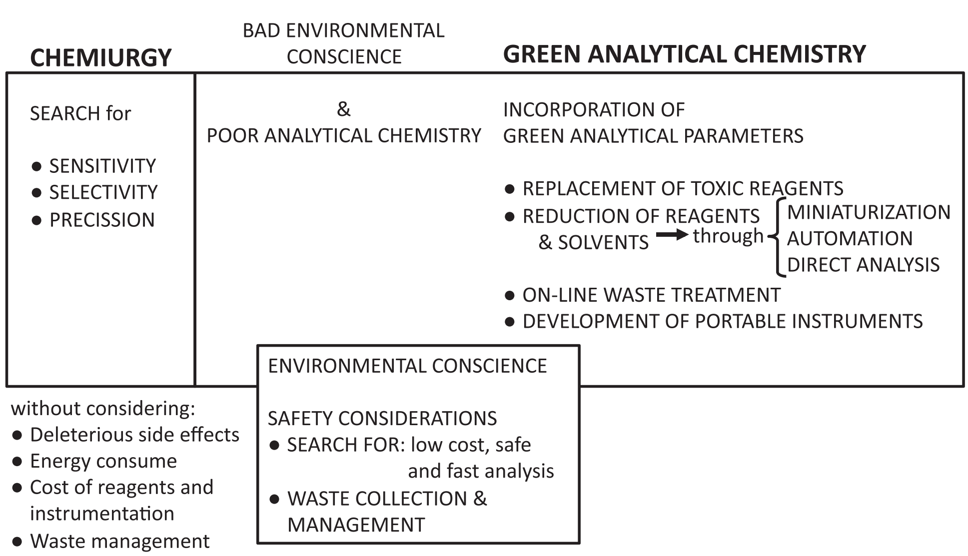

Fig. 2. Evolution of the analytical chemistry paradigm.

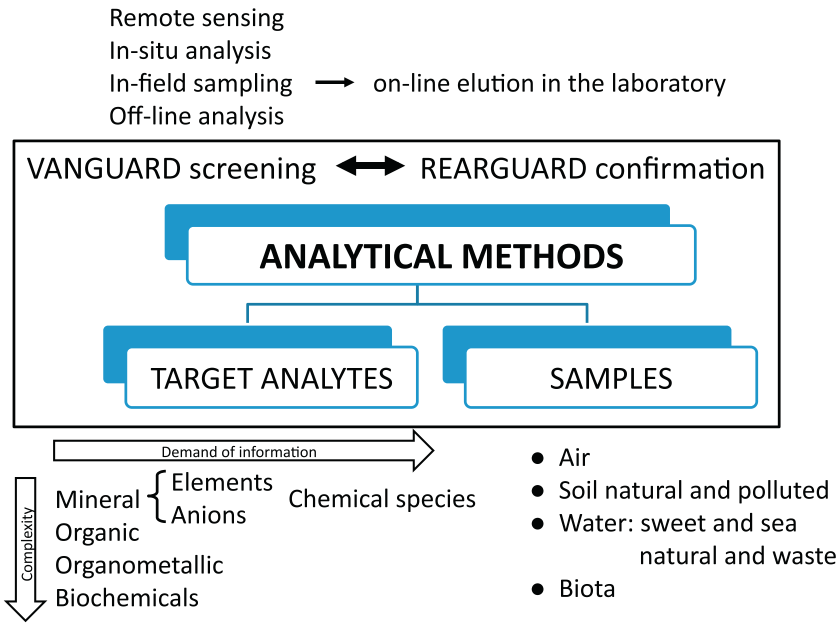

Fig. 3. Analytical problems and tools.

employed in the analytical measurements and the potential risk of their widespread in the environment.

In short, it is interesting to notice that environmental risks are not so far from the accuracy risk coming from the use of several steps in the analytical processes, also related to their transport to the laboratory. So, once again it seems that efforts must be concentrated on the ethical behavior of laboratories and organizations in order to follow the international norms regarding environmental protection and occupational health and safety requirements and international standard related to the ISO 26000:2010 [24] concerning the guidance on social responsibility, the ISO 14001:2004 [25] according to environmental management systems requirements and the OHSAS 18001:2007 and OHSAS 18002:2008 [26] concerning standards on occupational health and safety management systems. All that has created a frame in which the side effects of the analytical activities must be evaluated [27–29] for a social responsible analytical point of view.

Valcárcel et al. [27] has defined the social responsibility in analytical chemistry as “the awareness of the impact in societal areas (e.g., health, agro-food, industry) and on the environmental

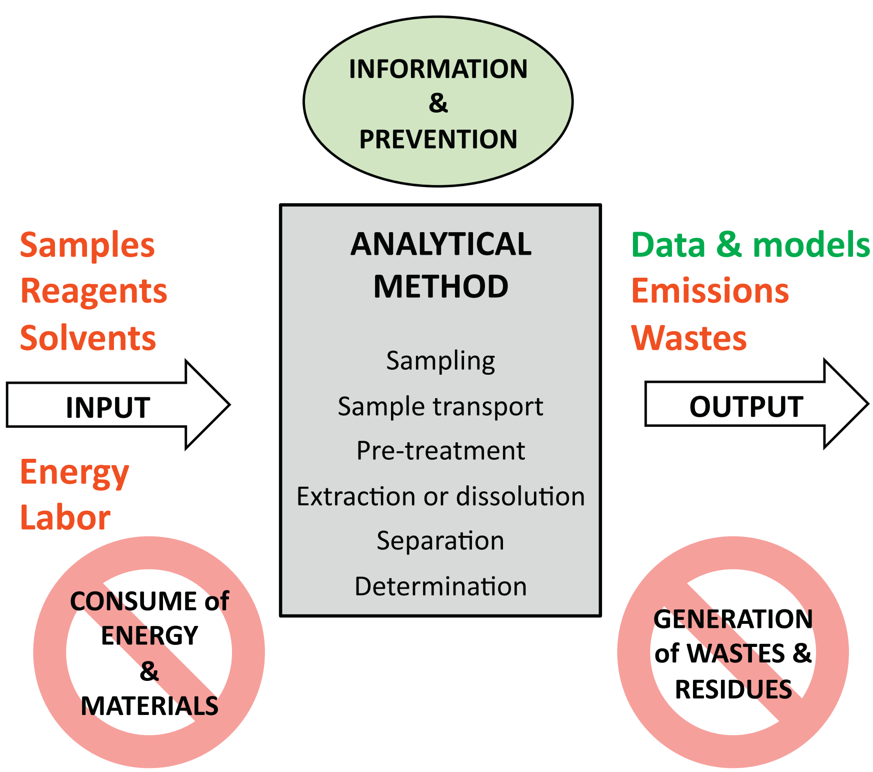

Fig. 4. Advantages and problems related to the environmental analysis from its positive and negative outputs.

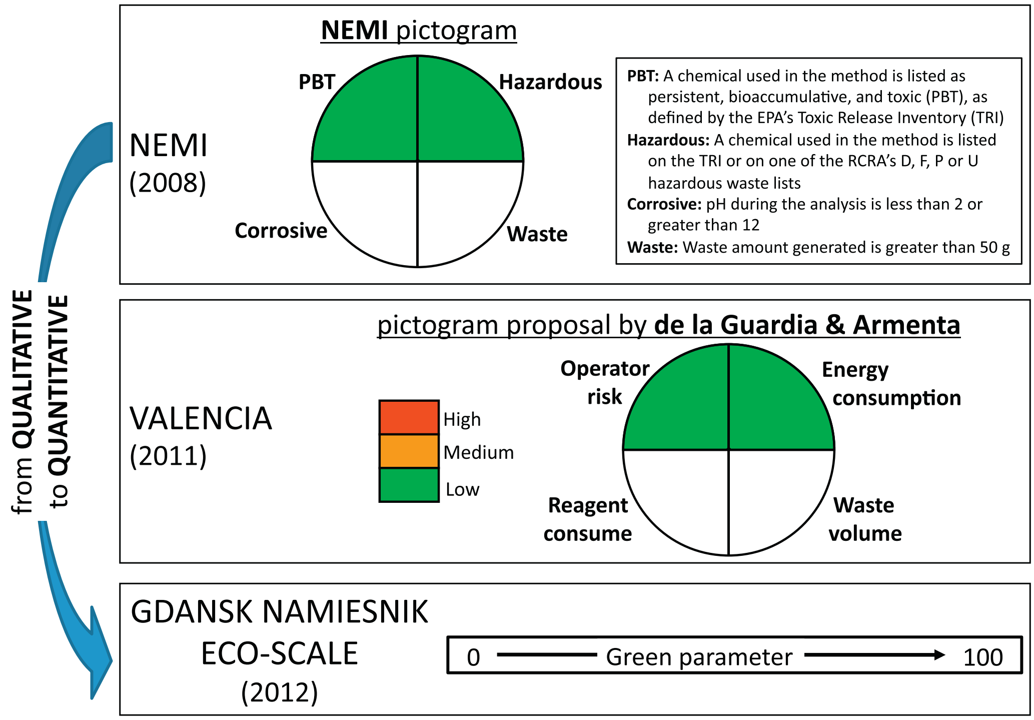

Fig. 5. Evaluation of the side effects of analytical methods: from qualitative to quantitative evaluation of method greenness.

of the (sustainability) produced (bio) chemical knowledge derived from the analysis of natural and artificial objects/samples and its correct transmission to circumvent misunderstanding false expectations and not justified alarms. It is related to the ethical principles of the people involved in analytical chemistry activities (technicians, analysts/researchers and managers) as well as the recipients of the analytical knowledge". The aforementioned comprehensive definition can be applied to evaluate the quality and sustainability of the information generation and the ethical transmission of results in the case of environmental studies, thus involving the equilibrium between the data obtained and the media invested to do it together with a correct transmission of environmental data and information in terms of that it could be reliable and timely.

So, it seems mandatory to do a correct evaluation of the economic and environmental cost of the analytical controls in order to select the most appropriated analytical tool to be used to solve environmental problems.

5. The analytical tools and their evaluation

Nowadays it becomes easier than before to evaluate the greenness of a method due to the efforts made by the National Environmental Method Index (NEMI) [30] our own team [7] and specially because of the development of the so called eco-scale [31] which Prof. J. Namiesnik has been adapted to evaluate quantitatively the environmental impact of an analytical methodology.

Fig. 5 summarizes the evolution of ideas about the environmental impact evaluation of analytical tools from the qualitative initial methodologies to the 0–100 quantitative scale.

6. The analytical results and information

In addition to the reduction or elimination of the deleterious side effects of the analytical methods in front of the environment and operators, one of the main concerns of the social responsibility of environmental analysis is the correct management of the

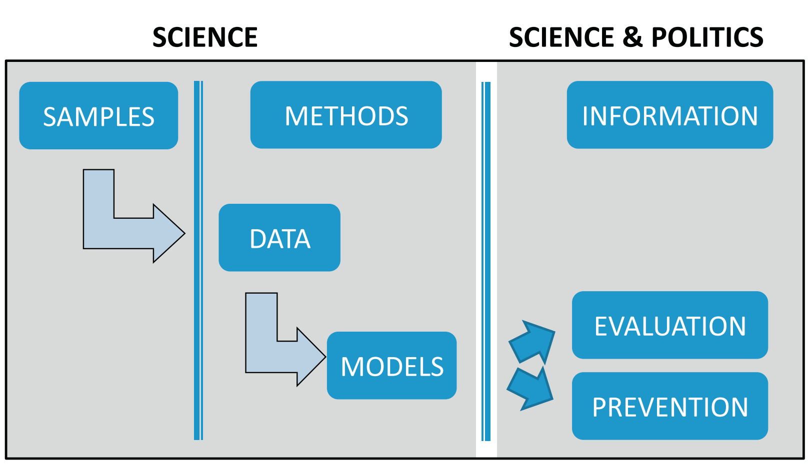

Fig. 6. Environmental analytical information.

information obtained. To do it, one of the basic rules is the quality assurance of all the elements involved in the analytical process in order to assure the accuracy and representativity of data obtained, which are in the base for obtaining a correct information. Because of that, together with the results it is the own concern of the laboratories to provide a complete picture of the validation process of each step of sampling, sample transportation and preservation, sample treatment and results in order that data found could critically evaluated by the referees and readers. We cannot forget that there are numerous results in the literature which have been modified after a deep evaluation of conditions used to obtain data in the past with a reduced capability of methods available.

A true information, well confirmed and seriously evaluated, is important in all the fields in order to avoid wrong transmissions of (bio) chemical information which can provide economic damages. However, we must take special care with the environmental information, because of its direct impact on the living conditions of people and the social alarm which can be created based on results regarding high pollution levels of an ecosystem or a specific area.

However, a correct information is not enough to guarantee the social responsibility in environmental analytical chemistry. It is also necessary to manage it carefully in order to avoid unjustified social alarm nor to create delays in its transmission which can reduce the capability of authorization to timely do correct actions to avoid present and future risks and these external connotations of the environmental work are difficult to be evaluated making extremely necessary a good connection between research and application laboratory activities in the environmental field with the local, regional and national authorities with political responsibility concerns. So, the transmission of environmental information move from pure science to a correct integration of scientific and political responsibility as indicated in Fig. 6.

7. Future trends and problems

The everyday activity of analytical laboratories working in the environmental field must be subjected to the rules regarding the deep evaluation of the methods employed for both, the fundamental and green perspective. Data produced must be coherent with the standards of accuracy and representativity. However they must be based on the most enviromentally friendly methodologies available. So, deleterious effects of used methods must be reduced or eliminated. In such a frame, it is clear the complementarity between the main analytical features of a method and its green characteristics, always depending on the capability of the selected method to solve the problem because the main objective of a method is the resolution of the analytical problem and thus, once solved the problem, the green characteristics of the method is the issue to be evaluated [32].

On the other hand, the social responsibility of environmentally involved laboratories must be concerned with the correct use of the information obtained in order to guarantee a correct transmission of well confirmed data, to avoid any kind of misinterpretation by people with a leak of scientific formation.

It seems a difficult equilibrium to be at the service of policy makers and national and international organizations, which must control the pollution problems and take the environmental decisions and to maintain a correct information of the general population which, at the end, will suffer from the damage of the environment of our cities and open areas and that is an ethical question which must be taken into consideration on the managing of information obtained from environmental studies, thus adding fundamental aspects to our social responsibility. In this way of the transference of the analytical information to both, the scientific community and the society, it must be taken into consideration the importance of the concentration units which are currently employed in the scientific language but not always understood by the society and, as a consequence, additional communication skills must be absolutely necessaries to communicate the environmental data.

In a new future it seems clear that efforts made in the definition and quantification of environmental side effects of analytical methods will provide a clear guide on the method selection to obtain environmental data and thus it will influence the relation of risks of all the steps of analytical processes. However, special care must be taken to guarantee a correct use on the information and to create a data bank suitable to evaluate the chemical parameters of the air, water, soil and biota in a medium and long term perspective to be suitable to be employed for the evaluation of predictive models about changes made in the earth by the human activities and it is a key environmental concern to be submitted to the ethical consideration.

Acknowledgements

Authors gratefully acknowledge the financial support of Ministerio de Economia y Competitividad and FEDER (Projects CTQ2011-25743 and CTQ2012-38635) and Conselleria de Educacio i Ciència (Project PROMETEO II/2014/077).

References

[1] D.H. Meadows, G. Meadows, J. Randers, W.W. Behrens III, The Limits to Growth, Universe Books, New York, 1972.
[2] D. Meadows, D. Meadows, J. Randers, Beyond the Limits, Chelsea Green Publishing Company, 1992.
[3] D. Meadows, J. Randers, D. Meadows, Limits to Growth: The 30-Year Update, Chelsea Green Publishing Company, 2004.
[4] P.T. Anastas, J.C. Warner, Green Chemistry: Theory and Practice, Oxford University Press, Oxford, 1998.
[5] P.T. Anastas, T.C. Williamson, Green Chemistry: Frontiers in Benign Chemical Syntheses and Processes, Oxford University Press, Oxford, 1998.
[6] M. Koeland, M. Kaljurand, Green Analytical Chemistry, RSC Publishing, Cambridge, 2010.
[7] M. de la Guardia, S. Armenta, Green Analytical Chemistry: Theory and Practice, Amsterdam, Elsevier, 2011.
[8] M. de la Guardia, S. Garrigues, Green Analytical Chemistry Challenges, RSC Publishing, Cambridge, 2011.
[9] UNEP/MAP/MED POL/WHO, Guidelines on Sewage Treatment and Disposal for the Meditarranean Region. MAP Technical Reports Series No. 152., UNEP/MAP, Athens (2004).
[10] A.Y. Glikson, Milestones in the evolution of the atmosphere with reference to climate change, Aust. J. Earth Sci. 55 (2008) 125–139.
[11] M. de la Guardia, J. Ruzicka, Guest editorial Towards environmentally conscientious analytical chemistry through miniaturization containment and reagent replacement, Analyst 120 (1995) 17N–17N.
[12] M. de la Guardia, S. Armenta (Eds.), Special Issue: Green spectroscopy analytical techniques. Spectrosc. Lett. 42 (2009) 275–439.
[13] M. de la Guardia (Ed.), Green Analytical Chemistry (special issue), TrAC–Trend Anal. Chem., 29 (2010) 577–780.
[14] M. de la Guardia, S. Armenta (Eds.), Green analytical methods. Anal. Bioanal. Chem. 404 (2012) 625–682.
[15] M. de la Guardia, S. Garrigues (Eds.), Handbook of Green Analytical Chemistry, John Wiley & Sons, Ltd., Chichester, UK, 2012.
[16] H. Malissa, in: E. Roth (Ed.), Changes of Paradigms in Analytical Chemistry, in Reviews on Analytical Chemistry, Euroanalysis VI, Les Editions de Physique, Paris, 1988.
[17] D. Barceló, Emerging pollutants in water analysis: editorial, TrAC–Trends Anal. Chem. 22 (2003) xiv–xvi.
[18] E. Eljarrat, D. Barceló, Priority lists for persistent organic pollutants and emerging contaminants based on their relative toxic potency in environmental samples, TrAC–Trends Anal. Chem. 22 (2003) 655–665.
[19] S. de la Guardia, M. Garrigues, Partial least squares attenuated total reflectance IR spectroscopy versus chromatography: the greener method (editorial), Bioanalysis 4 (2012) 1267–1269.
[20] G. McMahon, Analytical Instrumentation: A Guide to Laboratory, Portable and Miniaturized Instruments, John Wiley & Sons, Ltd., 2007.
[21] J. Moros, S. Garrigues, M. de la Guardia, Vibrational spectroscopy provides a green tool for multi-component analysis, TrAC–Trends Anal. Chem. 29 (2010) 578–591.
[22] S. Perino, E. Petitcolas, M. de la Guardia, F. Chemat, Portable microwave assisted extraction: an original concept for green analytical chemistry, J. Chrom. A 1315 (2013) 200–203.

[23] M. de la Guardia, The challenges of green nanotechnology, Bioimpacts 4 (2014) 1–2.

[24] ISO 26000:2010, Guidance on Social Responsibility, International Organization for Standardization, Geneva, 2010.

[25] ISO 14001:2004, Environmental Management Systems. Requirements, International Organization for Standardistion, Geneve, 2004.

[26] OHSAS 18001:2007 and OHSAS 18002:2008, Standards on Occupational Health and Safety Management Systems, Occupational health and Safety Advisory Services, 2007–2008.

[27] M. Valcárcel, G.D. Christian, R. Lucena, Teaching social responsibility in analytical chemistry, Anal. Chem. 85 (2013) 6152–6161.

[28] M. Valcárcel, R. Lucena, Synergistic relationships between analytical chemistry and written standards, Anal. Chim. Acta 788 (2013) 1–7.

[29] E. Caballero-Díaz, B.M. Simonet, M. Valcárcel, The social responsibility of nanoscience and nanotechnology: an integral approach, J. Nanopart. Res. 15 (2013) 1534–1546.

[30] National Environmental Method Index, NEMI searchable database. Available at https://www.nemi.gov/home/.

[31] A. Galuszka, P. Konieczka, Z.M. Migaszewski, J. Namiesnik, Analytical Eco-Scale for assessing the greenness of analytical procedures, TrAC–Trends Anal. Chem. 37 (2012) 61–72.

[32] M. de la Guardia, S. Garrigues, Partial least squares attenuated total reflectance IR spectroscopy versus chromatography: the greener method, Bioanalysis 4 (2012) 1267–1269.