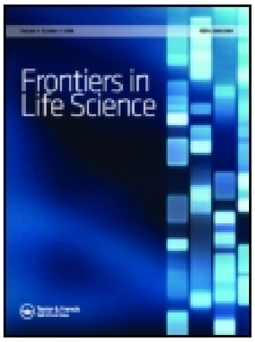

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Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas

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Although water constitutes 71% of the earth's surface, only 0.3% of it is available as fresh water for human use. Moreover, the quality of fresh water in ground and surface systems is of great concern, as potable water needs to have appropriate mineral content. Ground and surface water quality in rural and urban environments is affected by both natural processes and anthropogenic influences. Because of this, water is becoming scarcer as the population increases across the world. Natural processes leading to changes in water quality include weathering of rocks, evapotranspiration, depositions due to wind, leaching from soil, run-off due to hydrological factors, and biological processes in the aquatic environment. These natural processes cause changes in the pH and alkalinity of the water, and also phosphorus loading, increase in fluoride content and high concentrations of sulphates. Anthropogenic factors affecting water quality include impacts due to agriculture, use of fertilizers, manures and pesticides, animal husbandry activities, inefficient irrigation practices, deforestation of woods, aquaculture, pollution due to industrial effluents and domestic sewage, mining, and recreational activities. These anthropogenic influences cause elevated concentrations of heavy metals, mercury, coliforms and nutrient loads. This paper studies the effects of natural processes and human influences in rural and urban aquatic systems. Pollution due to environmental parameters such as heavy metal pollution, heavy metals and bacterial and pathogenic contamination of both urban and rural areas is discussed in detail.

Keywords: rural; urban; anthropogenic; water quality; fluoride

1. Introduction

Water covers 71% of the Earth's surface (CIA *The world fact book*) and thus is vital for life (Annan 2005). It is estimated that 96.5% of the water is in seas and oceans, 1.7% is groundwater, and 1.7% is fixed in glaciers and ice caps in the Arctic and Antarctic circles. A large proportion of water exists in water bodies, and a much smaller fraction (0.001%) is suspended in the air as vapours, clouds, etc., which falls as precipitation. Thus, only 2.5% of the Earth's water is fresh water, and 98.8% of this is held as ice and groundwater. Less than 0.3% of fresh water is contained in rivers, lakes and the atmosphere, while an even lower amount (0.003%) is in biological bodies and in manufactured products.

Safe drinking water is a necessity for humans as well as other organisms, although it does not contain any calories or organic nutrients. Globally, the availability of safe drinking water has improved in the last few decades. However, approximately one billion people still do not have access to safe drinking water, while another 2.5 billion do not have adequate sanitation. There is a clear correlation between access to safe water and GDP per capita expenditure incurred on goods and services including compensations of employees. However, it is estimated that by 2025 over half the world's population will be vulnerable to water shortages (Kulshreshtha 1998). A report published in November 2009 (Mckinsey 2009) indicates that by 2030 water demand in certain developing countries is likely to exceed supply by over 50% (Mckinsey 2010). Water has a role in the global economy; it has uses as a solvent in a wide range of chemical preparations, in cooling towers, transportation and industry. It is estimated that around 70% of fresh water is used in agriculture (Baroni et al. 2007).

Water is becoming scarcer as the human population continues to grow and demand high quality water for domestic purposes and economic activities. Precipitation has become unpredictable due to climate change (Trenberth et al. 2003; Giorgi et al. 2004; Raisanen et al. 2004). Water quality is important for human health as well as the quantity and quality of grain crops as it has an effect on soils, crops and environment (Kirda 1997; Hoek et al. 2001).

Water quality, measured by assessing the physicochemical and biological properties of water against a set of standards, is used to determine whether water is suitable for consumption or safe for the environment.

Some uses of water, e.g. for domestic purposes, agricultural production, industrial production, mining, power generation and forestry practices, cause deterioration in water quality and quantity. This impacts the aquatic

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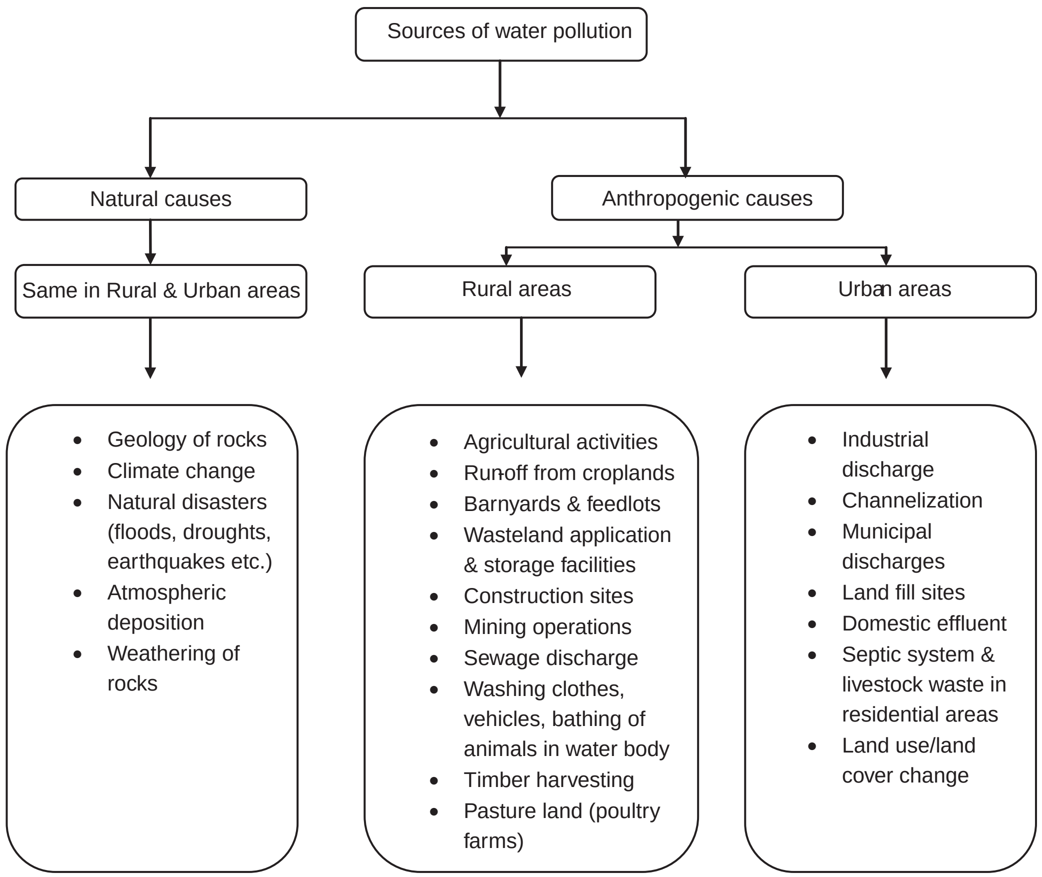

Figure 1. Flowchart showing natural and anthropogenic sources of water pollution in rural and urban areas.

ecosystem, and also access to safe drinking water for human consumption. Water quality and quantity are thus linked, although they are not often measured simultaneously. Water quantity is measured by hydrological monitoring stations that record water level, discharge and velocity. Water quality is determined by analysis of water samples collected periodically by these monitoring stations. The results of water quality monitoring are important in determining the spatial and temporal trends in surface water and groundwater.

Local, regional and global assessments of water quality monitoring data help to illustrate key features of aquatic environments, while explaining the positive and negative impact of human activities. Clear and concise background knowledge on water quality can help in other water assessments.

1.1. *Water quality*

The groundwater or surface water quality is a function of natural influences and human activities either severally or collectively. Without human influences, water quality would be influenced only by the natural processes such as weathering of bedrock minerals; atmospheric processes involving evapotranspiration; deposition of dust and salt by wind; natural leaching of organic matter and nutrients from soil; hydrological factors leading to run-off; and biological processes in the aquatic environment that may bring about changes in the physical and chemical composition of water. Thus, water in the natural environment may contain dissolved substance as well as non-dissolved particulate matter. Minerals and dissolved salts are necessary components of good quality water as they help maintain the health and vitality of organisms that rely on this ecosystem service (Stark et al. 2000) (Figure 1).

Water quality is affected by both point and nonpoint sources of pollution in rural and urban areas. Some of these sources include sewage discharge, industrial discharge and agricultural run-off. Water quality is also affected by floods and droughts, as well as lack of awareness among end users – aspects including hygiene, environment sanitation, storage and disposal need to be considered for the maintenance of water resources.

1.2. *Sources of water pollution*

(1) Rural run-off loads:
- agricultural lands, including pastures and grasslands;
- forest watersheds;

- barnyards and feedlots;
- wasteland and storage facilities in form of seepages or discharges; and
- construction sites.

(2) Atmospheric deposition (wet/dry deposition).
(3) Common sources of water quality impairment:
- channelization;
- animal husbandry;
- industrial wastewater;
- increased flows due to harvesting of trees;
- seepages from municipal solid waste disposal sites;
- seepages/leachates from landfill sites;
- domestic wastewater/sewage;
- flow from pasture land;
- silviculture and pasture management;
- stream bank modification;
- stream bank and shore line erosion; and
- oil and gas production.

Water can also contain substances that may be harmful to human health, e.g. metals such as mercury, lead and cadmium; organics such as pesticides and toxins; and even certain radioactive materials. Water that comes from natural sources generally contains organisms that are a part of the biogeochemical cycles of aquatic systems. However, certain bacteria, protists, parasitic worms, fungi and viruses may be harmful to human life if contained in drinking water. The availability of water and its physical, chemical and biological properties have an impact on the health of ecosystems, as well as on adequate supply of clean, usable water, which is a basic human requirement. Uses for water include, but are not limited to:

- human consumption and domestic water supply;
- irrigation and aquaculture;
- industrial use;
- electricity generation; and
- recreational use.

The required water quality varies with the use, and the criteria used to assess water quality also vary. Water quality is a function of natural background conditions and is necessary for maintaining the health of ecosystems; however some aquatic ecosystems can tolerate vast changes in water quality without the composition and function of the ecosystem being affected. In contrast many ecosystems are sensitive to small changes in the physical and chemical composition of the water body, resulting in degradation of the ecosystem including loss of biodiversity. The degradation in physical and chemical water quality due to anthropogenic reasons is mostly slow and gradual. Furthermore, subtle adaptations by the aquatic ecosystems to such degradation are not readily detected unless a notable shift takes place in the ecosystem.

For example, in many shallow European lakes, the gradual enrichment of surface water with plant nutrients has resulted in shifts from systems that once were dominated by aquatic plants to systems that are now dominated by algae suspended in the water column (Scheffer et al. 2001).

Direct relationships exist among water, sanitation, nutrition and health. Lack of availability of good quality drinking water, use of contaminated water, lack of personal hygiene, consumption of contaminated food and incorrect disposal of solid and liquid waste have been major causes of diseases in most nations. Many governmental programs such as "Health for All" (World Health Organization 2003) and total sanitation programs have focused on personal hygiene. Good personal hygiene can reduce water pollution. Better coordination between ministries of health and rural development may solve problems related to drinking-water hygiene and health.

2. Natural factors affecting water quality in rural and urban areas

The quality of both surface water and groundwater is affected by natural and anthropogenic factors. The natural factors that affect water quality in rural and urban areas are similar (Table 1). The composition of surface water and groundwater is dependent on e.g. geological, topographical, meteorological, hydrological and biological factors (Table 2). It varies with seasonal differences in weather conditions, run-off volumes and water levels.

Geological factors are due to the contribution of the geosphere to groundwater composition, mainly through the effect of chemical water–rock interactions in aquifers (Pönkka 1981; Rönkä 1983). The main factors affecting water quality in wells drilled into bedrock seem to be the rock type (Rönkä 1983) and the mode of weathering of the particulate minerals (Rönkä et al. 1981).

The composition of the bedrock influences not only the chemical composition of the groundwater in the fissures and fractures, but also that of the groundwater in Quaternary deposits (Banks et al. 1998).

When there are no human influences, changes in water quality occur due to factors such as weathering of bedrock evapotranspiration and the deposition of dust and salt by wind. Furthermore natural processes such as leaching of organic matter and nutrients from soil, hydrological factors leading to run-off and biological processes within the aquatic environment bring about changes in physical and chemical composition of water. Thus due to these natural processes, water in the natural environment may contain dissolved as well as undissolved solids. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of organisms that rely on this ecosystem service (Stark et al. 2000).

Natural water bodies such as lakes, rivers, streams and groundwater need to contain water of good quality

Table 1. Aspects of water pollution due to natural causes.

	Rural as well as urban areas
1	Water–rock interaction is the primary source of Ca^{+}, Mg^{+}, HCO_3 in groundwater
2	Atmospheric deposition of nitrate (minor source)
3	Sodium (Na) in groundwater from plagioclase in granite rocks
4	Potassium (K^{+}) from orthoclase and muscovite minerals present in granite
5	Chloride from natural sources such as rainfall, dissolution of fluid inclusions and chloride-bearing minerals.
6	Disturbance of riparian vegetation results in increased sedimentation of rivers.
7	Fluoride occurs naturally as a result of run-off from weathering of fluoride-containing rocks and soils and leaching from soils into groundwater

Table 2. Aspects of water pollution due to anthropogenic causes.

Rural areas	Urban areas
Nitrate and sulphate as a result of fertilizers used in agriculture and sewage effluents.	Chemical pollution
Sodium (Na^{+}) and potassium (K^{+}) in groundwater from chemical fertilizers.	Waste gas, waste water and waste residues cause increases in pollutants such as nitrogen, phosphate, chloride, sulphate, organic solvents and heavy metals.
Chloride from fertilizers and septic tanks	
Application of fertilizers, waste water discharges and concrete from constructions, etc., are the contributing factors for high calcium	Causes high level of chloride, nitrate, sulphate, sodium and potassium in the groundwater in construction and cultivated areas.
Discharge of sewage run-off directly into water bodies.	Sodium (Na^{+}) in groundwater from plagioclase in granite rocks, chemical fertilizers, domestic effluents, etc.
Disposal of solid waste into rivers and other water bodies.	Potassium from pollution sources such as chemical fertilizers and domestic effluents.
	Chloride from industrial effluent and domestic fertilizers and septic tanks.
	Sulphate sources include rainfall run-off, fertilizers, sewage effluents, and dissolution of sulphide minerals present in granite.
	Nitrate and sulphate enter groundwater from effluents from septic systems and livestock waste in residential areas.
	High sulphate content can be found in river water in areas where soil is formed from limestone, marble and gypsum.
	In snowy regions, de-icing agents such as rock salts, primarily consisting of sodium chloride (NaCl), can leach into water courses. Other agents used include ferrocyanide, used as an anti-clumping agent, and impurities consisting of trace elements (phosphorous, sulphur, nitrogen, copper and zinc).
	Chlorofluorocarbons (CFCs)
	Point sources of dissolved CFC contamination in groundwater include sewage effluent discharge, localized septic system, landfills and manufacturing leachate.
	Nonpoint sources of CFC include agricultural practices and urban run-off sewage effluent.
	Volatile organic compounds and CFCs Landfill and manufacturing plants have been identified as anthropogenic point sources of CFCs and other VOCs associated with disposal of aerosols, paint removers, dry cleaning agents, foam blowing agents and refrigerants.
	Heavy metal pollution
	Run-off from industrial and residential areas has been shown to contain Pb, Cu, Zn, and Ni.
	Miscellaneous
	Wastewater is one of the major sources of nutrients in coastal areas where no treatment exists.
	Intensive land use activities affect hydrological, biological, chemical and geomorphic aspects of aquatic systems.
	Land use and land cover changes are major anthropogenic activities that influence water flow and quality of rivers in particular.
	Industrial, agricultural and other anthropogenic activities often lead to increased inputs of metals in soils and water.

because they are the only natural water sources on which life depends (Mann and Williamson 1986). However, natural waters contain a variety of contaminants arising from erosion, leaching and weathering processes; such contaminants can only have their concentrations reduced by normal water and wastewater treatment processes, so their presence in a particular water source may limit its use (Nemerow 1985; Tebbutt 1992)

Floods and droughts may bring about changes in water quality through dilution or concentration of dissolved substances. Where there are low river flow rates, the main effect on water quality is when there is a temperature increase, increased concentration of dissolved substances and decreased concentration of dissolved oxygen (Prathumratana et al. 2008; Van Vliet and Zwolsman 2008).

Drought–rewetting cycles may impact water quality as they enhance decomposition and flushing of organic matter into streams (Evans et al. 2005). Droughts may have impacts on river water quality (Zwolsman and van Bokhoven 2007; Van Vliet and Zwolsman 2008), that depend on the properties of compound, which could be as well either negative or positive.

An increase in water temperature also has an impact on chemical processes in lakes, with an increase in pH (Psenner and Schmidt 1992). Seasonal variations in surface run-off, precipitation, interflow, groundwater flow and pumped inflows and outflows have a strong effect on river discharge and subsequently on the concentration of pollutants in river water (Vega et al. 1998).

Dissolved organic matter (DOM) affects the functioning of aquatic ecosystems through its influence on acidity, trace metal transport, light absorbance and photochemistry, and energy and nutrient supply (Evans et al. 2005). The main source of DOM in surface waters is soil leaching (Hejzlar et al. 2003). P loading exportation, which is governed by discharges following heavy rainfall, will tend to increase with climate change and consequently have an impact on lakes (Mooij et al. 2005)

Many rocks and minerals in the Earth's crust, e.g. fluorospar, cyyolite and fluorapatite (Jagtap et al. 2012), contain fluoride (Murray 1986; Loganathan et al. 2003) which can be leached out by natural weathering and rainwater, causing contamination of surface water and groundwater, and thus public water systems (Mandinic et al. 2010; Gandhi et al. 2012; Chen et al. 2010 [and references therein]; Rafique et al. 2013). For example, Choi and Chen (1979) reported extremely high fluoride concentration (> 1000 mg l^{-1}) in surface water in areas with fluoride-rich volcanic rocks.

One method of reducing excessive concentrations of fluoride in water is to blend water with a high fluoride concentration with water that has a low fluoride concentration from an alternative source. If such a source is not available, defluoridation is the only means remaining to prevent fluorosis (Fawell et al. 2006). There are many methods available for defluoridation of water, e.g. precipitation/coagulation, adsorption, ion exchange, reverse osmosis and electro-dialysis. Of these, precipitation/coagulation and adsorption are convenient methods and widely used, especially in the rural areas of developing countries.

Low-intensity rainfall mobilizes less nutrient laden sediment than high-intensity storm events, although soil moisture and permeability also contribute to sediment movement (Basnyat et al. 2000). Run-off sediment transport capacity is dictated by the shear stress relationship that develops between the dominant flow shear of the soil and the critical stress from rainfall events (Leon et al. 2001).

Groundwater with high concentrations of SO_4^{-2} in coastal areas often indicates seawater intrusion (Kim et al. 2003; Wang and Jiao 2012). As shown by Lahermo et al. (1990) and later by Karro (1999), relict seawater trapped in bedrock fissures and fractures and saline pore water in marine clay and silt sediments can be detected from increased concentrations of dissolved components in the groundwater, particularly SO_4, Cl and Na.

In some regions, natural geology or soils contain high background concentrations of phosphorus (e.g. Tualatin River in Oregon, USA; Boeder and Chang 2008) and arsenic (e.g. India and Bangladesh; Spallholz et al. 2004), that endanger human and ecosystem health.

A proportion of the chlorides, nitrates, potassium, sodium and sulphate in groundwater and surface water may be connected with precipitation (Lahermo et al. 1990).

3. Anthropogenic factors affecting water quality in rural areas

Most contaminants affecting water quality in rural areas comprise simple inorganic ions, more complex organic molecules or particulates. These can derive from various sources, including soils and decomposing vegetation, but also from animal manure (Goss et al. 2000). Agricultural run-off is one of the nonpoint sources of pollution that affect water quality. Agricultural activities that can cause pollution include poor animal husbandry practices; overgrazed grasslands; over and excessive use including untimely application of pesticides, ploughing over irrigated fields and application of fertilizers.

There is considerable agreement in recent studies that amounts of nitrogen and phosphorus in surface waters are significantly influenced by anthropogenic inputs associated with land cover, land use and point sources (e.g. Castillo et al. 2000; Ferrier et al. 2001; Valiela and Bowen 2002).

Pollutants that result from farming and cattle breeding are comprised of nutrients, sediments, pathogens, pesticides, metals and salts.

3.1. Sedimentation

The most common agricultural water pollution is loss of top soil that is washed from fields. Rainwater carries soil particles or sediments and deposits them in lakes or streams nearby, thus affecting water quality. Other pollutants such as fertilizers, pesticides, and heavy metals that stick to the soil particles are also washed into the water bodies. These pollutants cause algal blooms and deplete oxygen, threatening aquatic life. Turbidity, a measure of the light-scattering effects of suspended particulate material (SPM) in water, increases with suspended sediment concentrations and loading rates. It also depends upon characteristics such as particle size distribution and refractive index and colour of water. The suspended solid concentration in streams is often higher in the spring and autumn than in the summer (e.g. Braskerud et al. 2000, 2001).

3.2. Nutrients

Nutrient (nitrogen and phosphorus) loading in waters through point and nonpoint sources is an ecological concern and affects water quality in surface water bodies (Smith et al. 1999). Nutrients are essential to the survival of aquatic organisms, but excess nutrient loading to water bodies can impact the designated uses of water (Bricker et al. 2007; FDEP 2009; Freeman et al. 2009). Nitrates can be leached or transported in run-off (Blanchard and Lerch 2000). Nitrates are strongly associated with agricultural land and grasslands (Ferrier et al. 2001), and concentrations are highest in spring and in conjunction with high run-off events. The antecedent conditions – topography, soil type, farming practice and crop type – influence the movement of water as well as pesticide dispersal. All such factors are more significant than the physicochemical parameters of the ingredients in determining the run-off potential of the compound (Larson et al. 1995).

Ammonium and phosphate sorption onto sediments, sedimentation of nitrogen and phosphorus in particulate forms and phosphate co-precipitation with calcite enhance sediment storage (Withers and Jarvie 2008). Conversely, sediments can become a nutrient source through the release of dissolved species under well-defined pH and redox conditions (Gomez et al. 1999). Phosphorus is given special attention, because it is often the limiting nutrient for algal growth in freshwaters (Berge et al. 1997; Correll 1999).

3.3. Livestock grazing

Overgrazing by livestock leads to exposure of soil and increased erosion. This can result in ecosystem regression, encouraging invasion of unwanted species, destruction of stream banks, flood plain vegetation and fish habitats. It thus not only affects water quality filtration but also the habitat of flora and fauna.

3.4. Irrigation

The objective of irrigation is to supplement the natural precipitation and to protect crops against freezing or wilting, depending upon the location of the farm. Inappropriate irrigation can cause water quality problems. In arid/dry areas, for example, rainwater does not carry the minerals deep into the soil, leading to evaporation of irrigation water and overconcentration of salts in soils. Over-irrigating a field may lead to soil erosion, and transportation of nutrients, pesticides and heavy metals. It may reduce the natural surface flow in streams and rivers.

3.5. Pesticides

Insecticides, herbicides and fungicides are used to kill agricultural pests. They may enter water due to run-off from the fields or atmospheric deposition, or even due to direct application. Water may become polluted with a range of contaminants due to the use of land for agriculture (e.g. Hooda et al. 2000; Lovell and Sullivan 2006). Of these pollutants, dissolved organic carbon (Freeman et al. 2001; Holden 2005; Wallage et al. 2006), nutrients (nitrogen and phosphorus) (Heathwaite et al. 1996; Haygarth and Jarvis 2002; Dorioz et al. 2006) and pesticides (Environment Agency 1999; Blanchoud et al. 2007; Garrod et al. 2007) are the most important issues for some land-owning UK water utilities due to the need to remove them from raw water to meet regulatory standards.

Pesticide occurrence in water supplies is a concern for water-quality assessment, since a huge number of pesticides are widely used in agriculture (Nagafuchi et al. 1994; Kimbrough and Litke 1996). Pesticides are a group of hazardous materials with potential risk to human health (Ayranci and Hoda 2005). Herbicides are the most widely used pesticides, constituting more than 40% of total use, while insecticides account for approximately 30% and fungicides for some 20% (WHO 1992). Pesticides play an important role in harvest quality and food protection, providing enormous benefits in increasing production, as pests and diseases damage up to a third of crops (Tadeo 2008). As a result of massive global consumption (Sabik et al. 2000), pesticides as well as their degraded products spread through the environment and can contaminate water resources (M Filho et al. 2010).

Pesticide residues from agricultural fields contaminate water sources through nonpoint and point pollution sources, e.g. due to leaching or run-off directly from fields, or by dumping or washing of used containers. The extent of pollution of surface water and groundwater by pesticides depends on the physicochemical characteristics of the compounds. These characteristics include water solubility, retention by soil components, degradation rate, the properties of the medium in which they are applied, their abiotic and biotic degradation (B Caracciolo et al. 2010) and factors external to them, such as locally occurring precipitation and patterns of wind or the topology of the area (C Martínez et al. 2000; Arias-Estévez et al. 2008).

Surface water contamination may have ecotoxicological effects on aquatic flora and fauna, and on human health if used for public consumption (Forney and Davis 1981; Leonard and Knisel 1988; Miyamoto et al. 1990; Mulla et al. 1981). It is usually dependent on the agricultural season and it does not last long, while groundwater contamination has a strong inertia, which may cause continuous human exposure (Funari et al. 1995). Groundwater represents the most important source of drinking water supply in many countries (Bachmat et al. 1994; Mandl et al. 1994).

Poorly managed agricultural operations can lead to contamination of surface water and groundwater by nutrients and pesticides (Spalding and Exner 1993; Pereira et al. 1996; Kolpin et al. 1998; Novotny 1999; Gunningham and Sinclair 2005). Periodic use of these products in agriculture will cause dispersion within the environment by means of drift, run-off and drainage (Kolpin et al. 1998; Guzzella et al. 2006; Papastergiou and Papadopoulou-M 2001). This may result in residues being encountered in groundwater (Lacorte and Barcelo 1996), river waters (Irace-Guigand et al. 2004; Claver et al. 2006), and in coastal waters and lakes (Konstantinou et al. 2006), which suggests that mobilization may occur and that residues can be found far away from the point of application.

Livestock farming can be an important source of phosphorus and nitrogen in streams, thus contributing to eutrophication of surface water resources (Haygarth et al. 1998; Withers and Lord 2002). Nonpoint source pollution such as fertilizer, pesticide and herbicide run-off and soil erosion due to land use and cover change is more difficult and expensive to control than point source pollution (Baker 1992).

4. Anthropogenic sources affecting water quality in urban areas

Urbanization is a pervasive form of land cover/land use alteration that is rapidly growing (Paul and Meyer 2001). This involves conversion of croplands, forests, grasslands, pastures, wetlands and other cover types to residential, transportation, commercial and industrial uses, thereby increasing the areas of impervious surfaces (Tsegaye et al. 2006) (Table 3). Impervious surfaces are quantifiable indicators that correlate very closely with increases in nonpoint (diffuse) sources of polluted run-off which degrades the quality of aquatic resources (Arnold and Gibbons 1996).

Urban areas are more polluted than rural ones due to industrialization, sewage discharge and other domestic activities. Human activities such as discharge of industrial and domestic effluents, the use of agricultural chemicals, land use and cover changes are the major factors that influence surface water quality (Peters and Meybeck 2000; Buck et al. 2004; Alam et al. 2006; Zhang et al. 2007; Hussain et al. 2008).

Change in land use and land cover is one of the major anthropogenic influences on ecosystems (Dale et al. 2000), and affects the water flow and quality of rivers in particular. Changes in landscape pattern induced by human activities have major impacts on river conditions (Allan 2004; Bhat et al. 2006; Hopkins 2009). Land use and land cover change is strongly correlated with water chemistry parameters (Hunsaker and Levine 1995; Tran et al. 2010), the species diversity of freshwater fish and macro-invertebrates (Hopkins 2009; Weijters et al. 2009), and sediment metal concentrations (Hollister et al. 2008). Highly fragmented urban land uses, with a large proportion of impervious surfaces, tend to increase river flow and negatively affect water quality (Sliva and Williams 2001; Brabec 2009; Lee et al. 2009). The problem of soil erosion is severe in some areas because of rapid urban development in recent decades (Ho and Hui 2001). Dodds and Oakes (2008) found that riparian zone and land use/land cover close to streams were more important to water quality than the landscape pattern of the entire catchment. Ferrier et al. (2001) found that urban catchments were highly correlated with ammonium ions, reactive phosphates and suspended solids.

4.1. Stream channelization

Stream channelization aims to move, widen, narrow, straighten, shorten, cut off, divert, line or fill a natural or altered stream channel. Stream channelization can lead to changes in the amount and speed of the water flowing through the channel. Channelization may be done by lining the channels with concrete, excavating sand and gravel from the stream bed and sloping it back along the banks, or constructing culverts. Channelization may affect the water quality in the following ways:

- Drinking water quantity: an increase in the velocity of water may result in less recharge of groundwater. The impact would be more profound in areas where groundwater is an important source of drinking water and its replenishment is slow.
- Increased nutrients: Increased accumulation of nutrients in streams may lead to algal blooms, which would affect human health as well as animals such as livestock.
- Pollution in streams: Streams channelization can lead to floods, wherein huge water run-off picks up pollutants such as phosphorous, nitrogen, pesticides, sediments and heavy metals. This affects the stream water quality, and the cost of drinking water treatment also increases. Removal of trees and vegetation along the stream bank may further increase the pollutants in streams, including nitrogen, phosphorous, *Escherichia coli*, pesticides and sediment. There may be an increase in water temperature and consequently the dissolved oxygen in water may decrease. As temperature is critical to many aquatic species, death of fish may result.

4.2. Anthropogenic impacts on water quality

The quality of surface waters is a sensitive issue as far as health is concerned. Urban, industrial and agricultural activities lead to increases in water consumption. Natural processes, e.g. changes in precipitation, erosion and weathering of crustal materials, degrade the surface water. This

Table 3. Impacts on water quality due to primary sector activities.

	Agricultural activity	Impacts: Surface water	Impacts: Groundwater
1	Tillage/ploughing	Sediment/turbidity: sediments carry phosphorus and pesticides that are adsorbed by the sediment particles; siltation in the beds of river and habitat loss, etc.	No impact is generally observed.
2	Fertilization	Run-off of nutrients, especially phosphorus, leads to eutrophication; this causes changes in taste and odour in public water supplies. Excessive algae growth leads to de-oxygenation of water, and death of fish.	Leaching of nitrate in the groundwater; excessive use of fertilizer may endanger human health.
3	Use of manure	Manure is used as a fertilizer. It may contain pathogens, metals, phosphorus and nitrogen depending upon its source. May cause eutrophication and contamination of water.	Contamination of groundwater may occur especially by nitrogen.
4	Pesticides	Pesticide run-off causes contamination of surface water and biota; top predators may be lost due to growth inhibition and reproductive failure; human health may be affected due to consumption of contaminated fish. The entire ecosystem becomes dysfunctional. Wind can act as a carrier for pesticides, transporting them over great distances, which may be thousands of kilometres, thus contaminating aquatic systems. The presence of pesticides in subtropical Arctic mammals is an example of leaching of certain pesticides into may contaminate wells affecting human health.	Some pesticides may leach into groundwater, causing problems to human health from the contaminated wells.
5	Feedlots/animal corrals	Surface water contamination by pathogens such as bacteria and viruses. This can lead to chronic or acute human health problems. Also, contamination may be due to metals contained in urine and faeces.	Potential nitrogen and metal leaching into the groundwater.
6	Irrigation	Salts in run-off from salinization of surface waters; fertilizer run-off into surface waters leads to ecological disturbance, and bioaccumulation of metals and organics especially in edible fish species. High amounts of trace elements, e.g. selenium, in water can cause serious ecological damage and can impact human health.	Enrichment of groundwater due to salts, nutrients (may be nitrate). There can be a problem of contamination of groundwater with nitrates and phosphates.
7	Clear cutting of forests and vegetation	Erosion of soil, leading to turbidity in rivers and siltation taking place in downstream habitats, etc. Disruption and change in hydrological regime of the river, resulting in a seasonal instead of perennial stream; this causes health problems due to less availability of potable water.	The regime is disrupted, which is often coupled with increased surface run-off and decreased groundwater recharge; alternatively decreased surface flow, during the lean season leading to high concentration of nutrients and contaminants in such waters and consequently in recharge water.

(*Continued*)

Table 3. Continued

Agricultural activity		Impacts: Surface water	Impacts: Groundwater
8	Silviculture	Generally results are positive, if afforestation or reforestation is done. Harvesting of trees may result in increased contamination of surface water and fish, if pesticides are used; deforestation may cause problems such as erosion and sedimentation.	
9	Aquaculture	Release of pesticides such as tributyltin, and high levels of nutrients in surface water as well as groundwater due to feeds and faeces, causing extreme eutrophication.	

impairs its use for drinking, industrial, agricultural, recreation or other purposes (Carpenter et al. 1998; Jarvie et al. 1998).

4.2.1. *Surface water pollution in urban areas*

Surface waters are prone to pollution, as they are used for wastewater disposal in most countries. Both natural processes and anthropogenic influences together determine the quality of surface water in a region (Carpenter et al. 1998; Jarvie et al. 1998).

Seasonal variations in precipitation, surface run-off, interflow, groundwater flow and pumped inflows and outflows have a strong effect on river discharge and subsequently on the concentration of pollutants in river water (Vega et al. 1998).

Urbanization-related activities have been found to increase nitrogen, phosphorus, alkalinity, and the total dissolved solids in surface waters (Johnson et al. 1997; Boyer et al. 2002; Gergel 2005). Degraded streams and rivers that drain urbanized landscapes often have higher nutrient loads and contaminant concentrations, as well as altered stream morphology and reduced biodiversity (Meyer et al. 2005).

Generally, heavy metal pollution is considered to be point source pollution, and is primarily discharged from smelting and heavy industrial enterprises (Zhang et al. 2009); however, nutrient and organic pollution includes point source and nonpoint source pollution, such as domestic wastewater, effluent from wastewater treatment plants and agricultural run-off (Shrestha and Kazama 2007). Industrial, agricultural and other anthropogenic activities often lead to an increased input of metals in soils and natural waters (Cundy et al. 2003).

Higher nutrient concentrations of dissolved inorganic forms were observed in rural and urban streams in relation to those areas under natural cover (Silva et al. 2011). Further, chloride, a robust indicator of urban impact (Riva-Murray et al. 2010), has been linked to road de-icing salts that are transported to streams in surface run-off (Kelly et al. 2008). In the snow-belt of the USA de-icing agents are necessary to remove traffic obstructions in the winter. The primary agent used for this purpose is rock salt, consisting mainly of sodium chloride (NaCl). Other agents in the road salt mixture, such as ferrocyanide, which is used as an anti-clumping agent, and impurities consisting of trace elements (phosphorus, sulphur, nitrogen, copper and zinc), can represent up to 5% of the salt weight (Marsalek 2003). Other de-icing agents are also available (e.g. calcium, magnesium chloride and potassium acetate), but because of a large difference in cost, sodium chloride is applied most frequently (Novotny 1999).

4.2.2. *Groundwater pollution in urban areas*

Hydrogeological and hydrochemical conditions of urban groundwater can be disturbed by human activities (Lerner and Barrett 1996; Yang et al. 1997; Barrett et al. 1999; Lawrence et al. 2000; Jeong 2001; Zilberbrand et al. 2001; Foppen 2002; Lerner 2002; Cronin et al. 2003; Powell et al. 2003; Eiswirth et al. 2004; Vázquez-Suñé et al. 2005; Ellis and Rivett 2007). Groundwater quality in a region is largely determined by natural processes such as lithology, groundwater speed, quality of reloaded water, interaction of water with soil components and rock, and interaction with other types of aquifers. It is also affected by anthropogenic activities such as agriculture, industry, urban development, and increasing exploitation of water resources and atmospheric input (Helena et al. 2000; Chan 2001) (Table 4). Potassium ions in groundwater often come from orthoclase and muscovite minerals present in granite, and from pollution sources such as chemical fertilizer and domestic effluents. Chloride (Cl^-) may be derived from pollution sources such as industrial and domestic effluents, fertilizers and septic tanks (Bohlke and Horan 2000; Edmunds et al. 2003; Negrel and Pauwels 2003; Petelet-Giraud et al. 2003; Widory et al. 2004;

Table 4. Classes of nonpoint sources of water pollution.

	Agriculture activities	Impact	Contaminant/pollutant
1	Animal feedlots, cultivation, irrigation, dairy, pastures, farming, orchards, aquaculture	Agricultural run-off causes pollution in surface water and groundwater. In northern climates, a major problem is encountered due to run-off from frozen grounds, especially in areas where manure is used in the winters. Washing of vegetables in polluted surface waters in many developing countries contributes to contamination of food supplies. Growth of aquaculture is becoming a major polluting activity in certain countries. Irrigation return flows to surface waters carry salts, nutrients and pesticides. Tile drainage promptly carries leachates such as nitrogen to surface waters.	Metals, nitrogen, phosphorus, sediment, pesticides, salts, BOD (biochemical oxygen demand), trace elements (e.g. selenium) and pathogens.
2	Forestry	Increasing run-off from deforested land. Clear felling for urbanization is the most degrading activity.	Sediment, pesticides
3	Liquid waste disposal from scattered areas	Scattered industrial effluents and sludge, waste-water from domestic septic tanks; legal or illegal disposal in water courses.	Metals, Organic compounds, Pathogens,
4	Residential, commercial and industrial areas	Urban surface run-off from scattered parking lots, streets, roofs, etc., that do not drain into the sewer or a sewage treatment plant. Polluted run-off from various area sources, which enters receiving waters directly; cleaning of streets; salting of ice also causes surface and groundwater pollution.	Greases and oils, fertilizers, faecal matter and pathogens, organic contaminants, e.g. polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), heavy metals, pesticides, nutrients, sediment, salts, BOD (biochemical oxygen demand), COD (chemical oxygen demand), etc.
5	Rural sewage system	Overloading and malfunction in septic tanks causing surface run-off and/or infiltration into groundwater.	Phosphorus, nitrogen, pathogens (faecal matter)
6	Transportation	Expressways, highways, roads, railways, pipelines, waterways, etc. not connected to appropriate pipeline systems	Nutrients, sediment, metals, organic contaminants, pesticides , herbicides
7	Mineral extraction	Surface run-off from mines; mine dumps and mine wastes; quarries, well sites	Sediment, metals, oils, acids, organic contaminants, salts (brine)
8	Recreational land use	E.g. ski resorts, marinas and boating, campgrounds, parks waste and pollution due to grey water from recreational boats, especially in small lakes and rivers. Hunting that may cause lead pollution in waterfowl.	Nutrients, pesticides, sediment, pathogens, heavy metals
9	Solid waste disposal	Leachate which contaminates the surface water and groundwater.	Nutrients, metals, pathogens, organic contaminants. Air pollutant gases.
10	Dredging of rivers, harbours, etc.	Dispersion of contaminated sediments from dredged soil, leakage happening in containment areas.	Organic contaminants, metals
11	Atmospheric deposition	Long-range transport of atmospheric pollutants (LRTAP) and their deposition on land and water surfaces. This includes pesticides (from agriculture, etc.), nutrients, metals, etc., deposition in areas, move so in pristine systems.	Nutrients, metals, organic contaminants

Valdes et al. 2007), and from natural sources such as rainfall, the dissolution of fluid inclusions and chloride-bearing minerals (Negrel and Roy 1998; Negrel 1999).

Groundwater contamination due to nitrate has been a concern for some time. The reason for such contamination is domestic wastewater discharge, animal husbandry waste and agricultural run-off from farms that consume large quantities of fertilizers (Ministry of Environment of Japan). Urban groundwater may be significantly contaminated with organic matter, nitrogen compounds, pathogenic microbes, and heavy metals when sewage-contaminated water or wastewater infiltrate the aquifer (Barret et al. 1999; Zilberbrand et al. 2001; Cronin et al. 2003; Powell et al. 2003).

Elevated concentrations of mercury (Hg) in groundwater have been linked to industrial contamination or mining activities (e.g. Somasundaram et al. 1993; Srinkanth et al. 1993; Rytuba et al. 2000) and, rarely, to natural sources (e.g. Barber and Steele 1980; Sidle 1993). The methylation of mercury by sulphate-reducing bacteria in various environmental settings can be inhibited by high concentrations of DOM and sulphide, or promoted by sulphate inputs (Gilmour et al. 1992; Barkay et al. 1997; Benoit et al. 1999; Jay et al. 2000; H Schmidt and Fitzgerald 2004) Waste gas, wastewater and waste residues produced in the processes of industrialization and urbanization cause an increase of pollutants such as nitrogen, phosphate, chloride, sulphate, heavy metals and organic solvents (Andres et al. 1999; Wakida and Lerner 2006). Wastewater contaminates coastal areas leading to high nutrient load, particularly in urbanized estuaries. Where no treatment plants exist, nutrient load from this source is directly proportional to the population and the amount of water used per inhabitant (Smith et al., 1997), since nitrogen and phosphorus concentrations in wastewater vary within a narrow range (IC Consultants, 2001).

4.3. *Pollution due to sewage in urban areas*

Sewage is the most important source of coliform bacteria, which are present in human faeces. An adequate faecal indicator does not reproduce outside the animal host. *E. coli* and enterococci grow, survive and establish their populations in natural environments such as freshwater lakes and streams (Byappanahalli et al. 2003; Power et al. 2005), algal wrack (Olapade et al. 2006; Whitman and Nevers 2003), beach sand (Byappanahalli, Whitman, Shively, Ting, et al. 2006; Whitman et al. 2005), soils and sediments (Anderson et al. 2005; Byappanahalli and Fujioka 2004; Byappanahalli, Whitman, Shively, Sadowsky, et al. 2006; Fujioka et al. 1999; Ishii et al. 2006; Solo-Gabriele et al. 2000; Whitman et al. 2005), and plant cavities (Whitman et al. 2005).

Escherichia coli was found to be a good indicator of faecal pollution and its concentration showed a strong relationship with the incidence rate of swimming-associated illnesses such as skin and gastrointestinal illnesses (Cheung et al. 1990). A variety of animals, both warm- and cold-blooded, contain faecal indicator bacteria in their faeces (Harwood et al. 1999; Souza et al. 1999; Gordon and Cowling 2003). Humans and animal species contain different numbers and different ratios of *E. coli* and enterococci in their faeces, although data are contradictory (Geldreich 1978; Alderisio and DeLuca 1999; Fogarty et al. 2003; Field 2004; Weaver et al. 2005). *E. coli* and enterococci are not well correlated with pathogenic *Salmonella* spp. (Lemarchand and Lebaron 2003), *Campylobacter* spp. (Lund 1996; Bonadonna et al. 2002; Lemarchand and Lebaron 2003; Horman et al. 2004), *Cryptosporidium* and *Giardia* spp. (Lund 1996; Bonadonna et al. 2002; Lemarchand and Lebaron 2003; Horman et al. 2004; Harwood et al. 2005), human enteroviruses (Geldenhuys and Pretorius 1989; Lemarchand and Lebaron 2003; Horman et al. 2004; Harwood et al. 2005; Pusch et al. 2005) including adenoviruses (Noble and Fuhrman 2001) and coliphages (Jiang et al. 2001). Elevated levels of both nutrients and dissolved and suspended inorganic and organic matter, which are mainly generated from uneaten feed, fish excretion, and faecal production, might induce eutrophication in coastal zones (Holby and Hall 1991; Hall et al. 1992; Wu 1995; Lee et al. 2003).

5. Effect on water quality by anthropogenic and natural sources

Both natural and anthropogenic sources contribute to nutrient enrichment in surface water bodies. Nutrient loading in water bodies depends on a number of factors, e.g. source output and location, speciation and concentration, seasonal variation, mode of loading (continuous versus sporadic) and bioavailability (Withers and Jarvie 2008). Across the various areas, fertilizers and septic leachate are the primary sources of nitrate concentrations that are higher than drinking water thresholds in groundwater used for public supply (Dubrovsky et al. 2010). Potential effects of eutrophication in water bodies are: increased biomass of phytoplankton and macrophyte vegetation, growth of benthic and epiphytic algae, increased blooms of gelatinous zooplankton (marine environment), increased toxins from bloom-forming algal species, reduced carbon availability to food webs, loss of commercial and sport fisheries, reduced diversity of habitats, loss of coral reef communities, increased taste and odour problems due to an increase in mineral contents, dissolved oxygen depletion, increased treatment costs prior to human use, and decreased aesthetic value of the water body (US EPA 1990; Smith and Schindler 2009).

Groundwater with high concentrations of SO_4^{2-} in coastal areas often indicates seawater intrusion (Kim et al. 2003; Wang and Jiao 2012). The inflow of seawater and river water provides high levels of nutrients to the water column and sediments, making estuaries one of the most productive natural habitats worldwide (McLusky and Elliott 2004). Floods and droughts can also modify water quality by diluting or concentrating dissolved substances. For low river flow rates, the main effect on water quality is due to increases of temperature and concentration of dissolved substances in water, but a decrease of dissolved oxygen concentration (Prathumratana et al. 2008; Van Vliet and Zwolsman 2008).

6. Conclusion

Fresh water is a precious resource as it constitutes only 0.3% of total water resources across the globe. Water is essential for life. Availability of water is subject to natural influences and anthropogenic activities. However, anthropogenic influences on water quality have the most impact on life.

Natural influences on water quality include geological and hydrological processes and climatic changes, which may be gradual or rapid. High DOM and excessive concentrations of certain minerals or elements often occur due to these natural processes.

Anthropogenic factors affecting water quality in rural areas differ from those in urban areas. In rural areas they include agriculture practices, e.g. use of fertilizers, herbicides and pesticides; river siltation due to erosion; nutrient loading in waters; run-off from degraded forest areas; and animal husbandry. Anthropogenic factors that affect water quality in urban areas include industrialization, sewage discharge and other domestic activities. Changes in land use pattern including changes in land cover also adversely affect water flow and quality.

In rural environments, especially in developing countries, the anthropogenic influences are less profound; those due to industrialization and commercialization may not be present at all. Water pollution due to industrial wastewater is absent in rural areas while surface flow from commercial areas. The rural environment is thus a pristine one.

The quality of surface water and groundwater is a sensitive issue as far as health is concerned. Contamination of these resources should be prevented, controlled and reduced. Heavy metal contamination and contamination due to potassium ions, nitrates, phosphate, chloride and organic solvents need to be removed. Faecal pollution also urgently needs to be addressed.

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