5. BIOACCUMULATION OF XENOBIOTICS

During the course of translocation, non-polar or lipophilic and recalcitrant (resistant to degradation) xenobiotics having low water solubility often accumulate in certain tissues of organisms. The phenomenon of bioaccumulation attracted public attention in 1960s with the report of DDT and methyl mercury residues in fish, fish eating birds and wildlife. Although the organochlorines are in general persistent pesticides, yet DDT is particularly highly persistent. It has very high affinity for tissues rich in fat content. Therefore, it is stored in body fat for much longer time than other organochlorinated chemicals, such as methoxychlor. Such substances may persist in water for much longer time (6-12 months) and may cause cumulative toxicity to organisms.

Any chemical accumulates in the biological system only when its rate of uptake exceeds the rate of elimination. There are three general terms, *viz.* (*i*) Bioconcentration,(ii) Bioaccumulation, and (iii) Biomagnification. Before giving a detailed account of the process of bioaccumulation, it is essential to differentiate these three commonly used and closely related terms.

(i) ***Bioconcentration*** Bioconcentration may be defined as a process whereby a xenobiotic enters the body of organisms from the surrounding medium and accumulates in certain tissues.

(ii) ***Bioaccumulation*** Bioaccumulation is a wide term. It considers the accumulation of xenobiotics both from the medium and through the consumption of food. Thus, it takes into account the uptake of chemicals dissolved or suspended in the water and from ingested food and sediment residues.

Persistent hydrophobic xenobiotics may get bioaccumulated in aquatic organisms through different mechanisms, like bioconcentration, ingestion and biomagnification. Bioaccumulation should be regarded as a hazard criterion in itself even if the subchronic, chronic or acute effects are not visible, as some hazardous effects may only be recognized in a later phase of life. Bioaccumulation of xenobiotics in biota may be a prerequisite for adverse effects on ecosystems

(iii) ***Biomagnification*** Biomagnification is a broader term, which refers to the entire process of bioconcentration and bioaccumulation. In addition, it takes into account the gradual increase in the concentration of chemical in the tissues of organisms as it passes through the food chain. It indicates that the level of chemical increases as the position of the organism increases in the food-chain. That is, organisms occupying higher trophic levels gradually accumulate more amounts of xenobiotics in their tissues.

To estimate the level of xenobiotics in biological systems, the bioaccumulation tests are performed and the results of these tests are expressed in term of ***bioconcentration factor (BCF).*** The ***BCF*** may be defined as *the ratio of average concentration of chemical in the tissues of test organisms in relation to its concentration in the surrounding medium.* For instance, BCF for aquatic ecosystem may be expressed as:

$$\text{BCF} = \frac{\text{Concentration of chemical in tissues of organisms}}{\text{Concentration of chemical in water}}$$

where C_D is the chemical concentration in the organism (g chemical/ kg organism), C_s is the chemical concentration in the sediment (g chemical/kg dry weight sediment), L is the concentration of lipid in the organism (g lipid/ g organism), and TOC is the total organic carbon content in the sediments (g organic carboni g dry weight sediment). The amount of lipid factor comes in the calculation because mostly hydrophobic organic chemicals bioaccumulate in the lipid tissues of organisms.

(1) Process of Accumulation

As stated earlier, the bioaccumulation takes place when the rate of uptake of chemical exceeds the rate of its elimination. To have a clear picture all possible routes of chemical uptake should be taken into account. The process of uptake of chemical from water, sediment and food has been worked out more in the aquatic systems, hence the general process of bioaccumulation applicable for the aquatic systems is being described at length.

(i) ***Uptake of xenobiotics from water*** Various workers have reported direct uptake of chemicals from the water by the aquatic organisms (such as, algae, annelids, arthropods, mollusks, fish, *etc*.). The mechanism of uptake process of xenobiotics from water will be concentrated on the following three transport processes:

(a) Diffusion,

(b) Special transport, and

(c) Adsorption.

(a) Diffusion Various xenobiotics have been reported to enter the body of organisms by the process of passive diffusion. It is a physical process. It occurs across any permeable or semi-permeable barriers against a concentration gradient (ΔC). It is an energy independent process. That is it does not require expenditure of energy. For instance, the gills of fishes are particularly vulnerable against chemical insults. 2-4μm thin gill membranes possess 2-10 times the surface area of the body, which facilitates the diffusion of xenobiotics. The lipid bilayers of semi-permeable membranes of gills and lining of mouth and gastrointestinal tract of fishes permit the rapid passage of lipophilic chemicals.

Weakly acidic and basic substances pass across biological membranes in unionized form. The water and other small ions upto molecular weight of 100 pass through proteinaceous pores present in the biological membranes.

A few workers have demonstrated the diffusion of dieldrin and cadmium across isolated perfused gills of trout and *Mytilus*, etc.. Similarly, several investigators have reported *in vivo* uptake of various xenobiotics (such as, DDT, methyl mercury, mercuric chloride, copper, *etc.*) through the gills of fishes. Considerable proportion of xenobiotics passively diffuse across general body surface of various arthropods.

(b) Special transport: Uptake of xenobiotics across biological membranes may also occur by special transport mechanisms including active and facilitated transports. The active transport

takes place against concentration gradient and it requires energy to move xenobiotics. Therefore, it is considered as a true concentrating mechanism. The facilitated transport does not require energy input and does not concentrate xenobiotics against any concentration gradient. Metals accumulate by both these transport processes. But, it is not known as to which mechanism is more common. Usually metal uptake in aquatic organisms is directly proportional to the metal concentration in the water. Low water salinity enhances the rate of uptake of xenobiotics. The plasma proteins are known to facilitate the transport of xenobiotics into the blood.

(c) Adsorption: Adsorption is also a physical process and a surface phenomenon. Xenobiotics are often adsorbed either to the body surface of arthropods or to the gill surface of other aquatic organisms by covalent, electrostatic and molecular forces. Adsorption is particularly important as initial step in the accumulation process. The xenobiotics binding to the body surface generally do not contribute to the uptake upto toxic effect level within the body of organisms, but certainly contribute to the total body burden and affect the vulnerable functions of the epithelium. The process of adsorption is especially important for microorganisms owing to their high surface to volume ratio.

(ii) ***Bioavailability of xenobiotics in water:*** The uptake of xenobiotics by the organisms largely depends on their availability in dissolved form in the surrounding water. Therefore, factors affecting the concentration of chemicals in true solutions also affect the uptake of xenobiotics by the organisms owing to their effect on concentration of xenobiotics in the water. The important processes reducing the bioavailability of xenobiotics in water are adsorption to suspended solids, sediments, humic acids and other macromolecules, formation of colloidal suspension, chelation, complexation and ionization. Lipophilic xenobiotics having strong tendency of bioconcentration also partition into the organic fraction of sediment or suspended solids. Thus, the nature of sediments profoundly affects the availability of xenobiotics in the surrounding water. For instance, amphipods exposed to hexachloro biphenyl in the sediments of stream microcosm accumulate substrate-desorbed residues directly from water. The greatest bioaccumulation of xenobiotics has been recorded in amphipods exposed to sediments with least organic content and largest particle sizes.

Suspended particulates and adsorbents, such as humic acids, reduce the uptake of lipophilic xenobiotics by reducing their concentration in water. For instance, uptake of highly lipophilic chemical, benzo (a) pyrene, from the water by sunfish has been reported to be reduced due to the presence of humic acids whereasthe uptake of anthracene, a less lipophilic chemical remained unaffected.

Uptake of xenobiotics from food: The xenobiotics absorbed through the gill surface and the integument are also readily absorbed by the gastrointestinal tract by similar mechanisms of diffusion and transport. Lipophilic xenobiotics present in food are efficiently absorbed owing to long-term contact between the food and the membranes. Weak acids and bases are absorbed in unionized form. The stomach pH favours the diffusion of weak acids whereas the intestinal pH favours the absorption of neutral or weakly basic xenobiotics. Uptake of metals from food depends on their forms (*e.g.* free or bound). Xenobiotics of high molecular weight, *viz.* corrageenans (40,000Å) and polystyrene (2200Å), are absorbed in the intestine by the process of pinocytosis.