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A Review On Plasticizers In Water And Food And Their Impact On Human Health

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Abstract:
The production of plastic, which became indispensable for modern society in the last 70 years, has increased more than 300-fold; the global market will be 627 billion US dollars in 2023. To modify the flexibility and rigidity of the plastic, chemicals called plasticizers are added. Therefore, it is not surprising that plastic (micro, nanoparticles) and the plasticizers phthalates, bisphenols, and their substitutes are widely present in all segments of the environment (water, air, soil, food, animals). Plasticizers are also present in remote areas. Humans interact with plasticizers via food containers, medicines, toys, electronic devices, building materials, cosmetics, perfumes, and personal care products, in addition to water and food. Plasticizer exposure has negative health effects on humans and animals. Plasticizers in humans cause insulin resistance, dyslipidemia, increased visceral adiposity, obesity-associated CVD, cardiotoxicity, hepatotoxicity, nephrotoxicity, prostate, testicular and breast cancer, and reproductive toxicity. Allergy, asthma, delayed neurodevelopment, social impairment, improper thyroid function, and increased risk of thyroid cancer are also caused by phthalates. In females, phthalate exposure is responsible for miscarriage, disrupted secretion of estrogen and progesterone, endometriosis, eclampsia, impaired oocyte competence, ovarian dysfunction, and premature breast development. In fish and other aquatic organisms, plasticizers cause immunotoxicity, neurotoxicity, genotoxicity, and endocrine, metabolic, and developmental toxicities. This work reports the amount of plasticizers in water, food, and air and their impact on human and aquatic organisms' health.
Keywords: *Phthalates, Plasticizers, Bisphenol, Human Health, Air, Food*

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I. Introduction:

Plastic, being a relatively cheap material, ensures food safety and reduces food waste. The production of plastic has increased from 1.7 metric tons to more than 425 metric tons in the last seventy years and is expected to be 600 million metric tons by 2025. At present, we are at a point where life without plastic is not feasible, as plastic materials are used in everyday life, i.e., in packaging, in building and construction, in the automobile, electronic and electrical industries, in the medical field, in rockets and aircraft, in clothes, in cosmetics, in shampoos, in grocery bags, in bottles, in forks, wrappers of eatables, the agriculture sector, sports, furniture, toys, etc[1]. The global production of plastic bottles is more than one million per minute. The global market for plastic, which was 627 billion US dollars in 2023, is estimated to be 824 billion US dollars by 2030. Plastic, synthetic polymers (composed of carbon, hydrogen, oxygen, and chlorine) to increase their flexibility, extensibility, and processability are amended with chemical compounds termed plasticizers. The global demand for plasticizers in 2020 was 8.23 million metric tons and is expected to be 12.91 million metric tons by 2030. The global production of phthalate esters in 2023 was more than 8 million tons. In the year 2023, more than 1.40 million tons of plasticizers are consumed in Europe only. The global market of plasticizers in 2023 was 17.99 billion US dollars and is expected to be 23.88 billion US dollars by 2030. The most commonly used plasticizers are phthalate esters (PAEs), adipates, benzoate esters, citrates, and trimellitate esters. Bisphenol-A (BPA), Bisphenol-S (BPS), and nonylphenol (NP) are also used as plastic additives. Most of the plasticizers are used in polyvinyl chloride (PVC). Plastic in the microform with plasticizers, BPA, BPS, and NP is present in all the compartments of the environment (surface water, drinking water, groundwater, marine water, agroecosystems, atmosphere, food, biota, and other remote locations). Geologists used plastic material in archaeological studies as a marker of earth deposits[2]. Due to the large-scale use of plasticizers and other additives, these chemical compounds are reported not only in aquatic animals but also in wildlife animals and humans. Accumulation of these compounds in wildlife animals and humans causes reproductive toxicity, carcinogenesis (prostate, breast cancer), cardiotoxicity, hepatotoxicity, nephrotoxicity, atherosclerosis, and insulin resistance.

The aim of the present studies is to summarize the plasticizers in the environment, water, and food and their impact on human health. It will be helpful for environmental scientists and policymakers to find out the way to reduce the adverse effects of plasticizers and to discover other alternatives.

II. Plasticizers And Their Classification:

To increase the flexibility, extensibility, and processability of the plastic, non-volatile organic compounds called plasticizers are added.

The plasticizers can be classified as: primary plasticizers: these are those organic compounds that, due to the presence of polar group(s), are highly compatible with plastic polymers and enhance the elongation, softness, and flexibility of the plastic polymer when added in a large amount. Secondary plasticizers: These are those organic compounds that have fewer polar or non-polar groups, and compatibility with polymers is very low. These are used with primary plasticizers. Secondary plasticizers are used for viscosity reduction and low-temperature property improvement of plastic polymers.

Based on their chemical structure, the plasticizers are classified:
Phthalate Esters. Due to their low volatility, weather resistance, low solubility in water, and non-degradable nature, the phthalate plasticizers that are formed by the esterification of phthalic anhydride or phthalic acid (which may be obtained by the oxidation of o-xylene or naphthalene) are mostly used plasticizers. Diethylhexyl phthalate (DEHP), diisononyl phthalate (DINP), diisodecyl phthalate (DIDP), and diisobutyl phthalate (DIBP) are the most commonly used plasticizers.

Aliphatic dibasic acid esters: These plasticizers are formed by the reaction of aliphatic dibasic acids such as adipic acid and alcohol. Di-(2-ethylhexyl) adipate (DEHA) and diisodecyl adipate (DIDA) are commonly used adipate esters.

Benzoate Esters: These are produced by the reaction of benzoic acid and alcohols or diols. These plasticizers have high solvating power, low moisture sensitivity, and are resistant to stains that have replaced phthalates in adhesives. Dipropylene glycol dibenzoate, diethylene glycol dibenzoate, isodecyl benzoate, isononyl benzoate, and 2-ethylhexyl benzoate are generally used as plasticizers.

Trimellitate Esters: Trimellitate esters formed by the reaction of trimellitic anhydride (TMA) and linear or branched alcohol with C_8-C_{10} (2-ethylhexyl alcohol; octyl alcohol) are used as plasticizers as they are resistant to volatility and water; these are also known as high-temperature esters. Commonly used trimellitate esters are Tri-2-ethylhexyl trimellitate, Tri-octyl trimellitate, Tri-(7C-9C (linear)) trimellitate, and Tri-(8C-10C (linear) trimellitate.

Polyesters: These plasticizers are formed by the reaction of dicarboxylic acids (containing 4–10 carbon atoms) and difunctional alcohols (glycols with 2–5 carbon atoms) and are used in the rubber industry. These provide plasticizer permanence (the higher the viscosity of the plasticizer, the more the permanence) and non-stress cracking. The polyester plasticizers of three types are: i) Acid-Terminated polyester [RCO-{CO-O-G-OCO-(CH_2)n CO-}x O-G-O-COR], ii) Alcohol-Terminated polyesters [RO-{CO-(CH_2)n COO-G-O}y CO-(CH_2)n COOR], and iii) Unterminated (hydroxyl-functional) polyester [HO-{COO-G-OCO(CH_2)CO}z O-G-H].

Citrates: The citrate esters are formed by the reaction of citric acid with alcohols (C4-C8) and are colorless, odorless, oily liquids used in the medical field (blood bags), food packaging products, food wrap, toys, etc. Tributyl citrate and trioctyl citrate are some common examples.

Bio-based Plasticizers: The bio-based plasticizers are easily degradable and are formed from bio-based materials, which reduce the carbon footprint. Rigid polymers are softened by these plasticizers, and bio-based plasticizers improve cold temperature behavior. Epoxidized soybean oil (ESBO), epoxidized linseed oil (ELO), castor oil, palm oil, and other vegetable oils are a few examples of bio-based plasticizers. Besides these plasticizers, chemical compounds, viz., bisphenol A (BPA) and bisphenol S (BPS), are also used in the plastic industry.

Bisphenol A (BPA): Bisphenol A (4,4′-(propane-2,2-diyl)diphenol) is a phenolic compound used to produce sturdy, clear polycarbonate plastics. Shatterproof windows, eyewear, water bottles, and epoxy resins are formed with the help of polycarbonate plastics. Food packaging materials, take-away water bottles, lacquer coatings for tin, baby bottles, Sippy cups, and infant formula packaging also contain BPA. Polycarbonate plastic is also used in the manufacturing of medical devices such as dialysis equipment components, blood oxygenation equipment, barrels of syringes, electronic products, the automobile industry, bulletproof windows, helmets, safety glasses, etc.

Bisphenol S (BPS): For the preparation of less colored and high heat-resistant polycarbonate, BPS is used instead of BPA. The lining of canned food and drink contains BPS. Annual global production of bisphenols in 2023 was 6.4 million tons and is expected to be 9.3 million tons by 2030. In 2023, the global market was 23.52 billion USD and is expected to be 32.34 billion USD by 2031.

Camphor: Camphor is either obtained from a camphor tree or prepared from alpha-pinene and is used as a plasticizer in celluloid.

Triphenyl Phosphate: To form clear and tough cellulose acetate films and sheets, triphenyl phosphate is used as a plasticizer. Triphenyl phosphate is resistant to moisture and has lower volatility.

III. Sources Of Plasticizers In The Environment:

Plasticizers in the environment enter during the preparation of plastic products and their use by consumers. Globally extensive use and mismanagement cause plastic in all the segments of the environment. The main source of plasticizers in the continental environment (terrestrial and freshwater) is plastic debris. Plastic is not only used in consumer items and packaging but also in structural materials (wires, cabling, flooring, and wall covering). Plasticizers are mainly used in PVC, which is widely used in, e.g., building fittings and municipal water pipes. The literature survey revealed that almost all the food products, viz., fruits, vegetables, cereals, their products, milk and other dairy products, meat and their products, fish and other fish products, fats, oils, etc., contain phthalates and plasticizers. Cosmetics, hair sprays, hair gels, deodorants, hair mousses, nail paints, body lotions, body creams, antiperspirants, baby lotions, baby oils, diaper rash creams, perfumes, baby shampoos, and skin-cleansing products have phthalate plasticizers. Structural materials, e.g., wires, cabling, flooring and wall coverings, PVC, toys, curtains, packing material, and other electrical appliances, also contain phthalates[3]**.** Vinyl resins used in toys, food packaging films, medical devices, and pacifiers for infants are prepared by mixing prepared citrate with PVC, PVB, and polypropylene, as these polymers are very easily mixed with citrate plasticizers. Plastic with high-temperature resistance properties (PVC electrical wire insulation) contains trimellitate plasticizers. Automobile interiors also contain trimellitates. Polyurethanes, sealants, suntan lotions, and injection-molded water-based adhesives contain benzoate plasticizers. Automobile parts, PVC cables, vinyl flooring, and wire jacketing are prepared with PVC amended with bio-based plasticizers. Cosmetic products, nail polishes, and enamels contain triphenyl phosphate plasticizer as one of the ingredients. Triphenyl phosphate plasticizer with cellulose acetate forms stable and fireproof and is used in lacquers and varnishes, roofing paper, etc. Camphor is used as a plasticizer in lacquers, varnishes, and plastics and as a moth repellent. Bisphenols are present in canned foods (fresh, frozen, and plastic packaging), canned meat products, glass-bottled and PET-bottled carbonated beverages, packaging used for takeaway food, paper boxes and wrapping papers, and thermal papers used in credit card receipts. Epoxy resins used in dental fillings and paper currency also contain bisphenol[4, 5].

IV. Routes Of Exposure To Plasticizers:

The plasticizers in the human body and other organisms (aquatic or terrestrial) enter by[6]:

Ingestion: Means uptake by mouth, i.e., via the gastrointestinal route. Humans and other terrestrial animals uptake food, vegetables, fruits, milk and dairy products, meat and other meat products, seafood, including fish and other fish products, fats, oils, drinks, water, and beverages via the gastrointestinal route. Mother's milk is the source of the uptake of these pollutants by breastfeeding children.

Dermal: When uptake of these compounds occurs via absorption through skin/gills, this is termed dermal uptake. Dermal uptake by humans occurs via washing with contaminated water and/or by using body creams, body lotions, nails paints, etc., while the aquatic animals' bioaccumulate these plasticizers via gill (dermal contact).

Inhalation: Inhalation of house and street dust, hair sprays, deodorants, perfumes, and polluted air contaminated with plasticizers bioaccumulates these toxicants in humans and other terrestrial animals.

V. Plasticizers In The Environment:

Researchers have found plasticizers in all the compartments of the environment (water, air, soil, food chain) within and/or beyond permissible limits.

Plasticizers in Aquatic Medium: Due to modernization and industrialization, the use of plastic has increased manyfolds during the last 25 years, so plasticizers, particularly phthalate esters, which are classified as a priority pollutant by the United States Environmental Protection Agency (USEPA), the European Union, and other agencies, are found globally in water (surface, ground, drinking, river, marine), air, sediments, and soil[7]. As the phthalates cannot form chemical bonds with other compounds due to weathering, evaporating, and leaching during their uses and production, the phthalates enter the environment[8, 9]. Plasticizers enter the surface and groundwater via wastewater treatment plants, solid waste disposal units, manufacturing units, and agricultural activities[10]. Due to more plastic manufacturing units and more uses of plastic by the urban population, the phthalate concentration in the urban environment is higher than in the rural environment. The plasticizers leached from the plastic dumped and are present in the environment. The plasticizers enter the marine environment via rivers (which carry agricultural and storm runoff) and human activities through agricultural and storm runoff[11-13]**.** Čelić et al.[14] during their studies found that 20–47% of municipal and industrial wastewater, surface waters, and drinking water samples were contaminated with bisphenol (BPA), and concentration ranged from 0.5–338.2 ng/L. They also reported a higher concentration of the BPA in the industrially impacted waters. The concentration of different plasticizers in sewage water, surface water, groundwater, river/lake water, and marine water is recorded in Table 1.

Plasticizers in house dust and air: With the indiscriminate and wider use of plasticizers in industrial and consumer products, indoor and outdoor dust contains plasticizers as particulate matter, which contaminates the environment. Both phthalate and non-phthalate plasticizers are reported in the indoor air and house dust. Diisononyl phthalate (DINP) and diisodecyl phthalate (DIDP), acetyl tributyl citrate (ATBC), tricapryl trimellitate (TCTM), trioctyl trimellitate (TOTM), glycerol monooleate (GMO), methyl oleate (MO), and diisobutyl adipate (DiBA) bisphenols are mainly reported in air and house dust[52, 80]**.** Tan et al.[52] reported a median concentration of 17.8 to 252 μg/g of the non-phthalate plasticizers in house dust of China. Demirtepe et al.[81] during their studies found 12–2765 μg/g of phthalate plasticizers and 45–13,260 μg/g of alternative plasticizers in the house dust of Eastern Slovakia. Wind speed, temperature, atmospheric pressure, and relative humidity are the major factors that influence the concentration of plasticizers in air and dust. The maximum concentration of the BPA was reported at auto repair and car repair shops. The concentration of plasticizers in air and house dust is recorded in Table 1.

Plasticizers in Food: Plasticizers from soil, water, air, and food packaging migrate to crops, vegetables, fruits, and food/milk. The main route of human uptake of plasticizers is food and water. The concentration of phthalates in common food is so high that it falsely indicates that phthalates are the ingredient of food**.** Friedman[82] studied the concentration of phthalates in different foods and reported that in beverages the phthalates concentration was up to 7467 ng/g, while in dairy products, fast food, grains, infant food, meat and poultry, packaged fruit and vegetables, prepared meals, and seafood the accumulation was 20452; 33980; 10980; 4267; 9985; 24928; 53579; 24321 ng/g, respectively. Fat et al.[83] found phthal0.060-0.298 mg/kg phthalates plasticizers in raw milk samples and in commercial milk 0.038 to 0.173 mg/kg. The concentration of non-phthalate plasticizers in aqueous and low-alcohol food ranged from 0.02 to-0.165 mg/kg[84]**.** Packed food besides phthalates also contains bisphenols; BPA in vegetable oils ranged from 0.41 to 8.4 ng/g, and in palm oils it ranged between 2.35 and 11.6 ng/g. The BPA concentrations in the canned beef and the canned chicken were 5.88to21.3 ng/g and 2.94to6.36 ng/g, respectively. In dairy products, the BPA concentration ranged from 1.45to3.43 ng/g, while in milk it ranged from 0.20to4.80 ng/g. Phthalate and non-phthalate plasticizers are also found in vegetables and fruits[52]. The concentration of the plasticizers in water and food is given in Table 1.

Plasticizers in Animal Food: Globally, plasticizers are present in most of the water bodies (lakes, rivers, ponds, surface water, and seas). These pollutants contaminate surface water via discharge from urban drainage systems, road runoff, agricultural soils, landfill leachate, and wastewater treatment plants. Aquatic animals living in such water accumulate the plasticizers in their bodies. These compounds are also accumulated in the edible parts of crops (fruits, vegetables) via the uptake of the phthalate and non-phthalate plasticizers from the soil and irrigated water. The accumulation of these compounds in animals and plants adversely affects the ecosystem. The data are given in Tables 1 and 2.

VI. Human Health Impact:

Plasticizers (both phthalate and non-phthalate) in human animals act as endocrine disruptors[85, 86]. The adverse impact of the plasticizers on the citizenry depends on age, sex, and lifestyle. Plasticizers negatively impact the adipose tissue, the major energy reservoir of the human body and the largest endocrine organ. Adipose tissue dysfunction in humans' causes' insulin resistance, dyslipidemia, increased visceral adiposity, obesity-associated CVD, etc. Lucaccioni et al.[87]reported that as the concentration of phthalates in the environment is increasing, their negative impacts on humans at any time of life are unavoidable. The negative effects caused at foetal, perinatal, and early childhood phases impact throughout life. Phthalates in the human body bind to steroid hormone receptors, affecting normal hormonal functioning and declining the proper production of androgens and progesterone (sex hormones), which not only adversely impact the children's sex organ development but also adult sexual behavior[88]. Several studies[89,90] have shown that phthalate plasticizers in the human body not only disrupt endocrine functioning but also cause mutagenicity, teratogenicity, genotoxicity, neurotoxicity, cytotoxicity, reproductive toxicity, and carcinogenicity. Liposoluble phthalates, after entering the erythrocyte membrane, alter the structure and functioning of haemoglobin, which reduces erythrocytes and causes anemia[91]**.** Erythrocytes in the presence of phthalate increase the level of methaemoglobin (MetHB) and reactive oxygen species (ROS) levels that cause changes in enzyme activity, apoptosis, and necrosis. Research has shown that phthalate exposure causes a decrease in sperm motility and concentration and an abnormal number of heads and flagella in spermatozoa[88]. Huang et al.[92] have reported female reproductive abnormalities on bioaccumulation of phthalates. Premature puberty in the young women exposed to phthalates was observed by Mesquita et al.[93]. A survey of literature denotes that when females are exposed to phthalates for a longer period, it not only causes miscarriage but also endometriosis, eclampsia, impaired oocyte competence, ovarian dysfunction, premature breast development, and breast cancer[10, 94]. The studies done by Chung et al.[95] have shown that phthalates in abdominally obese men increase the chances of prostate cancer. Allergy, asthma, delayed neurodevelopment, social impairment, obesity, Type II diabetes and insulin resistance, improper thyroid function and increased risk of thyroid cancer, and higher systolic blood pressure are some adverse health effects to children caused by exposure to phthalates[96]. Prolonged exposure of the bisphenols to humans causes

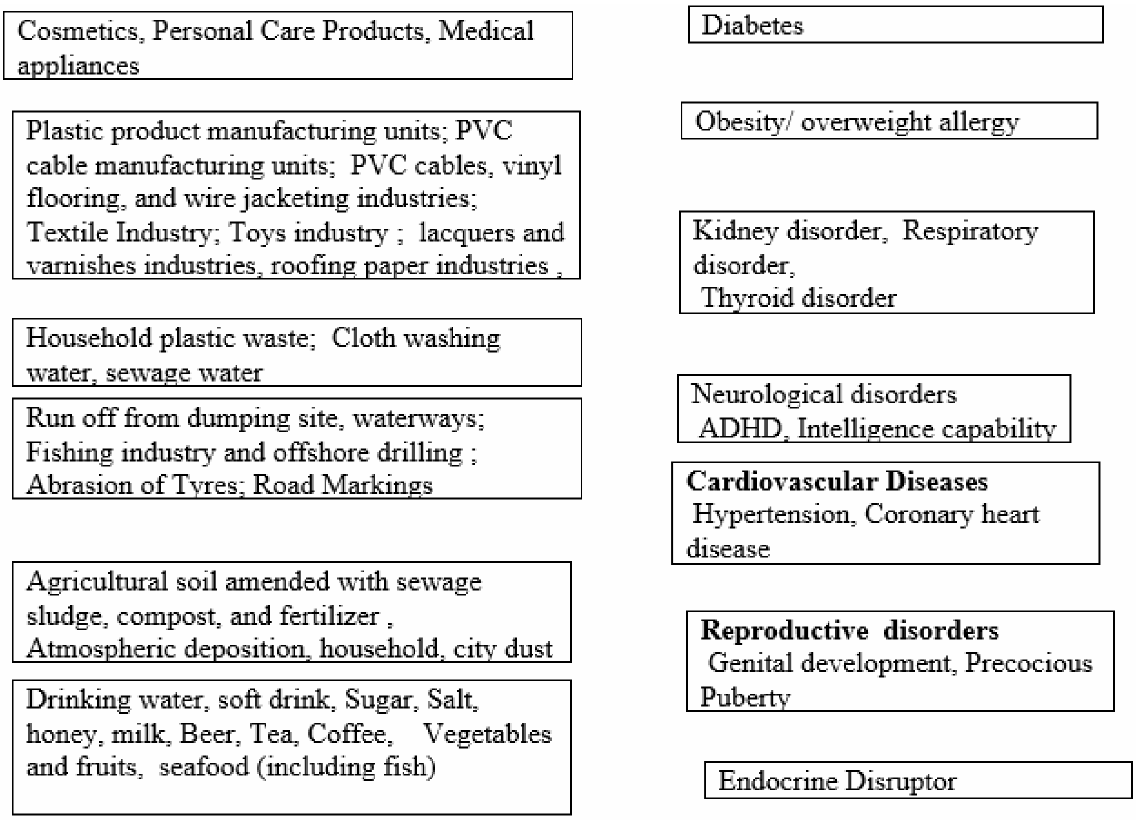

Fig. 1. Plasticizer application and disorders caused in different organs of human body

Obesity (due to promotion of the abdominal lipid accumulation), cardiovascular disease (hypertension; coronary artery disease), neurotoxicity, cytotoxicity, thyroid dysfunction, reproductive disorder or reproductive complications, and breast cancer[53, 97]. Prasse et al.[98] after their intensive study concluded that bisphenol in human bone metabolism shows an adverse impact. A literature survey denotes that type 1 and 2 diabetes and liver abnormalities in humans generally occur due to the accumulation of bisphenol. Studies have shown[72] that total and free testosterone concentration in males is inversely proportional to bisphenol concentration, while the concentration of SHBG (sex hormone-binding globules) is directly proportional to BPA concentration. Researchers Khan et al.[5] and Salamanca-Fernandez et al.[99] have found that prolonged exposure to bisphenol enhances the risk of cancer. There is a significant positive correlation between BPA exposure and the development of reproductive diseases (polycystic ovary syndrome, endometriosis), the risk of implantation failure, and adverse birth outcomes[100, 101.]

VII. Impact On Animals:

Plasticizers, after entering the bodies of water, come into contact with aquatic organisms and cause several adverse effects. Immunotoxicity, neurotoxicity, genotoxicity, endocrine, metabolic, and developmental toxicities are reported in fish and aquatic invertebrates due to the presence of phthalates [49]. Crooked tails, necrosis, cardiac oedema, lack of tactile response, and death of aquatic animal embryos in the presence of phthalates have been reported by many workers[42, 102.] Lu et al.[45] found gonadal dysgenesis in aquatic organisms in the presence of ng/L of phthalates. In rodents, phthalates decrease the testicular weight and sperm production, resulting in infertility[31]**.** In male rodents, the phthalates cause infertility by lowering testicular weight and decreasing sperm production[31]**.** Damage to the liver, kidney, and other organs of aquatic organisms in the presence of phthalates is also reported by Zhang et al.[49] and Chen et al.[103.] Studies[104, 105] have shown that non-phthalate plasticizers, particularly bisphenol, negatively impact aquatic organisms, alter behavior and physiology, retard growth, negatively impact the cardiovascular system, and amphibians are most affected at an early stage. Fabrello and Matozzo [106] found that bisphenol in marine fish species alters the development and neuroendocrine systems cause oxidative stress. When marine fish are exposed to bisphenols, it causes vacuolation, karyopyknosis, and karyolysis in the liver, impacting antioxidant and inflammatory response genes negatively affecting overall health[107]**.** In goldfish spermatogenesis disruption is due to prolonged exposure to bisphenol, is the finding of Wang et al.[89.]

VIII. Conclusion:

In modern society of the time, it is not possible to live without plastic, and the use of plastic in the agricultural field is increasing. Through leaching and migration, the plasticizers from the plastic enter all the segments of the environment, i.e., air, water, and soil. These chemicals remain in the soil for decades, and via absorption, leaching enters the food chain. Studies have shown that meals available at fast food restaurants also contain plasticizers. Phthalate is the most widely used plasticizer, and bisphenols (the most widely used non-phthalate plasticizers) are endocrine-disrupting chemicals. The plasticizers adversely impact human health and aquatic organisms' health and disturb the ecosystem. The plasticizers impact the reproductive system (males and females, infertility and early puberty), causing neurological disorders, developmental issues, cardiovascular health, and type 1 and 2 diabetes. Bisphenol in the animals also impacts the bone marrow area. So to minimize the negative impacts of plasticizers, it is need of the hour to find such plasticizers that have the least adverse impacts, and the freshly cooked food must be used as much as we can.

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Table 1: Concentration of plasticizers in **sewage wastewater, ground water, river water, seawater, sediments and Vegetables /Crops**

Compound	Wastewater/ Sewage water/ sewage	Groundwater	Freshwater/ Surface water	River water/ Lake water	Drinking water	Vegetables/ fruits/ Crops	Estuarine/coastal/ Sea water/ Sediments	Others
Phthalates	3.31-8633.5 ug/L[15]; 159-225 ug/L[16]; 2.6-27.1 ug/L[17]; **Leachate**-114-303 ug/L[18]; 0.0-394.4 ug/L[19];0.0-249 ug/L[17]; **Suspended Particulate Matter**-64.2-156 ug/kg[20]	6.04 ug/L[17]; 3367.4 ug/L[21]; 180-220 ug/L[22]	4.66-7553.9 ug/L[15]; 1.292-4.544 ug/L[20] **Sediments**:2.0-14.75 ug/kg[20]; 1-220 ug/L[22]	7.48-30.03 ug/L[23]; 0.178-1.362 ug/L[3] ;0.67-4.5 ug/L[24] ; 0.165-11.28 ug/L[25]; 0.124-2.591 ug/L[12]; 0.45-106.6 ug/L[26]; 0.18-11.13 ug/L[27]; 592-2750 ng/L[28]; 1.42-14.8 ug/L[29] **Pond water**-0.0-11.05 ug /L[25]; **Wetland**: 0.53-2.01 ug/L[27]; **Sediments**: 129 ug/kg[20]; 1120-6610 ng/g[28]; 0.27-10.52 ug/g[26]; 190-2010 ug/kg [30];	0-447ng/ L[31]; 0.77-1438.2 ug/L[15]; 1.28-5.28 ug/L[30];5.46 ug/L[32]; 158ug/L[33] **Water vending Machine**- 0-841ng/ L[31]	18.2 - 28.6ng/g[34]; 4.1-71.8 (SA)[34]	7.4-71700 ng/L[35]; 1300 ng/L[27]; 240300 ng/L[36]; 1-28 ug/L[37]; 286 ng/L[38]; 1367 ng/L[39]; 68.8-1500 ng/L[40]; 100-527 ng/L[41]; 172-3365 ng/L[42]; 365 ng/L[43]; 169.4 ng/L[44]; **Sediments**-9.2-11965 ng/g[35];64.5-733 ng/g (dw)[45]; 1-1203 ug/kg[37]; 650-915 ug/kg[20]; 235.4-608.7 ug/kg[46]; 2-766 ug/kg[47]; 654-2603 ug/kg[48]; 462.1-15133ug/kg[49]; 71.80 ug/kg[50]; 49.2-440 ng /g[40]; 512-610ng/g[41]; 190-2430ng/g[42] **Landfill chealate**: 114-303ug/L[18]	**Soil**-9.25-492.44 mg/kg[51]) **House Dust:** 132-1880 ug/g (China); 73-825 ug/g (Vietnam); 42-747 ug/g (Australia); 254-1410 ug/g (USA)[52];
Bisphenol-A	0.79-10ug/L [53];0.05-1.37 ug/L[15]; 1337-16118 ng/L (Influent) (Chirac et al., 2021); 15-96 ng/L (Effulent) [54] **Fish Habitat**-0-13.5 ng/L[45]; 0-5927 ug/L[55]	228.04 ug/L [21];0-35.5 ug/L [45]	0.307-1.42 ug/L[15]; 85.5 ug/L [56]; 16.3-30.1[21]; 34-240 ng/L[54]; 78.9-310 ng/L[53];	0.76-18.96 ug/L [57]; 0.04-4.46 ug/L [27]; 1.42-14.8 ug/L[29]; 16.3-30.1 ug/L[55]; 0.71-47.4 ug/L[58]; 7.02-13.95 ug/L[59]; 1-30.2 ng/L [60] **Wetland**: 0.21-2.82 ug/L [27];0-37ug/L [61]; **Sediment**: 11.09-63.46 ug/kg[59]; 0-0.95ug/kg [61];	0.002-2.84 ug/L [15]; 2.23 ug/L [56]; 6-53 ng/L[55];2.5-35.6 ng/L [14]; 228 ug/L [21]**;** **2.3-16ng/L [62];**	Fruit & Vegetables: 10.98-94ng/g[63]; 1.7-11.3 ng/g [34] **Cereals**-0.9-3.7 ng/g[63]	5.26-12.04 ng/L (Gao et al., 2023); 2.7-52ng/L (Xie et al., 2022); 2.3-49 ng/L (Zhao et al., 2021); 9.5-173 ng /L (Zhao et al., 2019); 0.0-0.247 ng/L (Marcotti-Murua et al., 2020); 240 ug/L (Song et al., 2020); 15-38ng/L (Nejad et al., 2023) **Sediments**: 0.56-5.22 ng/g (Gao et al., 2023); 1-1.35ng/g (dw) (Lu et al., 2021)	**Indoor Dust-Nonphalate:** 10-1310ug/g (China); 1.5-203 ug/g (Vietnam);26.9-748ug/g (Australia); 25.6-**2220** ug/g (USA[52]; **Milk**: 1.33-175 ng/g[63] ; 1.47 ng/g[70]; 0.0-0.37 ng/mL[71]
Bisphenol-S	0-438 ng /L[29]; 90-1100ng/L[53]; 0.1-932 ng/L72		0-341ng /L[29]; 0.07-133 ng/L[72]; 19.9-65600 ng/L; 0-1584 ng/L[73]; 6.15-8.23 ng/L[54] ;3.2-	27.8-234.3ng/L[60]		Vegetables:0-0.21 ng/g[34]	0.07-0.63 ng/L[64]; 0.15-12ng/L[65]; 0.12-11ng/L[66]; **Sediments**: 0.0-0.19 ng/g64	**Milk:** 0.22-0.49 ng/g[70]; 0.0-1.62 ng/mL[71]

			7.8ng/L[53]; **Suspended Particulate**: 4-21 ng/L[41];					
Nonyl phen ol;	0-9560 ug/L[55]	5.6 ug/L[45]		0.28-12.42ug/L[57] ;75.4 ug/L[72]; 12.4-286.1 ng/L[60]; **Sediment**; 22.34ug/kg[72]	1.2-7.9 ng/L[14]; 29.1-80.5 ng/L[75]		730 ug/L[68] **Sediment:** 14.1-29.8ng/g (dw)[45]	

Table 2 Average concentration of plasticizers in freshwater, marine water fish and other invertebrates

Comp ound	Marine Fish		Other Invertebrates
	Concentration in ng/g		
	Whole body	Tissues	Concentration in ng/g
Bisphe nol-A	1-208ng/g[45]; 7.2-103ng/g[63]; 0-11.5ng/g[34]; 2.99-11.55 ng/g[69]] **Canned Fish** 14.6-28.5 ng/g (SA)[34]	0.6-7.1 [76]; 3.9-16.2 ng/g [77] Shark: 105.3ng/g[77]	
Bisphe nol-S	0-50.5 ng/g[34]		
Phthal ate	178-248 ng/g (dw)[45]; 41.5-222.6ng/g [34]; 0-127 ng/g (SA)[34] **Canned Fish;** 31.8-71.8 ng/g[34]; 44.8 ng/g (SA)[34]	Canned Fish-820-4926 ng/g[49]	Crab (Muscle)- 495.7-2033.4 ug/kg ; (Hepatanopancreas)-159.7-651.7[78]
Nonyl pheno l	16.1-34.5 ng/g (dw)[45]	0.8-8.9[76]; 110ug/kg[79]	