Indian Journal of
Advances in Chemical Science

Article

Importance of Standard Scientific Units for the Measurement of Quantities and Properties in Environmental Science

P. Osman Basha[1], M. Sridhar Reddy[2]*

[1]Department of Genetics and Genomics, Yogi Vemana University, Kadapa, Andhra Pradesh, India, [2]Department of Environmental Science, Yogi Vemana University, Kadapa, Andhra Pradesh, India

ABSTRACT

Environmental Impact Assessment reports, greenhouse gases national inventory reports, Forest Survey of India reports, and technical reports of several states and central pollution control boards comprise measurements of soil, water, and air pollutants being reported in concentrations and contents in various units. As a multidisciplinary science, researchers from varied fields wish to publish and read reports and publications and information of measured quantities in different units may confuse them. Hence, the objective of this paper is to help researchers and common people to understand about the widely used measurements and units in Environmental Science reports.

Key words: Environmental science, SI units and measurements, Global warming potential.

1. INTRODUCTION

The study of Environmental Science involves a multidisciplinary approach and can be defined as the scientific study of the influence of anthropogenic activities on natural processes [1]. This branch of science provides a framework to deal with challenges being faced by present human kind such as climate change/crisis, water scarcity, biodiversity loss, land degradation, pollution, and as well suggest strategies to achieve progress in 17 sustainable development goals dealing with greenhouse gas emissions, renewable energy sources, critical raw materials availability, biodiversity conservation, resource efficiency, zero waste, circular economy, etc [2]. Overall, it provides a scientific framework on which pollution monitoring schemes and conservation programs can be organized [3]. Hence, acquiring reliable information on these issues through standard measurements that remain comparable and consistent worldwide is utmost necessary [4]. Further, reporting the results of measured concentrations and properties in standardized units will build confidence and trust not only among scientific community and among public on the environmental issues In this regard, the International System of Units (SI) is a consistent system of units for use in all aspects of life, including manufacturing, security, health and safety, and protection of the environment [5].

The definitions of SI system are decided by General Conference on Weights and Measures (CGPM). In 1960, the 11th CGPM has formally defined and established the SI units and also revised it time to time based on the users' requirements and advances in science and technology. Further, these were subsequently elaborated by international standardization bodies such as International Organization for Standardization (ISO) and International Electrotechnical Commission and have specified more details for quantities and units and rules for their applications; but based on SI unit definitions. International Union of Pure and Applied Chemistry (IUPAC; formed in 1919) was the first international organization being involved in standardizing the chemical quantities. In this line, IUPAC has published Manual of Symbols and Terminology for physicochemical quantities and units in 1969. After publishing three editions, the manual was replaced with another three editions of Green Book. In 1988, the ISO has published the first edition of International Standards for 31 quantities and 1000 SI units in 13 sections for utility. Further, ISO has developed 24000 international standards and kept them in ISO standards catalogue under 97 fields [6].

It is observed that environmental science studies involve measurements of both extremely large quantities such as energy availability or needed in future, expressed in tera (10^{12}) watts and very small entities such as the concentration of toxic substances and presence of flouride in drinking water measured in parts per billion (ppb). India, along with other 195 countries in the world, except three countries like United States of America, Myanmar and Liberia, have confirmed that physical and chemical quantities related to environment are measured and will be reported in the International System of Units (SI units) based on the meter-kilogram-second; hence, information in this regard is utmost necessary. In SI system, the value of a quantity is expressed as the product of a number and a unit. After adjudicating the exact numerical value, the unit becomes defined, as the product of the numerical value and the unit has to equal the value of the constant [7]. For example, the speed of light in vacuum is a constant, denoted by c, and the value in SI units is given as c = 299 792 458 m/s, in which the numerical value is 299,792,458 and the unit is m/s. In S.I. system the physical quantities are described in terms of seven basic quantities which have specific symbols for quantity and dimension. In addition there are 22 derived units which are the products of powers of the base units and they also possess specific names and symbols [Table 1]. In addition, there are eight quantities with

***Corresponding author:**
M. Sridhar Reddy,
sridharmullangi@yahoo.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2022.1004002

Received: 18th June 2022;
Revised: 16th November 2022;
Accepted: 02th December 2022

Table 1: The seven base quantities and dimensions along with 22 derived units with names and symbols used in SI system.

S. No.	Quantity	Unit name	Unit symbol
1.	Length	meter	m
2.	Mass	kilogram	kg
3.	Time	second	s
4.	Luminous intensity	candela	cd
5.	Amount of substance	mole	mol
6.	Electric current	ampere	A
7.	Temperature	kelvin	K
8.	Resistance	ohm	$\Omega = kg\ m^2\ s^{-3}\ A^{-2}$(OR) V/A
9.	Frequency	hertz	$Hz = s^{-1}$
10.	Force	newton	$N = kg\ m\ s^{-2}$
11.	Energy	joule	$J = kg\ m^2\ s^{-2}$(OR) N.m
12.	Power ($J.s^{-1}$)	watt	$W = kg\ m^2\ s^{-3}$(OR) J/s
13.	Voltage ($W.A^{-1}$)	volt	V
14.	Plane angle	radian	rad = m/m
15.	Solid angle	Steradian	$sr = m^2/m$
16.	Electric charge	Coulomb	C = A s
17.	Electric potential difference kg	Volt	$V = m^2$ s–3 A–1
18.	Capacitance	Farad	$F = kg^{-1}\ m^{-2}\ s^4\ A^2$
19.	Electric conductance	Siemens	$S = kg^{-1}\ m^{-2}\ s^3\ A^2$
20.	Magnetic flux	Weber	$Wb = kg\ m^2\ s^{-2}\ A^{-1}$
21.	Magnetic flux density	Tesla	$T = kg\ s^{-2}\ A^{-1}$
22.	Inductance	Henry	$H = kg\ m^2\ s^{-2}\ A^{-2}$
23.	Celsius temperature	degree Celsius	°C = K
24.	Luminous flux	Lumen	lm = cd sr
25.	Illuminance	Lux	$lx = cd\ sr\ m^{-2}$
26.	Activity referred to a radionuclide	becquerel	$Bq = s^{-1}$
27.	Absorbed dose	Kerma	gray $Gy = m^2\ s^{-2}$
28.	Dose equivalent J/k	Sievert	$Sv = m^2\ s^{-2}$(OR) J/kg
29.	Catalytic activity	Katal	$kat = mol\ s^{-1}$

non-SI units but are accepted and used along with SI units due to their wide usage [Table 2]. In S.I. system the measured units are written in a specific manner, like 8 MHz, 12.2 µF, in which the measured value is in numbers followed by space then the prefix symbol and unit symbol without space. It is notable that SI prefix symbols for multipliers of 10^6 and larger are capitalized, and lower case is used for multipliers of 10^3 and smaller [Table 3]. Further, a lower case is used in writing a unit symbol and the symbol letter is capitalized when the unit is named after a person. For example to use correct capitalization, the symbol for decibel is written as dB and kilo hertz is written as kHz. We have to use a raised

Table 2: Widely used Non-SI units accepted to be used with SI units Non-SI units accepted for use with the SI Units.

Quantity	Name of unit	Symbol for unit	Value in SI units
Time	Minute	Min	1 min = 60 s
Length	astronomical unit	Au	1 au = 149 597 870 700 m
Plane angle	Degree	O	$1^o = (\pi/180)$ rad
Area	Hectare	Ha	$1\ ha = 1\ hm^2 = 10^4\ m^2$
Volume	Litre	l, L	$1\ l = 1\ L = 1\ dm^3 = 10^3\ cm^3 = 10^{-3}\ m^3$
Mass	Tonne	T	$1\ t = 10^3$ kg
Energy	electronvolt	eV	$1\ eV = 1.602176634 \times 10^{-19}$ J
Ratio quantities	decibel	dB	

Table 3: SI prefixes showing decimal multiples and symbols.

Factor	Prefix name	Symbol	Factor	Prefix name	Symbol
10^1	deca	da	10^{-1}	deci	d
10^2	hecto	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	µ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

dot between units combined by multiplication like N.m (for Newton. meter). For the unit formed by division, a slash is used and written as m/s for meters per second set off a single-element denominator and for a unit having a complex denominator like meters per second squared, we have to use exponent notation and written as $m.s^{-2}$. In SI system, the unit for temperature is kelvin, K, and it has no degree sign, while for the symbols in non-SI units, Celsius (°C) and Fahrenheit (°F) have degree signs [5]. In environmental science, the concentrations of chemicals/substances in soil, water, and air are expressed in different units. By following SI system, the concentrations can be based on mass (mg or g), volume (L or m^3), or in moles (mass = molecular weight). The conversion factors and understanding them among these concentrations may reduce the confusion [8].

In soil, concentrations of chemicals in soil are expressed in units of the mass of chemical (milligrams, mg or micrograms, µg) per mass of soil (kilogram, kg). This can be written as mg/kg or µg/kg. Alternatively, concentrations in soil are also expressed as parts per million (ppm) or parts per billion (ppb); 1 ppm = 1,000 ppb.

A measurement of 8 mg/kg Arsenic in the soil is the same as 8 ppm or 8000 ppb, which is equal to 8000 µg/kg.

2. IN LIQUIDS

The presence of pollutants/chemicals dissolved in water is reported in terms of mass or number per unit volume. The units are milligrams (mg), micrograms (μg), and moles (mol) of chemicals per liter (L). Sometimes, they are reported as grams per cubic meter (g/m^3). This is equal to grams per 1000 liters and can be converted to milligrams per liter (mg/L). Hence, 1 g/m^3 = 1 mg/L = 1 ppm. Similarly, 1 milligram per cubic meter (mg/m^3) is equal to 1 microgram per liter (μg/L), which is equal to 1 ppb. Thus, the concentrations in liquid are also expressed as ppm or ppb.

1 mg/l =	1g/m^3 =	1 ppm (by weight)
1 μg/l =	1mg/m^3 =	1 ppb (by weight)

Example: The optimum dose of fluoride (Mol. Wt = 19) in drinking water is 0.053 mM (millimole/liter). We can convert it into mass concentration (ppm) as

$$F = \frac{0.053\ \text{mmol/L} \times 19\ \text{g/mol} \times 1000\ \text{mg/g}}{1000\ \text{mmol/mol}}$$
$$= 1.01\ \text{mg/L} = 1.01\ \text{ppm}$$

3. GASES

In air pollution studies, the air pollutant concentrations are reported in volumetric terms, that is, units of the mass of chemical (milligrams) per volume of air (m^3). The particulate matter is usually represented in micrograms/m^3. These concentrations can also be reported as parts per million (ppmv) or parts per billion (ppbv) using a conversion factor. The conversion factor is based on the molecular weight of the chemical and also on the atmospheric temperature and pressure.

Thus, the conversion from ppm to mg/m^3 is given by

$$\text{mg/m}^3 = \frac{\text{ppmv} \times \text{mol.wt}}{22.414} \times \frac{273.15\text{K}}{\text{T (K)}} \times \frac{\text{P(atm)}}{1\ \text{atm}}$$

$$\text{At } 25°\text{C and 1 atm} = \text{mg/m}^3 = \frac{\text{ppmv} \times \text{mol.wt}}{24.465}$$

$$\text{At } 0°\text{C and 1 atm} = \text{mg/m}^3 = \frac{\text{ppmv} \times \text{mol.wt}}{24.414}$$

For the conversion of ozone, standard value of 0.09 ppmv in to mg/m^3 at 1 atm of pressure and 25°C is

$$\text{mg/m}^3 = \frac{\text{ppmv} \times \text{mol.wt}}{24.414} \times \frac{273.15\text{K}}{\text{T (K)}} \times \frac{\text{P(atm)}}{1\ \text{atm}} \times \frac{0.09 \times 48}{22.414}$$
$$\times \frac{273.15}{(273.15 + 25)} \times \frac{1}{1} = 0.177\ \text{mg/m}^3$$

(OR)

$$\text{mg/m}^3 = \frac{0.09 \times 48}{24.465} = 0.177\ \text{mg/m}^3$$

For Example, the average concentrations of SO2 are 400 μg/m3 at 25°C and 1 atm. If we wish to know, whether it exceeds the 24 h air quality standard of 0.14 ppmv. We have to change 400 μg/m^3 to mg/m^3 = 400/1000 = 0.4 mg/m^3.

$$\text{ppmv} = \frac{24.465 \times SO_2\text{mg/m}^3}{\text{Mol.wt}} = \frac{24.465 \times 0.4}{64} = 0.152\ \text{ppmv}$$

Yes, the value indicates that SO_2 concentration in the ambient air exceed the threshold level.

In Environmental Impact studies/reports, the standards for certain pollutants are mentioned to provide sufficient scope for safety to protect health. These were standardized with the assumption that pollutants have specific thresholds and exposure to them greater than these threshold levels will cause harm. However, exposure to certain carcinogenic pollutants such as dioxins, Dieldrin, and Chromium VI may generate risks like cancer. Considering these factors, the information on the risk assessment of pollutants has become important in Environmental Impact studies. For these chronic toxic studies, factors such as potency factor (PF) and chronic daily intake (CDI) will be calculated to find out incremental lifetime risk for cancer. From the dose-response curve generated by having the incremental risk of cancer above back ground rate on Y-axis and dose of toxicant on X-axis, a dose-response curve is generated and its slope PF. Another factor is CDI that is the total life time dose averaged over a 70-year lifetime [9].

$$\text{CDI (mg/kg – day)} = \frac{\text{Average daily dose (mg/day)}}{\text{Body weight (kg)}}$$

$$\text{CDI} = \frac{\text{Concentration (mg/L)} \times \text{Intake rate (L/day)} \times \text{Exposure (Days/life)}}{\text{Body weight (kg) 70 (yr/life)} \times 365\ \text{(days/yr)}}$$

Incremental lifetime cancer risk = CDI × PF.

Example: Benzene has PF of 0.01 mg/kg-day. Calculate the Cancer risk for a person of 70 Kg body weight and breaths 20 m3 /day of air containing 10−3 mg/m3 of benzene having a potency factor (PF) of of 0.01 mg/kg-day throughout his entire life time.

$$\text{CDI} = \frac{\text{Concentration (mg/L)} \times \text{Intake rate (L/day)} \times \text{Exposure (Days/life)}}{\text{Body weight (kg) 70 (yr/life)} \times 365\ \text{(days/yr)}}$$

$$\text{CDI} = \frac{10^{-3}\text{mg/m}^3 \times 20\text{m}^3\text{/day}}{70\ \text{kg}} = 0.000285\ \text{mg/kg – day}$$

Risk = CDI × PF

= 0.000285 mg/kg-day × 0.01 mg/kg-day = 2.9 × 10^{-6}.

For non-carcinogenic effects, human health risk assessment is done by calculating the Hazard Quotient (HQ). Here, the toxicity is considered during the exposure time only.

$$\text{HQ} = \frac{\text{Average daily dose in the exposure period (mg/kg – day)}}{\text{Reference dose (RfD)}}$$

Reference dose (RfD) is the No-Observed-Adverse-Effects-Level of a particular non-carcinogen pollutant divided by uncertainty factor that lie between 10 and 1000.

If the value of HQ lies between 0.1 and 1.0, it suggests low hazard, HQ value of 1.0-10.0 indicates moderate hazard reflecting negative human health problems, and HQ value greater than 10.0 indicates higher human health effects.

When exposure includes several chemicals, the sum of the individual HQs for each chemical is used to produce a cumulative Hazard Index.

Hazard Index = Sum of the Hazard Quotients.

India is committed to net zero carbon emissions by 2070, for which both emission reductions from the target sources and removal of excess atmospheric greenhouse gases such as Carbon di-oxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Chlorofluorocarbons, hydrofluorocarbons, hydrochlorofluorocarbons, perfluorocarbons, and sulfur hexafluoride are essential. GHGs have different effects on the Earth's warming and these variations arise from their ability to absorb energy in infrared region (radiative efficiency) and their life

Table 4: Global warming potential for 100-year time period and its residence time in atmosphere for selected greenhouse gases.

Green house gas	Atmospheric life period (years)	Global Warming Potential GWP (100-yr)
Carbon dioxide	50–200	1
Methane (Fossil-CH_4)	12±3	28
Methane (biogenic-CH_4)	12	25.25
Nitrous oxide	120	265
Hydrofluorocarbons	1.5–209	150–11700
Perfluorocarbons	2600–50000	6500–9200
Sulfur hexafluoride	3200	23900
Carbon tetrachloride	35	1800
Halon-1301	65	6900

period in the atmosphere. For example, CH_4 stays in the atmosphere in and around 12 years but absorbs heat effectively in comparison to carbon dioxide which stays for a longer period of 200 years and sulfur hexafluoride has enormously high ability to trap heat and as well as longer residence period in the atmosphere. Hence, global warming potential (GWP) was developed to compare global warming impacts among different greenhouse gases and also help to prepare a national GHG inventory. GWP is a measure of how much of radiation energy the emissions of one ton of a GHgas will absorb over a period of time (usually 100-year period) relative to the emissions of one ton of CO_2. CO_2 was chosen by the Intergovernmental Panel for Climate Change (IPCC) as a reference gas and its GWP is set equal to one (1). Three key factors such as the ability of the gas to absorb infrared radiation, spectral location of the absorbed wavelength in the electromagnetic spectrum, and the atmospheric lifetime of the gas will determine the GWP value of a GHG. UNFCCC has adopted the IPCC 2013 Assessment Review (AR5) values for reporting and IPCC intends to update the GWP values in each of their assessment reports that this kind of using a common scale for all GHGs helps to compare emissions from different sectors and activities and decisions can be taken to reduce them with minimum economic loss. GWP values allow you to compare the impacts of emissions and emission reductions/removals of different gases. Example: Annual anthropogenic emissions of CO_2, CCl_4, and N_20 are estimated to be 47000 $MtCO_2$/yr, 570 $MtCCl_4$/yr, and 9 MtN_2O/yr (Mt – Million metric tons). To compare the impacts and to find the total CO_2 emissions equivalents, we have to multiply the emission rates [Table 4] and GWPs.

CO_2: GWP (100 yr period) × emissions rate = 1 × 47000Mt/yr = 47000 Mt/yr

CCl_4: GWP (100 yr period) × emissions rate = 1800 × 570Mt/yr = 1026000 Mt/yr

N_2O: GWP (100 yr period) × emissions rate = 265 × 9 Mt/yr = 2385 Mt/yr

Total CO_2 equivalents emissions = 47000 Mt/yr + 1026000 Mt/yr + 2385 Mt/yr = 1075385 $MtCO_2$-eq/yr.

By multiplying total emissions with C/CO2 ratio = 12/44, we can get Carbon values

1075.3 GigatonsC-eq × 12/44 = 29.3Gt.C-eq.

Among the total three GHgases, CCl4 comprises 95.4% emissions.

4. REFERENCES

1. M. B. Bush, (2000) ***Ecology of a Changing Planet.*** 2nd ed. New Jersey, United States: Prentice Hall. p1-11.
2. Available from: http://ijacskros.com/aguidelines.html; https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf [Last accessed on 22 June 18].
3. M. Sandeep, K. Om, R. Ramesh, K. Kumar, (2018) Understanding units of measurement in agricultural and environmental sciences, ***International Journal for Environmental Rehabilitation and Conservation,*** **9(2):** 45-51.
4. Available from: https://www.ijacskros.com/aguidelines.html; https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6 [Last accessed on 2022 Jun 06].
5. Available from: https://www.ijacskros.com/aguidelines.html https://www.bipm.org/documents/20126/41483022/SI-Brochure-9-EN.pdf [Last accessed on 2022 Jun 18].
6. Available from: https://www.ijacskros.com/aguidelines.html; https://www.iso.org/iso-9001-quality-management.html [Last accessed on 2022 Jun 18].
7. P. Glavic, (2022) Quantities and units in chemical and environmental Engineering, ***Standards***, **2:** 43-51.
8. A. J. Both, L. Benjamin, J. Franklin, G. Holroyd, L. D. Incoll, M. G. Lefsrud, G. Pitkin, (2015) Guidelines for measuring and reporting environmental parameters for experiments in greenhouses, ***Plant Methods,*** **11:** 43.
9. G. M. Masters, W. P. Ela, (2012) ***Introduction to Environmental Engineering and Science*** 3rd ed. New Delhi: PHI Learning. p1-14.

***Bibliographical Sketch**

The author did his Masters in Environmental Sciences from Jawaharlal Nehru University and Ph.D from Pondicherry central University under the guidance of Dr. N. Parthasarathy. At present he teaches Biodiversity, Ecology and Biostatistics to the post graduate students in Yogi Vemana University, Kadapa. His research interests include studies on forest ecology, Soil organic carbon dynamics and socio-economic factors intertwined with natural resources.