SELECTION OF APPROPRIATE ON-SITE WASTE MANAGEMENT SYSTEMS TO REMOVE SYNTHETIC ORGANICS

Dr. Prasanthi Hagare
Infrastructure and Environment Group
Faculty of Engineering
University of Technology, Sydney

Abstract

Rural and/or un-sewered urban areas rely mostly on on-site waste systems to handle domestic wastewater which is collected, treated and reused/disposed on the premises. This system can also be designed specifically for small collection of units or house or large industrial applications.

In this paper on-site waste systems for the management of domestic wastewater only are considered. These systems range from simple septic tank technology to advanced treatment systems that are designed to remove not only organic matter and suspended solids, but also aim to remove nutrients and disinfect wastewater before disposal or reuse. Currently on-site waste systems can be designed to manage all the wastewater in one single system or to treat blackwater and greywater separately.

Due to our current lifestyle practices, the characteristics of wastewater generated in a household has changed considerably in the past few decades. The domestic wastewater not only has organic matter and suspended solids, but also contains synthetic inorganic and organic contaminants. These include the chemicals that are used for household cleaning, personal care and also pharmaceuticals. The household cleaning and personal care products enter the wastewater stream directly, where as the pharmaceutical residues enter the waste stream either as human excrement from a course of medical treatment or via the improper disposal. Even though these substances can be degraded biologically in the treatment process to some extent, their presence decreases the overall efficiency of the process. In addition, any material that is not metabolised can be discharged into the environment either via irrigation or when/if the sludge is applied as a soil-conditioner. These substances can find their way back into the environment and water supply through different transport mechanisms and have a tendency to bioaccumulate. The effect of these substances on human health and on ecosystems is well researched. Without appropriate treatment there is a risk of these wastes contaminating the catchment.

Factors influencing the selection of an on-site waste treatment system are: the regulatory requirements of treatment, disposal and reuse; the health goals of people (in the household and the neighbourhood); the surrounding environment particularly the water catchment area. Though the major sources of pollution of waterways are direct discharge of pollutants from industries and sewage treatment plants, in-direct non-point sources of pollution from improper land use including ill-maintained on-site wastewater treatment systems is also common and is mostly uncontrollable and unmanageable.

In recent times, due to increased environmental awareness people are enthusiastic about developing and maintaining sustainable wastewater treatment options. It is important to consider the effect of trace organic contaminants while choosing a treatment system for recycling water both for potable or non-potable use. The current paper aims to review the different on-site wastewater treatment processes in terms of their efficacy in removing these synthetic trace organic contaminants, and recommend a process of selecting an appropriate system with a view to enhance catchment management.

1. Introduction

In most urban areas wastewater generated in a household is collected, transported and treated in a sewage treatment plant. This method of wastewater management first started when continuous water supply to a household made it possible to develop water closets and drainage systems to carry waste away. Wastewater collected from residences, and today also from industries, is treated by complex processes that provide primary, secondary and tertiary treatment before the treated water is discharged into water ways. However, for some communities, which live on the fringes of an urban sprawl and where there is no current access to a treatment plant, on-site waste management systems take the role of treating and disposing the household wastewater. In recent years due to water restrictions and lack of rainfall, the role of wastewater treatment plants in providing recycled water will become a necessity rather than be confined to scientific research. Even though centralized wastewater treatment plants are commonplace in most developed countries, the use of on-site waste management systems has increased in the past few decades. In USA, initially these systems were used as a temporary means; but now they are an integral part of an overall wastewater infrastructure (USEPA 1997 as cited by Dejong et al., 2004).

In Australia there was always a need for on-site waste management systems as many areas are not sewered, and setting up a fully reticulated system and a wastewater treatment plant may not always be a wise economic investment, especially when the population density is low. In recent times, the increase in public awareness in water conservation and sustainable waste management solutions is forcing local councils and governments to approve more on-site systems. In order to meet this demand, the number and variety of these systems manufactured has increased in recent years. The types of systems now available range from simple systems (septic tank and absorption field) to complex (aerated wastewater treatment) systems that include state-of-art disinfection. The market also offers systems that only treat greywater or those that provide an integrated treatment system for all waste (organic solid) and wastewater generated in a household.

The need for regulation in approving on-site waste management systems is well recognized in Australia. Australian Standards are available for on-site domestic wastewater management and for different treatment units (AS/NZS 1546.1:1998, 2:1998, 3:2001, 1547.2000). Local governments are the regulatory authorities that approve the installation of these systems, and they also oversee the proper operation and maintenance of these systems. The state Environment Protection Authorities provide overall assessment processes and guidelines for the protection of environment from any pollution.

Even with adequate regulation for installation, operation and maintenance, there will be incidents where pollution of surface waterways from on-site waste mangement sytems cannot be avoided totally. The resulting issues become more complicated due to the changing nature of wastewater generated in today’s households. The domestic wastewater not only has organic matter, suspended solids and nutrients such as nitrogen and phosphorus, but it also contains synthetic trace organic contaminants. These include the chemicals that are used for household cleaning, endocrine-disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs). The variety and the frequency of usage of these substances has increased rapidly in recent years. These chemicals end up in surface water supplies through the pathway of wastewater treatment plants. The effect of simple household cleaning products on the performance of septic tanks is well known; however the combined effect of household cleaning products, EDCs and PPCPs on the peroformance of septic tanks or other complex on-site waste management systems is not known. The aim of this paper is to present the different pathways these compouds take leading up to their presence in the environment, and the effect of different treatement processes in removing these substances. This paper also presents considerations while selecting an on-site waste management system especially if treated wastewater is to be used for recycling.

2. Types of on-site waste management systems

An on-site waste management system should comprise of processes to collect, treat, and store and dispose wastewater within the boundaries of the allotted plot. Depending on the type of scheme chosen, a separate greywater and blackwater treatment can be provided, or more appropriately for this study, a combined system is used to treat all wastewater generated in the household. In some instances the wastewater treatment system is modified by the use of vermiculture and bio- filters to integrate the disposal and treatment of organic solids along with wastewater (Mobbs, 1998). In this study however, the treatment of *all* wastewater is only considered.

The treatment of all wastewater can be divided into primary, secondary and tertiary processes. The complexity of secondary and tertiary treatment processes can depend on the ultimate use or reuse of treated water. A schematic is provided in the figure below:

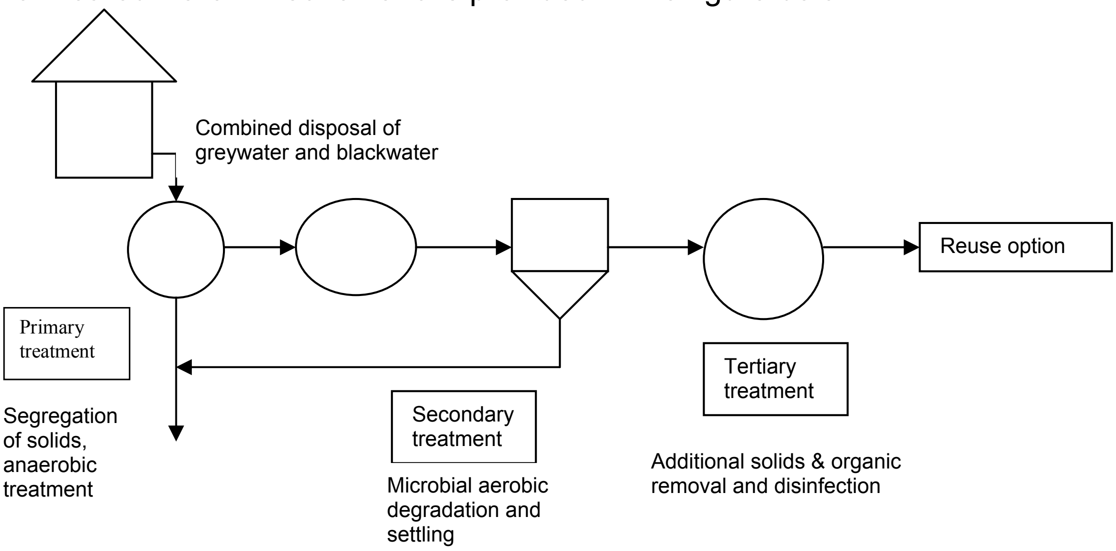

Figure 1. Schematic of a treatment processes in an on-site wastewater treatment system

This section will attempt to describe each of the processes only briefly. More specific information about different types of treatment systems can be obtained elsewhere (Dharmappa et al., 1998, Hagare et al., 1999, Crites et al., 1998).

Primary Treatment:
The purpose of primary treatment is to collect all wastewater, segregate liquids, solids and oil and grease and provide some degree of anaerobic treatment for organic solids. The effluent that emerges from this process is usually 30% less in its organic content and about 70% less in its solids content. The solids (or sludge) that fall to the base of the tank undergo anaerobic treatment and are removed from the tank annually (or biannually, depending on the design capacity) by pump out. This sludge is either taken to a sewage treatment plant where it is mixed with other sludge and converted to biosolids; which then has a potential to be applied to agricultural land as a soil conditioner or disposed directly in to a landfill.

Secondary Treatment:
The primary effluent undergoes aerobic biological treatment. Depending on the detention time of the tank(s) and the aeration capacity, the organic solids are biodegraded and nitrification takes place. The secondary treatment is usually divided in to two sections: aeration process and settling process. In some cases, chemicals are added in the settling zone to aid the precipitation of phosphorous. The secondary effluent is 80 to 90% less of organic content and has very small concentration of suspended solids.

Tertiary Treatment:
In this section of the treatment, the system can opt to have an additional process to remove solids (such as sand filters) or may only use disinfection. Depending on the make, a system can use chlorine pellets, ozone or UV as disinfectants.

After tertiary treatment, the effluent is either stored (in wet weather), used for irrigation or be directed in to the household for non-potable use.

Wastewater that is treated by the above means is usually not recommended for potable purposes. For potable use advanced treatment techniques such as membrane filtration coupled with activated carbon are recommended.

3. Presence of synthetic trace organic substances in wastewater

Traditionally the water quality parameters that govern the design and performance of treatment processes are BOD, suspended solids, feacal coliforms and nutrients such as nitrogen and phosphorus. In recent days however, these parameters do not always reflect the actual composition of pollutants in the wastewater. Other pollutants such as PCBs and dioxins may not be relevant to domestic wastewater generated from single households, but cleaning products, pharmaceuticals, personal care products and pesticides are prevalent in domestic wastewater. Some of the specific compounds include medicines such as antibiotics, painkillers, hormones, anti-depressants and impotence drugs and personal care products such as deodorants, hair sprays and fragrances.

The presence of synthetic trace organic substances in wastewater effluents, surface water, groundwater and even in drinking water is well researched and documented (Ternes, 1998, Buser et al., 1998, Ternes et al., 2004, Westerhoff et al., 2005). Ternes (1998) reported microgram per liter concentrations of many pharmaceuticals, hormones, metabolites and biocides in the wastewater treatment plant flows in Germany. Westerhoff et al., 2005 reported the presence of these substances in surface waters that provide raw water to water treatment plants. Cosmetics and personal care products such as deodorants, lotions, fragrances and hair sprays contain a group of chemicals called phthalates (Pickrell, 2002) that can end up in wastewater. Dejong et al., (2004), in their analyses of many on-site waste systems found the presence of varying concentration of emerging organic chemicals such as 4-nonylphenol, caffeine, triclosan, 3-β-coprostanol and cholesterol. Many of the pharmaceuticals and some organic compounds would be excreted from human body as metabolic compounds, while personal care products enter the wastewater during cleaning or showering. Some of these compounds may be included in conventional water quality parameters such as BOD or COD, or TOC or DOC, or TDS or electrical conductivity (salts in kitchen and laundry products) but most of them are not detected. Westerhoff et al., (2005) reported the use of liquid and gas mass spectroscopy methodologies to detect very small concentration of endocrine-disrupting compounds (EDCs) as well as pharmaceuticals and personal care products (PPCPs) in drinking water supplies. Though the use of these and other analytical methods to measure these substances are reported, they are either not readily available or not sophisticated enough to detect low concentrations that are discharged in wastewater.

4. Fate of pollutants in the environment

For the purpose of this paper, the source of chemicals (household cleaning products (HCPs, endocrine-disrupting substances (EDCs) and pharmaceutical and personal care products (PPCPs)) is considered to be the individual usage in a household. This section deals with fate of these substances once they leave the household, and the pathways they take up in the environment (Figure 2).

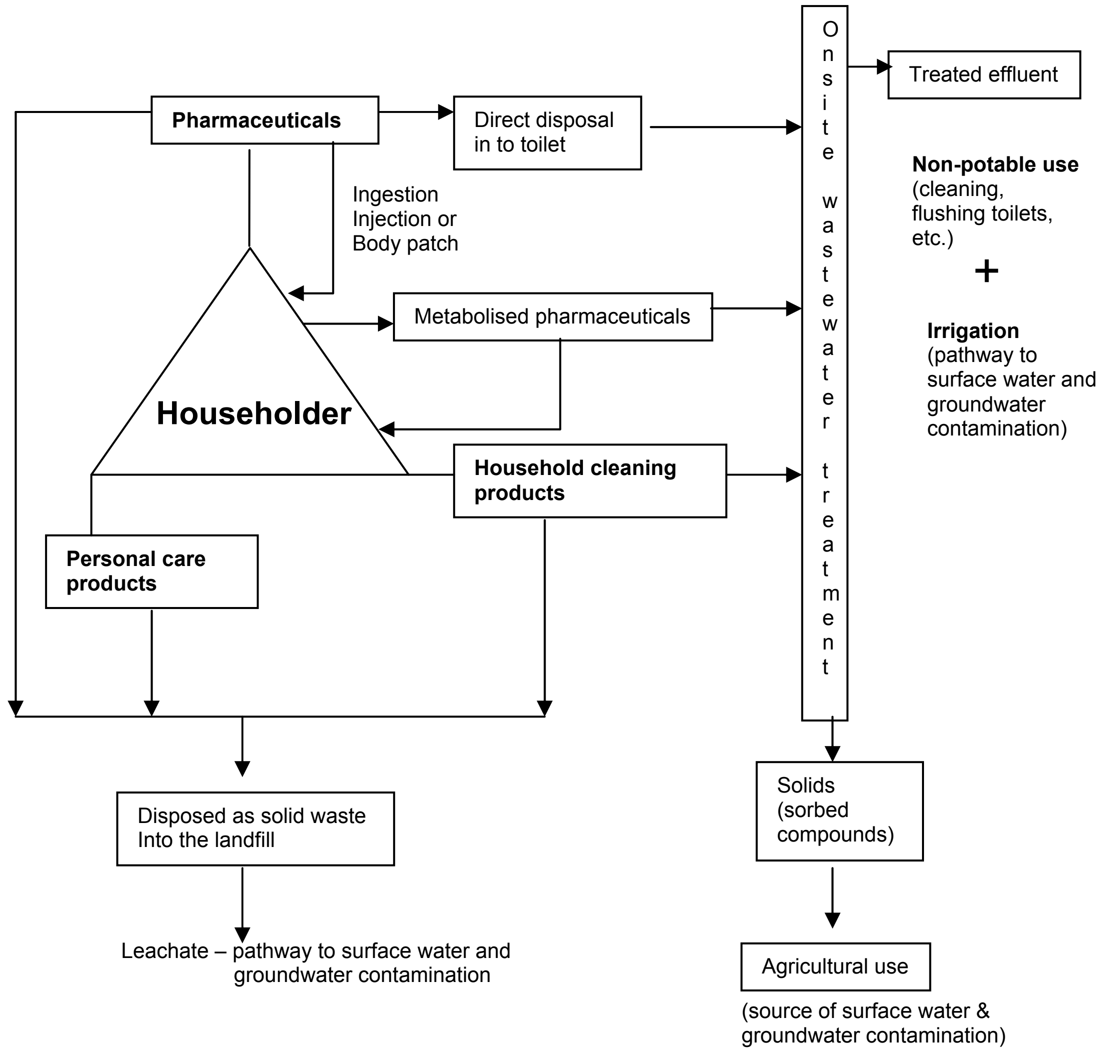

Figure: 2 Fate and possible pathway of compounds disposed in domestic wastewater

4.1 Direct discharge of substances into the wastewater:

Personal care products such as fragrances, hair sprays, deodorants and hair colourants and household cleaning products such as kitchen and laundry chemicals will enter the wastewater after every use during cleaning, washing and/or showering. The chemical structure of these compounds is altered only moderately.

There is a high likelihood of the presence of unchanged compounds in drugs due to the direct disposal of unused or expired drugs in the toilet. These compounds may only undergo transformation from solid or semi-solid medium to a liquid medium without any significant changes to their chemical structure.

4.2 In-direct discharge of substances into the wastewater:

When medicinal drugs are administered (either orally, by injection or through using skin patches), a significant proportion of the drug may pass through the human body without metabolisation (Ternes et al., 2004). Most substances transform within the body based on the function of the active ingredient and the reaction of the human body. Some compounds may be assimilated by the body completely. Due to all these pathways, the body excretes compounds either in their original state, or in a metabolized state, and in some instances by-products may be eliminated too.

4.3 In the wastewater treatment system:

Once disposed, all the compounds (HCPs, EDCs and PPCPs) enter the treatment system along with other substances in the wastewater. Here, depending on their structure, they can either be absorbed or adsorbed on to the sludge in the primary treatment, undergo anaerobic or aerobic degradation in the primary and/or secondary treatment, and oxidize further with the disinfectants used in the tertiary treatment. Most of the substances, even after some degree of treatment, may remain in a dissolved state in the treated water.

Finally, these compounds can end up in the sludge that is removed from the primary treatment process (septic tank) or be disposed in to the environment as part of the treated water.

5. Effect of pollutants on ecosystems and human health

Researchers have found that many of the compounds listed as EDCs or PPCPs are persistent and can bioaccumulate. Some of these substances have direct and adverse effect on biota and ecosystems and indirect impact on human health. Many scientific papers have been published highlighting environmental effects such as feminization or masculization by hormones or structurally related compounds (Routledge et al. 1998, Betty and Lim, 1999 and Bound et al. 2005). Betty and Lim (1999) found that male mosquitofish in a waterway downstream to a sewage treatment plant in Western Sydney had significantly shorter anal fins (growth of these fins is triggered by testosterone) than those that dwell in the upstream. Laboratory tests showed that these are caused by the female hormones present in the sewage effluent. A reduction in sex drive in male fish collected from waterways contaminated by sewage effluent could also be observed.

Phthalates are a group of compounds that are found in personal care products. When used by a pregnant mother these are found to cause harm to the male foetus. Companies that manufacture cosmetics are not obliged to list their ingredients; they can claim that some of the ingredients are trade secrets and the law allows them to keep these off ingredient lists. Animal tests show damage to the developing male reproductive system (Pickrell, 2002). Phthalates were also found to cause premature thelarche in children younger than 2 years (Colon et al. 2000). The effect of poly chlorinated biphenyls (PCBs), their metabolites and other persistent organohalogen chemicals on maturation and thyroid regulatory pathway in people is well documented (Jacobson and Jacobson 1996 as cited by Wang et al., 2005).

Some of these EDCs and PPCPs have also been found in drinking water supplies where the wastewater effluent is discharged from treatment plants upstream to the community. Studies such as Ternes (1998) and Daughton et al. (2002) show ubiquitous presence of these compounds in water supplies and wastewater effluents. Though specific studies were not reported for Australian conditions, as the lifestyle habits of Australians are similar to those in other countries, and as wastewater effluent sometimes becomes the source for water supply, it is likely that these compounds are present in waterways in Australia. Research is currently underway around the globe to study the removal of these substances in a water treatment plant (Adams et al., 2002 and Westerhoff, et al., 2005).

From the research documented it can be concluded that the wastewater from on-site waste treatment systems that is irrigated on land can also be a source of EDCs and PPCPs in the surface water or ground water (See Figure 2). As the on-site systems are spread across any catchment area, the likelihood of monitoring the extent of migration of pollutants into the waterways becomes a difficult task and highly improbable.

6. Fate and removal of pollutants in the on-site wastewater treatment system:

Wastewater treatment plants employ physical, chemical and biological treatment processes. The physical processes involve intentional settling; however unintentional screening, absorption and filtration may also occur depending on the particles present in the wastewater. Chemical processes include the reactions due to any addition of coagulants such as Alum or iron based salts to induce precipitation of phosphorus as metal hydroxides. Disinfection provided by chlorine and ozonation are also chemical processes. Biological treatment is provided by aerobic and anaerobic processes where organic matter is oxidized or stabilized.

There is documented research in assessing the removal of endocrine-disrupting compounds (EDCs) and pharmaceutical and personal care products (PPCPs) in drinking water treatment as well as wastewater treatment plants. Concerns of detrimental health effects in humans lead to research into removal of these substances from water supplies (Westerhoff et al., 2005 and Adams, et al., 2002). There is also much research conducted into studying the removal of these substances in a wastewater treatment plant (Ternes et al., 2003, Ternes et al., 2004 and Bound et al., 2005).

Suspended solids are significantly removed by settling in the septic tank (primary treatment) and to some extent in the secondary sedimentation tank in the biological treatment. Trace organic compounds can be absorbed on to the suspended solids due to the interaction of aliphatic and aromatic functional groups. In some instances adsorption of trace organics on to microorganisms in the solids is possible if polar functional groups are present. Golet et al. (2003) conducted studies to test the removal of an antibiotic, ciprofloxacin in a wastewater treatment plant in Switzerland. The results showed that about ~20% of the antibiotic was sorbed on to the primary sludge where as twice as much was found in the secondary sludge. Musk fragrances were found to have a higher sorption capacity as they are not charged at neutral pH. Ternes et al (2004) reported that anti-inflammatory drugs such as ibuprofen and acetylsalicylic acid are negatively charged at neutral pH and therefore the sorption of these compounds on to the sludge was found insignificant.

Some wastewater treatment plants administer aluminum or iron salts either in the primary or secondary settling tank. The main purpose of these compounds is coagulation and this removes mostly the suspended solids; this in turn can remove some dissolved organic matter. Research shows that even though these salts alone are not effective in removing all of trace organic pollutants, at least <25% of removal of most EDCs and PPCPs can be possible (Westerhoff et al., 2005). Addition of powdered activated carbon can increase these removals to about 50-90%. Some coagulants may be added in on-site waste treatment systems, but studies with addition of powdered activated carbon are not documented. From these discussions it can be observed that addition of coagulants may only increase the removal of trace organic pollutants to a small extent.

In an aerobic treatment process, microorganisms oxidize organic matter in the presence of oxygen. The organic matter is used as a substrate or a carbon and energy source. When trace organic pollutants such as EDCs or PPCPs are present, microorganisms may use these substances too as a substrate thus affecting their direct or indirect transformation. The traditional activated sludge process is designed to have a sludge age of 6-12 days. Modified versions of this process used in on-site systems were found to have a lower sludge age (Hazelwood, 1999). It is known that the biological degradation of a substance increases with an increase in sludge age. Buser et al (1998) reported that an anti-inflammatory diclofenac and the contraceptive 17 α-ethinylestradiol showed significant decomposition when the sludge age was at least 8 days. In general the higher the sludge age, the higher is the decomposition of trace organic pollutants. It is observed that pharmaceuticals such as aspirin are removed to about >80% in biological processes. In the case of ibuprofen, while 15% of the ingested drug may directly be excreted, the remaining undergoes transformation in the body and thus its removal in the biological process can be affected (Ternes et al., 2004).

Much research is documented regarding the effect of chlorine and ozone on trace organic pollutants. Westerhoff et al (2004) reported that chlorine is found to react effectively with easily oxidized compounds. Ozone on the other hand was found to react more readily with trace organic compounds and substantially improve their removals from water. Overall, some compounds such as atrazine, iopromide and meprobamate had low removals by all treatment processes where as compounds such as ibuprofen and gemfibrozil had low removals unless ozone was used. In another study conducted by Ternes et al. (2003), it was found that when 10-15 mg/L of ozone was applied, all the pharmaceuticals investigated as well as musk fragrances were not detected. However, even with a high dose of ozone compounds such as diatrizoate with ionic functional groups were only slightly removed.

Though chlorine is found to remove trace organic pollutants, it is known to increase the presence of carcinogenic compounds in the effluents due to its reactions with even minute quantities of natural organic matter (Marhaba et al. 2000). It is also found to cause reproductive toxicity in aquatic organisms (Hu et al. 2002). These ecotoxicological risks have significance when the type of disinfectant is chosen in an on-site wastewater treatment system, especially when treated effluent is used for irrigation.

7. Concluding remarks:

Many part of Australia are supported by on-site systems to manage wastes discharged by householders. With changing life-styles, and change and increase in the use of products in the house, the characteristics of wastewater are changing rapidly. The chemicals such as HCPs, EDCs and PPCPs, once discharged, follow a pathway through wastewater treatment plants into the environment and result in affecting organisms in the ecosystem or have a potential risk for human health. Research shows that these substances can to some extent be removed by the physico-chemical and biological processes. Further research is warranted to study the effect of modified design criteria for on-site wastewater treatment processes on the increase in removal of trace pollutants. At this stage the characterization of these compounds is very difficult; research should be conducted to establish water quality parameters that help in determining the concentration of these substances. Additional research is also required to study the efficacy of advanced treatment processes in removing trace organic contaminants. These studies coupled with appropriate community education will help in reducing the effect of different contaminants on the environment.

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