Introduction

Without it, we cannot survive. It can be found just about anywhere on earth, but not all of it can be used by humans. Yes, this amazing yet limited amount is clean water. Out of the 70% water on earth, 3% is fresh water and only 0.26% is accessible by humans. It is essential to human life and to the health of the environment. It has the central role in mediating global-scale ecosystem processes, linking atmosphere, lithosphere and biosphere by moving substances between them and enabling chemical reactions to occur. Though we have an extremely limited amount of clean or usable water and it will become even smaller if we continue to pollute it. The major share of valuable freshwater on the surface was used for the irrigation and industries so that, water flow in the rivers and streams is very less and tends to get highly polluted. Because of rapid increase in industrialization, urbanization and agricultural innovations leads to the production of huge amount of wastes, indiscriminate and untreated disposal which cause environmental pollution, especially the hydrosphere.

Since last few decades, there is an explosive development in the textile and dyeing industries. At the same time it is also recognized to be the root cause for environmental perspective. The understanding that environmental pollution is a worldwide threat to public health has given rise to new initiatives for environmental restoration for both economic and ecological reasons. Toxic and hazardous pollutants are found in the industrial effluents, especially synthetic azo dyes and its intermediates. Among synthetic dyes, reactive dyes are the major pollutants present in textile industry effluents because of its low fixation capacity to fiber. This process is going on till to date with exponential increase.
The global demand for dyes and pigments is increased at an average rate of 3.5% per annum, from 1.9 million tonnes in 2008 to 2.3 million tonnes in 2013. Among the different dye products types, reactive and disperse dyes are dominated in the global markets (FICCI, 2013). In fact, the demand for these two dyes is expected to grow in the future also. Nations like China, South Korea and Taiwan are strong players in the field of disperse dyes. Interestingly, India has taken lead in production of reactive dyes because of the availability of an intermediate called vinyl sulfone in the country (Mangal, 2010). In 1995, China became the largest exporter of textiles in the world and it has maintained that position ever since (Finnish Environment Institute, 2010).

Azo dyes consist of a diazotized amine coupled to an amine or a phenol. They are the largest class of dyes with the greatest variety of colors. At least 3,000 different varieties of azo dyes are most widely used in textile dyeing, printing, color photography, pharmaceutical, food, cosmetic and leather industries (Chang et al., 2004; Jirasripongpun et al., 2007; Couto, 2009). Azo dyes are highly recalcitrant xenobiotic compounds characterized by the presence of one or more azo bonds (N=N) with aromatic rings (Jain et al., 2012). Amongst various applications of synthetic dyes about 300,000 tonnes of different dyestuffs are used per year for textile dyeing operation (Keharia et al., 2004). Among these dyes, azo dyes are the most widely used and they constitute 60-70% of all dyestuffs manufactured in the world (Bafana et al., 2011). In all 100,000 different dyes and pigments are commercial available with million tonnes of synthetic dyes are produced worldwide annually (Ogugbue and Sawidis, 2011). On the basis of chemical composition there are various classes of azo dyes, reactive dyes are the most important. Most of the reactive dyes (80-95%) have an azo group as chromogen (Zollinger, 1991; Edward et al., 2000).
Reactive azo dyes absorb light in the visible spectrum due to their chemical structure. These dyes which are the only textile colorants designed to bond covalently with cellulosic fibers, are extensively used in the textile industry because of their ease and cost effectiveness for synthesis as compared to natural dyes, and also their great structural diversity, high molar extinction coefficient and medium to high fastness properties in relation to light as well as to wetness (Bafana et al., 2011). These dyes are considered as most problematic compounds in textile industrial effluents and highly resistant to biodegradation.

The textile industry is one of the largest polluters in all over the world. The World Bank estimates that almost 20% of global industrial water pollution comes from the treatment and dyeing of textiles (www.sustainablecommunication.org). Among all the countries, China has the worst water polluters in the world (Karasov, 2000), with as much as 70% of its natural water bodies being affected (CIGEM, 2005). In India about 70% of water pollution caused by various activities of the textile industries, including small and large scale industries. Total of 72 toxic chemicals such as aromatic amines, heavy metals, ammonia, alkali salts, toxic solids and large amount of pigments, chlorine (a known carcinogen) etc., reach our water bodies from textile dyeing (www.sustainablecommunication.org). Many of these chemicals cannot be filtered or removed. Cotton production accounts for 2.6% of annual global water usage. A single T-shirt made from conventional cotton requires 2700 liters of water and a third of a pound of chemicals to produce (www.sustainablecommunication.org). The continuous dumping of these chemicals in to natural water bodies causes severe environmental damage and human diseases. Effluents released from dyeing and finishing processes are associated with the water pollution caused by the discharge of untreated or poorly treated effluents. Wastewater resulting from these processes has adverse impacts in terms of total organic carbon (TOC), biological oxygen demand (BOD), chemical oxygen demand (COD),
suspended solids, salinity, color, a wide range of pH (5-12) and the recalcitrance of organic compounds, such as reactive azo dyes (Faryal and Hameed, 2005; Savin and Butnaru, 2008; Akan et al., 2008; Kuberan et al., 2011). The ratio of BOD/COD ranges from 0.2 to 0.5 and indicates that these effluents contain a large proportion of non-biodegradable organic matter (Yusuff and Sonibare, 2004; Savin and Butnaru, 2008). For example, 0.6-0.8 kg NaCl, 30-60 g dyestuff and 70-150 liters of water are necessary to dye 1 kg of cotton with reactive dyes; the wastewater produced has 20-30% of the applied unfixed reactive dyes, with an average concentration of 2000 ppm, high salt content and dyeing auxiliaries (Babu et al., 2007).

Worldwide 280,000 tonnes of textile dyes are discharged in industrial effluents every year (Saratale et al., 2011a) and the main concerns involve the adverse effects of reactive azo dyes in the environment, including their inhibitory effect on aquatic photosynthesis, ability to deplete dissolved oxygen and toxicity to flora, fauna and humans. If the dyes are broken down anaerobically, aromatic amines are generated, which are very toxic, carcinogenic and mutagenic. The reactive azo dyes are synthetic origin and their complex aromatic compounds with significant structural diversity. Their properties are enhanced to provide a high degree of chemical, biological and photocatalytic stability and resist breakdown due to time, exposure to sunlight, microorganisms, water and soap; in other words, they are resistant to degradation. Thus, treatment of industrial effluents containing reactive azo dyes and their metabolites are essential before released into the natural water bodies.

The dyes were earlier obtained from vegetable or animal sources. However, modern dyes are synthetic. Technically synthetic dyes are distinguished from the intermediates based on the presence of auxochrome, the group that allows the basic unit to attach and impart color to the substrate. These synthetic dyes are manufactured through
different stages involving nitration, reduction, halogenation, amination, sulfonation, diazotization and oxidation using benzene, phenol, cresol, acridine, quinoline, toluene, xylene, naphthalene and anthracene as raw materials. Most of these raw materials are derived from the distillation of coal tar and are aromatic hydrocarbons. These compounds are different from the actual dyestuffs and they must first be changed into other compounds called intermediates. Examples of such compounds are nitrobenzene, aniline, \( \beta \)-naphthol and \( \beta \)-naphthalene sulfonic acid. Benzene and naphthalene are the coal-tar primaries used extensively to prepare useful intermediates in the dye preparations (Austin, 1984). In this study, the selected Reactive azo dyes i.e. Reactive Violet 5 and Reactive Red 2 are sulfonated polycyclic aromatic compounds, which are derived from the raw material such as naphthalene. These dyes contain more than one sulfonic acid groups that confirm the recalcitrant and xenobiotic character of selected dyes. Hence, these dyes are listed in Toxic Substances Control Act (TSCA). These dyes are most widely used in a large scale in several textile and dyeing industries.

Large quantity of textile industry effluents containing these dyes if left untreated may bring death and disaster in the surrounding areas. These effluents may also affect the soil by decreasing soil fertility, groundwater, human beings, animals and economy of the surrounding areas. Therefore, the remediation of industrial effluents containing reactive dyes becomes essential before discharged into the environment. Existing conventional physicochemical methods like oxidation, ozonation, electrolysis, adsorption, filtration etc., for color removal which are very expensive and low efficiency/commercially unattractive (Asgher et al., 2012). Biological processes provide an alternative to existing physicochemical methods because they are cost effective, environmentally friendly and do not produce large quantities of sludge and can be applied to wide range of dyes containing industrial effluents (Asgher et al., 2013). Therefore, in situ microorganisms from the dye contaminated sites have fascinated researchers to employ them for complete cleanup of the
environment. These environment cleaners are well-adapted to the affected sites and sometimes use these pollutants as a source of nutrition.

Use of microorganisms for the remediation purpose is an economic and ecofriendly way of textile dyes degradation (Pérez et al., 2013). Among all microorganisms, bacteria make them invaluable tools in textile wastewater treatment because of its ubiquitous nature. Thus, biodegradation offers a cheaper and environmentally friendlier alternative tool for removal of color textile effluents containing reactive azo dyes. In recent years growing research and review articles dealing with the biodegradation of synthetic dyes especially, reactive dyes is an indication and proof of the global concern over this issue. Hence, the present investigation was undertaken to study the biodegradation of Reactive dyes by an isolated bacteria. The target dyes for this research work were chosen from a class of cotton reactive dyes i.e. Reactive Violet 5 and Reactive Red 2 are extensively used in a large scale by several textiles and dyeing industries. These dyes are sulfonated polycyclic aromatic compounds and well known to be highly recalcitrant.