ABSTRACT: Nonylphenol (NP) is an alkylphenolic compound classified as an endocrine disrupter capable of interfering with the hormonal system of different aquatic organisms. It is mainly originated from degradation of Nonylphenol Ethoxylates. Due to its physical and chemical characteristics, it is persisted in sewage sludge and river sediments. In river water and sediments the concentration of NP is 4 µg/l and 1 mg/kg, respectively. The fate and occurrence of NP in the environment is clearly correlated with different anthropogenic activities like wastewater treatment, land-filling and sewage sludge recycling. Different types of aquatic vertebrates and invertebrates are trashily affected by the NP. The impact of the NP on the fish as follows: decrease in male fertility, altered sex ratio, reducing hatching rate. Also different types of alteration are occurred in haematological, biochemical and histopathological parameters. Due to the bioaccumulation properties the human beings are dangerously affected by the NP.

Key words: Nonylphenol, toxic effects, aquatic organisms.

INTRODUCTION

Nonylphenol [4-(2, 4-dimethylheptan-3-yl) phenol] (NP) is a xenobiotic alkylphenolic compound which is used in the manufacturing of antioxidants, detergents, emulsifiers, solublizers, lubricating oil additives and herbicides etc. During alkylation process of phenol it is synthesised (OEHHA, 2009). NP is mainly used as surfactants which are composed of phenol bearing a 9 carbon-tail. Another major source of NP in the environment is the discharge of effluents from the sewage treatment plants (Soares et al, 2008). The major degradation product of Nonylphenol polyethoxylate (Nonylphenol) is gained significant environmental concern due to their estrogenic effects (Carrera et al, 2006).

Nonylphenol is a static compound with a boiling point between 293-297°C and a melting point between -8 to 2°C. The molecular formula for NP is C_{15}H_{24}O and the chemical has a molecular weight of 220.35. Appearance of NP is light yellow and viscous liquid with phenolic smell. Solubility of NP in water is very low near about 6mg/l at pH 7. The octanol-water partition coefficient (log K_{ow}) of NP is 4.48 so that the compound no readily soluble in the water, therefore it partitions favourably with the organic matter. When the pH becomes more alkaline then solubility of NP increases in the water. However, NP is easily dissolved in a various organic solvents. The compound has very low mobility and its capacity for spreading in the aqueous phase of soil and sediments is limited. It is semi-volatile organic compound having a capacity of water/air exchange. Henry’s law constant of NP are 2.07x10^{-2} Pa and 8.39x10^{-1} Pa m^3/mol, respectively (Soares et al, 2008).

The compound is moderately soluble in the water and the half-life is more than 60 years. In aquatic environment the detection level of NP is 0.7 µg/l to 15 µg/l and in soil sediment 1 mg/kg respectively (Soares et al, 2008). Recently, NP gains much more attention due to its eco-toxicological consequence on the aquatic environment and its potential role as an endocrine disruptor and xenoestrogen due to its ability to act with estrogen like activity (Mergel and Maria, 2013).

FATE AND SOURCES OF NONYLPHENOL IN ENVIRONMENT

In surface water, sediment, ground water, soil and air the fate on NP is controlled predominantly by its physical and chemical properties and this in turn calibre its degradation. NP is a semi-volatile compound with the capacity of water-air exchange. Initially, it reaches to
the atmosphere then through the wet deposition it is transported to the aquatic and terrestrial environment. It is a photo degraded compound therefore, it can be degraded by the sun light in surface layer of water but its estimated half-life is more than 60 years in sediments. Through the action of aerobic and anaerobic microorganisms, biodegradation of NP can be achieved but it is restricted to oxygen supply. Under environmental condition microorganisms have been used to stimulate the outcome of nonylphenol. The degradation rate of (from high to low) NP through anaerobic microorganism is: sulphate reducing conditions > methanogenic conditions > nitrate reducing conditions (Soares et al, 2008).

**Occurrence of from Sewage Treatment plants**

Treatment of nonylphenolic compounds is a very authentic factor in the prediction of the environmental fate of these compounds. Bench-scale experiments and batch tests have been widely performed to assess the behaviour of NP. The concentration of NP in municipal treatment plant effluents is more than 1 µg/l (OEHHA, 2009). Soares et al (2008) explained that temperature and oxygen are also very important factors in the fate of nonylphenol which has been demonstrated in the bench-scale activated sludge system. Analytical works on full-scale sewage treatment resulted frequent occurrence of NP as stable intermediate in sewage sludge with heavy load in treated industrial waste water or from urban area of higher population density. In same study it was pointed out that 60-65% of the NP compounds of STW were released into the environment in the form of 19% nonylphenol carboxylate, 11% short nonylphenolethoxylates (1 and 2 ethoxylate group), 25% nonylphenol and 8% untreated compounds. In associated form with the sludge, NP was mainly released. The important pathway for NP removal from waste treatment plant is sorption of the sludge solids (Soares et al, 2008).

**Exposure of Nonylphenol in river waters, estuaries, sediments and oceans**

The concentration of nonylphenol is 0.89 µg/l, 1 µg/l, and 2.76 µg/l in freshwater, municipal treatment plant effluent and coastal water respectively. NP is deposited and persisted in sewage sludge, river sediments and other environmental compartments due to its physical and chemical properties. The fate of NP in aquatic environment is mainly correlated with the anthropogenic activities like waste water treatment, land filling and sewage sludge recycling (OEHHHA, 2009). In most Asian countries the concentration of NP is very high in aquatic environment. In aquatic environment main sources of NP are domestic waste water, industrial waste water as well as surface run off. In the affected river the spatial variation of NP mainly depends on the distribution and properties of pollution sources. In aquatic environment, high concentration of NP is due to inadequate treatment of domestic waste water. The Kaoping River’s tributaries were polluted with NP due to improper treatment of waste water which caused high risk in downstream of the river (Chen et al, 2010). Zhang et al (2009) found in their experiment that the main discharge point of NP in Jialu River was Zhenghou city from where the annual discharge of NP was 726 kg, which increased the NP level of this river up from 75.2 ng/l to 1520 ng/l (Zhang et al, 2009). Soares et al (2008) found that different types of factor such as temperature, flow rate, sedimentation rate, particle size, microbial activity etc. which affected the variation of NP in surface water. In summer season the microbial activity got increased which enhanced the degradation of nonylphenol ethoxylate (Soares et al, 2008). Mao et al (2012) reported that in summer season the NP also came from detergent, shower cream and plastic ware because in this season the use of those commodities was more than any other season.

Mao et al (2012) also reported that due to hydrophobic properties, NP of surface water got deposited in sediments which caused a preferential accumulation in sediment. The concentration of NP in sediments is more than 1mg/kg (Soares et al, 2008). According to Mao et al (2012) concentration of NP is 119, 100µg/kg in Donghu Lake of China, which is referred as most contaminated sediment. Gong et al (2011) found that there was a positive correlation between NP and total organic carbon (TOC) of the sediment. In present condition some areas of Europe the concentration of NP in sediments were very high, like the maximum concentration of NP was 2830/kg in the sediment of Danube River (Miciæ and Hofmann, 2009). The NP concentration is more in the sediment of developing countries than the developed countries which is seen in Table no. 2 (Mao et al, 2012).

**Occurrence of Nonylphenol in soil**

the occurrence of NP in soil is closely related with anthropogenic activities like as sewage sludge application, landfiling and accidental spillage. The activity that has gained much more attention is sewage sludge recycling to agricultural land. Jensen and Jepsen (2005) & Langford and Lester (2002) reported that according to a Danish study 66% of the total production of sewage sludge was recycled by the farmers in 2002 which raised the importance of investigating the occurrence and fate of contaminants such as NP. Falkenberg et al (2003) and Vikelsoe et al (2002) reported that the elevated concentration of NP have been found in soils exposed to high addition of sewage sludge (1.4-1.6mg/kg) and points of run-off (34-14 µg/kg) than unamended soils or soils fertilized with manure or with limited amounts of sewage sludge (0.01-0.98 µg/kg). According to Oman and Hynning (1993), NP has also been found in landfill leachates that were approaching anaerobic condition at concentrations ranging from <10 to 170 ig/l. The occurrence of nonylphenol in soil is influenced by various factor such as: biodegradation, sorption and volatilization (Soares et al, 2008). He also reported that the rate of biodegradation mainly depends on bioavailability of NP to the soli microflora and availability of oxygen. Hollrigl-Rosta et al (2003) reported that non dissolved organic matter (DOM) through non-specific lipophilic interactions NP conjugates with humic acid strongly which is fully regulated by the diffusion and are not completely reversible. They also reported that often stronger sorption is observed at pH value near the pKₐ that’s maximized interactions with soil matrix. Trocmé et al (1988) found that the volatilization rate of NP from soil is very minimum. During a 40 days period of time volatilization rate of NP is 0.22% of 1g nonylphenol/kg of soil. Vogel et al (2000) also found that the mobility of NP is very less in soil and consolidated with the soil particles. Almost 99% of the contaminant was found within 30 cm of the surface of soil after 730 days.

**Availability of NP in groundwater**

The appearance of NP in aquifers is relatively attached to anthropogenic activities like as the discharge of STW effluent with concentrations averaging 790ng/l (Barber et al, 1988), in the vicinity of contaminated rivers 0.1-0.8mg/l (Ahel et al, 1996; Zoller et al, 1990), septic systems 1.2g/l (Rudel et al, 1998) but can also be due to agricultural activities 0.16-0.38 ig/l (Latorre et al, 2003), landfill leachate and the discharge of industrial waste water <100-280ng/l (Ahel et al, 1991; Langwaldt and Puhakka, 2000) analysed that usually the removal of contaminants is very slow in ground water because the chemical and biological characteristics in aquifers are not suitable for degradation. Soares et al (2008) determined that the temperature of groundwater is in psychrophilic range and both the carbon sources and oxygen are limited that’s why the microbial degradation rate of NP in groundwater is very slow. Ahel et al (1996) reported that occurrence of NP in groundwater is mostly affected by the variation in temperature. He also reported that during winter season the highest concentrations are observed. Montgomery-Brown et al (2003) found that the availability of oxygen is a very important factor during the permeation of NP to the aquifers.

Another important factor is hydrological characteristics of the sites. Prompt infiltration is observed at sites with highly permeable sediments. Mass transfer of NP is very low due to its low solubility (Barber et al, 1988) but its sorption is monitored by the organic carbon content of the sediment (Zoller et al, 1990).

**Availability of NP in atmosphere and air**

Dachs et al (1999) reported that in late 1990s first measurement of NP was initiated where the sample was taken from urban and coastal environment and found that unexpectedly high concentration on nonylphenol (2.2-70 ng/m³) which mainly exceeded those of PCBs and PAHs. In another study Cincinelli et al (2003) found that NP in atmosphere was directly correlated with anthropogenic activities such as the operation of STW. Fries and Puttmann (2004) analysed that NP becomes conjugated with the aerosols produced by the aerator of the sewage treatment plants which lead to a decrease in air quality in the surrounding of the STW. They also found that through the wet deposition (rain and snow) the atmospheric NP can be returned to aquatic and terrestrial environment. In same study they also reported NP was found in the rain and snow of urban, suburban and rural area in Germany and Belgium where concentration of NP in rain water varied with the region of sampling such as: suburban areas-0.534 µg/dm³, urban area-0.062 µg/dm³ and rural area-0.099 µg/dm³ respectively. Rudel et al. (2003) determined that in snow sample the mean value was found around 0.242 µg/dm³, with higher value in the urban area 0.478 ig/dm³. They also found that NP has been identified in indoor environments in air and dust at concentration higher than outdoor value (air-110 ng/m³ and dust-2.58 ig/g). Soares et al (2008) reported that the occurrence and the fate of NP in the atmosphere are of considerable important.

**Availability of NP in drinking water**

Soares et al (2008) reported that Nonylphenol is identified in river water, ground water and other source of portable water at relatively high concentrations.
Berryman et al (2004) found that in waste water treatment plants removing of NP was found to be very highly variable ranging from 11% to 99%. Petrovic et al (2003) observed that ozonation and activated carbon filtration with chlorination were able to remove 95 % of NP. They also found that concentration of NP in treated drinking water varied from 85 ng/l in Spain to 15 ng/l in Germany. Shao et al (2005) determined that in major city of south-western China, the NP removal rate of water treatment plant varied from 62% to 94%. In present condition the Drinking Water Safety has received significant attention to the NP concentrations in potable sources of water (Mao et al, 2012).

ORIGIN OF NP

Nonylphenol is an alkylphenolic compound consisting of a phenol ring and a nine-carbon chain on the para position (Fig. 1) (Soares et al, 2008). In normal condition, it is a viscous liquid with a light yellow colour and do not get mixed with the water. In industry during alkylation of phenol, the compound is produced. More than 22 isomers of 4-substituted monoalkylphenols are composed in final mixture (Thiele et al, 2004; Wheeler et al, 1997). Servov et al (2003) found that the direct discharge of NP was estimated to be 0.5% (96 tons) from the industrial sector in Canada (Servov et al, 2003).

However, the major source of NP to the environment is the degradation of Nonylphenolethoxylates (NPE) (Langford and Lester, 2002). In the chemical structure of an ethoxylate chain is present which follows a poisson distribution (Hager et al, 1998). Shao et al (2003) and Soares et al (2005) found that whenever the number of ethoxylate group got decreased, the recalcitrance of the compound got increased. Langford et al (2005 a,b); Mann and Boddy (2000) observed that the biodegradation of Nonylphenol ethoxylate in fundamental bench-scale study resulted in production of more recalcitrant compound than the parent compound. These products include nonylphenol di-ethoxylate (a major product) and mono ethoxylate as well as the carboxylic form of this compound. Corsi et al (2003) and Koh et al (2005) reported that no bench-scale study has been referenced to identify NP as a product of aerobic degradation of NPE but the field studies reported

<table>
<thead>
<tr>
<th>Country</th>
<th>STW sampled</th>
<th>Sample source and NP concentration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switzerland</td>
<td>30</td>
<td>Sludge anaerobically stabilized:450-2530mg/kg</td>
<td>Giger et al (1984)</td>
</tr>
<tr>
<td>Germany</td>
<td>29</td>
<td>Sludge anaerobically stabilized:640-2200mg/kg</td>
<td>Brunner et al, 1988</td>
</tr>
<tr>
<td>Switzerland</td>
<td>11</td>
<td>Primary effluent:43.5 ig/l</td>
<td>Ahel et al., 1994a</td>
</tr>
<tr>
<td>Germany</td>
<td>149</td>
<td>Sludge:128.2mg/kg</td>
<td>Jobst, 1995</td>
</tr>
<tr>
<td>Japan</td>
<td>40</td>
<td>Primary effluent:Nd</td>
<td>Fujita et al., 2000</td>
</tr>
<tr>
<td>USA</td>
<td>1</td>
<td>Heat treated sludge:496mg/kg</td>
<td>La Guardia et al., 2001</td>
</tr>
<tr>
<td>USA</td>
<td>1</td>
<td>Sludge anaerobically stabilized:754mg/kg</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>1</td>
<td>Sludge before anaerobic digestion:242mg/kg</td>
<td>Bruno et al., 2002</td>
</tr>
<tr>
<td>USA</td>
<td>1</td>
<td>Sludge anaerobically stabilized 1100-1800mg/kg</td>
<td>Pryor et al., 2002</td>
</tr>
<tr>
<td>Spain</td>
<td>2</td>
<td>Raw effluent:&lt;1.5 ig/l</td>
<td>Farre et al., 2002</td>
</tr>
<tr>
<td>UK</td>
<td>1</td>
<td>Raw effluent:&lt;0.02-0.1 ig/l</td>
<td>Sheahan et al., 2002</td>
</tr>
<tr>
<td>China</td>
<td>1</td>
<td>Final effluent:1.5 ig/l</td>
<td>Shao et al., 2003</td>
</tr>
<tr>
<td>Norway</td>
<td>17</td>
<td>Final effluent:0.05-1.31 ig/l</td>
<td>Johnson et al., 2005</td>
</tr>
<tr>
<td>Japan</td>
<td>5</td>
<td>Raw effluent:0.1-0.9 ig/l</td>
<td>Nakada et al., 2006</td>
</tr>
</tbody>
</table>

the occurrence of NPE in well-aerated environment which hinders the process of degradation of NPE in bench scale experiment. Temperature is also a strong stimulator in the process of biodegradation of NPE (Manzano et al., 1999). In same study it was found that the biotransformation of these compounds is 2-10 times higher at 22.5°C than at 13°C. The degradation of NPE in anaerobic condition is very scarce (Scrimshaw and Lester, 2002). Soares et al. (2005) reported that NP is the major product of degradation; it does not undergo further transformation and is sharply adsorbed onto the sludge solids.

**TOXICOLOGICAL EFFECT OF NP ON DIFFERENT AQUATIC ORGANISMS**

In the environment NP is a virtually ubiquitous contaminant. The occurrence of NP has been reported all over the world in water, sediment, air and soil (Mao et al., 2012). NP is very toxic to wide variety of marine and freshwater vertebrate and invertebrate species. Its toxicity mainly affects the reproductive system and endocrine system. It also affects growth, behaviour, respiration and osmoregulation. It has been found that NP affects various indicators of reproduction in aquatic organisms at concentration ranging from 0.13µg/l up to the mg/l range (OEHHA, 2009).

**Haematological indices**

According to Satyanarayanan et al. (2011) when Clarias gariepinus was exposed to 250 µg/l concentration of NP, the levels of haemoglobin (Hb) and haematocrit (HCT) got significantly increased (p<0.05). It also has been found that when the dose was increased up to 750 µg/l then the level of Hb and HCT got drastically reduced.

Satyanarayanan et al. (2011) found that a significant increase (p<0.05) in RBC count was occurred in NP treated Clarias gariepinus (250 and 500 µg/l). In other hand when the concentration of NP was increased up to 750 µg/l then the RBC count considerably got decreased, showing a higher decrease at 1000 µg/l NP exposure.

With respect to the WBC count, Satyanarayanan et al. (2011) noted that, irrespective of the toxicants and their concentration, there was a gradual significant increase throughout the experiment.

During their experiment Sayeda and Hamdy (2018) observed occurrence of apoptosis in the erythrocytes of the NP treated fish sample Clarias gariepinus.

**Biochemical indices**

Satyanarayanan et al. (2011) found that the level of total serum bilirubin was significantly higher in all the concentrations of NP in Clarias gariepinus. The maximum increase of total serum bilirubin was found in 1000 µg/l concentration of NP.

According to Satyanarayanan et al (2011) the toxic effect of NP asserted a reduction in the level of serum protein in the body of Clarias gariepinus. The maximum reduction of serum protein occurred in the 1000 µg/l concentration.

On the other hand Satyanarayanan et al. (2011) found that the level of serum glucose significantly increased at all the concentrations of NP in Clarias gariepinus, showing the lowest increase at 250 µg/l and the highest increase at 1000 µg/l concentration.

Schwaiger et al. (2000) found a highly significant elevation of the mean corpuscular volume (MCV) and mean corpuscular haemoglobin (MCH) in juvenile Common carp (Cyprinus carpio). They also found that the corpuscular haemoglobin concentration (MCHC) got significantly decreased.

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**Table 2** : Distribution of NP in river, ocean, estuaries and sediments in different countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>NP concentration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>River water:&lt;1 µg/l River sediments:&lt;3000mg/kg</td>
<td>Naylor et al.,1992</td>
</tr>
<tr>
<td>Switzerland</td>
<td>River water:0.015-2.25 µg/l River sediment:3520mg/kg</td>
<td>Ahel et al.,1994b</td>
</tr>
<tr>
<td>Canada</td>
<td>Lake and river water:0.01-0.92 µg/l River sediment:0.17-72mg/kg</td>
<td>Bennie et al.,1997</td>
</tr>
<tr>
<td>Italy</td>
<td>River water:1.58 µg/l</td>
<td>Davi and Gnudi 1999</td>
</tr>
<tr>
<td>Portugal</td>
<td>River and ocean water:&lt;10 µg/l</td>
<td>Azevedo et al.,2001</td>
</tr>
<tr>
<td>Germany</td>
<td>River water:0.0007-0.0044 µg/l Estuaries:&lt;0.03 µg/l Marine sediment:0.01-0.153mg/kg</td>
<td>Bester et al.,2001</td>
</tr>
<tr>
<td>Japan</td>
<td>River water:0.051-1.08 µg/l River sediment:0.5-13mg/kg</td>
<td>Isobe et al.,2001</td>
</tr>
<tr>
<td>Spain</td>
<td>River water:15 µg/l River sediment:0.022-0.645mg/kg Ocean water:0.15-4.1 µg/l Ocean sediment:0.008-1.05mg/kg</td>
<td>Petrovic et al.,2002a,b</td>
</tr>
<tr>
<td>Holland</td>
<td>Estuary water:0.031-0.934 µg/l Estuary sediment:0.0004-1.08mg/kg</td>
<td>Jonkers et al.,2003</td>
</tr>
<tr>
<td>Korea</td>
<td>River water:0.0232-0.1876 µg/l River sediment:0.0254-0.932mg/kg</td>
<td>Li et al.,2004</td>
</tr>
<tr>
<td>China</td>
<td>Lake water:1.9-32.8 µg/l Lake sediment:3.5-32.4mg/kg</td>
<td>Wu et al.,2007</td>
</tr>
</tbody>
</table>

Soares et al. (2008).
Histopathological indices

According to Schwaiger et al. (2000) severe morphological alterations occurred in the kidney, liver, gill and spleen during experiment. They also found that the kidney lesions consisted in extensive haemorrhages within the kidney tubules, Bowman’s space and in renal tubular epithelium. The liver lesions were characterized by massive hepatocellular necrosis, haemorrhages and infiltration of mononuclear cells. Gill lesions included haemorrhages, inflammation and necrosis of gill filaments. The spleen lesions were characterized by lymphoid depletion and necrosis of splenic follicles.

Table 3: Effect of NP on different fish species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Exposure (µg/l)</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flounder (Psetta miniata)</td>
<td>333</td>
<td>↑ vitellogenin (an egg yolk precursor protein levels expressed in female fish)</td>
<td>Kirby et al., 2007</td>
</tr>
<tr>
<td>Cod (Gadus morhua)</td>
<td>30</td>
<td>↓ glucuronidation of estradiol</td>
<td>Martin-Skilton et al., 2006</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>↑ plasma vitellogenin</td>
<td>Larsen et al., 2006</td>
</tr>
<tr>
<td>Medaka (Oryzias latipes)</td>
<td>5.4</td>
<td>↓ Hepatic vitellogenin levels (♂)</td>
<td>Ishibashi et al., 2006</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>↓ Fecundity &amp; fertility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-100</td>
<td>↑ female/male ratio, mixed sex characteristics</td>
<td>Bulch and Metcalfe, 2006</td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>↓ reproduction</td>
<td>Kang et al., 2003</td>
</tr>
<tr>
<td>Rainbow trout (Oncorhynchus mykiss)</td>
<td>0.28-0.75</td>
<td>↓ embryo development &amp; survival</td>
<td>Lahnsteiner et al., 2005</td>
</tr>
<tr>
<td></td>
<td>0.13</td>
<td>↓ semen volume</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>↑ liver vitellogenin</td>
<td>Ackermann et al., 2002</td>
</tr>
<tr>
<td></td>
<td>10.2</td>
<td>↑ liver zona radiate protein</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>↑ liver vitellogenin</td>
<td>Thorpe et al., 2001</td>
</tr>
<tr>
<td>Tilapia (Oreochromis mossambicus)</td>
<td>10-100</td>
<td>↓ thymidine uptake in cartilage</td>
<td>Ng et al., 2001</td>
</tr>
<tr>
<td>Fathead minnow (Pimephales promelas)</td>
<td>10</td>
<td>Vitellogenin induction</td>
<td>Pickford et al., 2003</td>
</tr>
<tr>
<td>Zebrafish (Danio rerio)</td>
<td>10-100</td>
<td>↑ Female/male ratio, ↓ swim-up</td>
<td>Lin and Janz, 2006</td>
</tr>
<tr>
<td></td>
<td>17.7</td>
<td>↓ population growth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>39-100</td>
<td>Ovatesteres @ 60 days, not after 100-day recovery</td>
<td>Hill and Janz, 2003</td>
</tr>
<tr>
<td>Atlantic salmon (Salmo salar)</td>
<td>5-50</td>
<td>↓ brain p450 aromatase B mRNA ↑ zonariada protein mRNA ↑ liver &amp; brain ER á, ↓ VTG</td>
<td>Meucci and Arukwe, 2006</td>
</tr>
<tr>
<td></td>
<td>15-50</td>
<td>↑ VTG in plasma &amp; mucus</td>
<td></td>
</tr>
<tr>
<td>Platypus (Xiphophorus maculatus)</td>
<td>80</td>
<td>Hypertrophied Sertoli cells &amp; efferent duct cells.</td>
<td>Kinnberg et al., 2000</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>↓ gonad development, ↑ spermogenesis,</td>
<td>Magliulo et al., 2002</td>
</tr>
<tr>
<td>Swordtail (Xiphophorus helleri)</td>
<td>100</td>
<td>Testicular necrosis</td>
<td>Kwak et al., 2001</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
<td>↓ sword length</td>
<td></td>
</tr>
<tr>
<td>Sea bream</td>
<td>200 µg/kg bw</td>
<td>↓ kidney Na+,K+-ATPase, ↓ plasma osmolality</td>
<td>Carrera et al., 2007</td>
</tr>
<tr>
<td>Fathead minnow (Pimephales promelas)</td>
<td>14 (NOE = 7.4)</td>
<td>↑ fry survival</td>
<td>USEPA, 2005</td>
</tr>
<tr>
<td>Atlantic salmon (Salmo salar) smolts</td>
<td>10</td>
<td>↓ plasma cortisol</td>
<td>Lerner et al., 2007</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>Loss of osmoregulatory control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>↓ gill (Na+, K+-ATPase) ↑ preference for &amp; tolerance of seawater</td>
<td>Lerner et al., 2007a</td>
</tr>
</tbody>
</table>

OEHHA (2009)
interstitium. Hypertrophy, degenerative and necrotic changes were found in the tubular epithelia. Eosinophilic material was found to be accumulated in the renal tubules and in the sinusoids of the head kidney. Hypertrophy of the hepatocytes was found in liver. Schwaiger et al (2000) also observed the enlargement of the cell nuclei and reduction of glycogen deposits in the liver. Haemorrhages, a massive proliferation and hypertrophy of reticuloendothelial cells were also found in the spleen.

According to Amaninejad et al (2018) no histological changes were found in the ovaries of control fish when the fish sample (koi carp) were exposed to 10-50µg/l then loaded of oocytes in different vitellogenic stages and late vitellogenesis were decreased. A reduction in size of the growing vitellogenic oocytes, ova damage and irregular shape of ovum with rupture of follicular layer were also found when the fish sample (koi carp) was exposed in 100 µg/l NP concentration. A large extended sperm duct loaded with spermatozoa and seminiferous lobules with different amounts of spermatozoa were detected when the fishes (koi carp) were treated with 50 µg/l NP. In that experiment it was also found that a decrease in spermatid and spermatozoa, degeneration of Leydig cells and atrophy of testis cells occurred in the fish (koi carp) treated with 100 µg/l NP. Necrosis, degeneration, psychosis, sedimentation of cytoplasmic materials and cytoplasmic vacuolization of hepatic parenchyma were observed in the liver of all treated fish. Mucus cell hyperplasia and epithelial lifting were also observed in the gill of all treated fish in that experiment.

Sayeda and Hamdy (2018) observed some histopathological alteration in the liver of treated fish sample (Clarias gariepinus) such as vacuolization of...
hepatocytes, congestion in vein and necrosis. They also found the depletion of glycogen content in the cytoplasm of the hepatocytes.

Chitra and Sajitha (2014) assessed the effect of Bishphenol-A in the fish species Oreochromis mossambica for 20 days and they found upliftment of gill epithelium, gill lamellar fusion and hypertrophy and vasodialation in secondary lamellae.

**Enzyme Essay**

Oxidative stress is a normal phenomenon in the body, and various enzyme systems are involved in maintaining redox homeostasis. On the other hand, endogenous and exogenous substance can alter biochemical homeostasis, thus continuously rising reactive oxygen species (ROS) levels much higher than the detoxifying (antioxidant enzyme or non-enzymatic scavengers) capability of tissues. Oxidative stress is often defined as an imbalance of pro-oxidants and antioxidants (Satyanarayan et al, 2011).

Ecological toxicity of NP was examined on the Clarias gariepinus to study the biochemical responses including changes in the activity of Aspartate Transaminase (AST) and Aka alanine Amino transferase (ALT). The results showed that the activity of AST and ALT found to be increased in 250 to 500 µg/l NP concentration. On the other hand the activity of AST and ALT were found to be decreased in 750 to 1000 µg/l NP concentration (Satyanarayan et al, 2011). Chitra and Sajitha (2014) assessed the effect of Bishphenol A in the Oreochromis mossambica and they found a significant decrease in the activities of Superoxidase dismutase (SOD), Catalase (CAT) and Glutathione-S-transferase (GST).

Sayeda and Hamdy (2018) observed the antioxidant activity response in Clarias gariepinus to NP exposure. Fish samples (Clarias gariepinus) were exposed to different concentrations of NP for 15 days. Results showed that activity of GST, CAT, SOD and Ache (Acetyl cholinesterase) was significantly decreased.

Xiao et al (2007) exposed the fish sample (Paralichthys olivaceus) to 40 µM concentration of NP. They found that the activity of SOD and CAT got increased within 2 hours but after 4 hours the activity of both enzymes got significantly decreased.

According to Carrera et al (2006), the activity of CAT and GST was inhibited very badly in the body of sea bream (Sparus auratus) during their 10 days exposure.

Li et al (2008) assessed the effects of Bisphenole-A in the freshwater snail (Bellamya purificata) in 15 days exposure.

### Table 4: Effects of on different invertebrates species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Exposure (µg/l)</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Killifish (Fundulus heteroclitus)</td>
<td>65</td>
<td>↑ liver vitellogenin mRNA</td>
<td>Garcia-Reyero et al., 2004</td>
</tr>
<tr>
<td>Worm (Tubifex tubifex)</td>
<td>610 µg/g sediment</td>
<td>Surviving adults had empty spermatheca if present, ovocytes do not developed</td>
<td>Bettinetti and Provini, 2002</td>
</tr>
<tr>
<td>Pond snail (Lymnaea stagnalis)</td>
<td>105-124</td>
<td>↓ egg masses, ↑ embryo mortality, delayed development</td>
<td>Lalah et al., 2007</td>
</tr>
<tr>
<td>Freshwater mud snail (Potamopyrgus antipodarum)</td>
<td>100</td>
<td>↓ fecundity</td>
<td>Czech et al., 2001</td>
</tr>
<tr>
<td>Zebra mussel (Dreissena polymorpha)</td>
<td>500</td>
<td>↑ vitellogenin</td>
<td>Quinn et al., 2006</td>
</tr>
<tr>
<td>Sea urchin (Para-centrotus lividus)</td>
<td>0.27</td>
<td>↓ fertilization (sperm toxicity EC50)</td>
<td>Ghirardini et al., 2001</td>
</tr>
<tr>
<td>Daphnia magna</td>
<td>40</td>
<td>↓ fecundity, Altered sex ratio</td>
<td>Brennan et al., 2006</td>
</tr>
<tr>
<td></td>
<td>25,50</td>
<td></td>
<td>Zhang et al., 2003</td>
</tr>
<tr>
<td>Rotifer (Brachionus calyciflorus)</td>
<td>&gt;0.59 M (130 µg/L)</td>
<td>↓ population growth</td>
<td>Radix et al., 2002</td>
</tr>
<tr>
<td>Mussel (Mytilus sp)</td>
<td>228</td>
<td>Hemocytelysomal membrane de-stabilization</td>
<td>Canesi et al., 2007</td>
</tr>
<tr>
<td>Algae (Isochrysis galbana)</td>
<td>1000</td>
<td>Absence of photosynthesis</td>
<td>Correa-Reyes et al., 2007</td>
</tr>
<tr>
<td>Oyster (Crassostrea gigas)</td>
<td>1-100</td>
<td>↓ sperm motility</td>
<td>Nice, 2005</td>
</tr>
<tr>
<td>Copepod (Eurytemora affinis)</td>
<td>3</td>
<td>Delayed development</td>
<td>Forget-Leray et al., 2005</td>
</tr>
</tbody>
</table>

OEHHA (2009).
exposure. They found that the activity level of GST was significantly lower in the body of treated snails.

Physico-chemical parameters of water are critical for the optimum physiological response and wellbeing of aquatic organisms, especially fish. Poor water quality due to contamination can affect the growth, reproduction and survival of fish species. It may even lead to diseases. In general when there is depletion or deficiency in some of the water quality parameters like the dissolved oxygen, pH, temperature and alkalinity, the fish may face survival challenges (Datta et al., 2017). In West Bengal sewage feed aquaculture has increased day by day. Sometimes sewage water is contaminated by different alkylphenolic compounds like, Nonylphenol, Octylphenol, Bishphenol-A etc. These compounds are very toxic to the aquatic environment and also terrestrial. These compounds have diverse effects on aquatic organisms up to consumer level. So as a consequence most emerging alkylphenolic compound i.e, Noylphenol is selected to evaluate its toxicity level Nonylphenol. (2019, March 09). Retrieved March 09; 2019, fromhttps://en.wikipedia.org/wiki/Nonylphenol.

*Labeo rohita* is an important species of carp family. It is a column feeder omnivore species. In West Bengal most culturable species is *L. rohita* among the carps. The commercial value of this species is very high. It is also the most favourable species to the consumer. Due to being column feeder the *L. rohita* is affected by Noylephenol. In the surface of the water NP is degraded by the sunlight but in mid-level of the water body, NP is not easily degradable by the sunlight. If this species is affected by the NP, the freshwater aquaculture production of West Bengal may totally damage [Nonylphenol. (2019, March 09). Retrieved March 09; 2019, fromhttps://en.wikipedia.org/wiki/Nonylphenol].

**CONCLUSION**

The present study shows that the main source of NP is sewage treatment plant. Positive findings of NP have been reported in sediments, atmosphere, ground water and drinking water. The ground water and drinking water mainly contaminated by landfill leachates. The present study also shows that different types of adverse biological effects were observed in various aquatic organisms. The alteration occurred in histopathological, biochemical and haematological parameters. NP is a very common and virtually ubiquitous contaminant in the environment. The fate and occurrence of NP has been reported around in waters, sediments, airs and soils. The amount of NP in environment and sewage treatment can be decreased through the action of aerobic and anaerobic biodegradation. Although, NP is present at low concentrations, the risks of long-term exposure to low concentrations remain largely unknown. Purification or removal techniques such as ozonation or membrane filtration are able to remove contaminations of NP efficiently from drinking water, surface water or even from municipal sewage effluents. But more research needs to be done to determine the potential human and environmental health risks posed by exposure to NP in the environment.

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Toxic effects of nonylphenol on aquatic organisms


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and hepatic estrogen receptor and P450arom isotypes in juvenile Atlantic salmon (Salmosalar) after waterborne exposure to the xenooestrogen, 4-nonylphenol. Aquatic Toxicol. 77(2), 167-177.


