RESEARCH STUDY WATER PURIFICATION TECHNOLOGY

M/S Tashfeen & Associates; Corporate Consultants has been mandated by the NGO to conduct Research Study for the betterment of Humanity on sustainable basis with respect to providing Safe Drinking Water Feasibility Study to the citizen of Pakistan without any discrimination. All rights reserved.

Introduction about Water Statistics:

As per latest Global Water Supply and Sanitation Assessment Report published by UNICEF and WHO, with the support of Water Supply and Sanitation Collaborative Council (WSSCC);

- Around 4.8 billion people in Developing Countries are still without access to Improve Sources of Water, while Half of them do not have access to Adequate Sanitation.
- Around 4.2 billion cases of Diarrhea in the World each year, killing some **3.5 million children under the age of 5 year**.
- Ice mostly in form of Glaciers comprises 69% of the World’s Fresh Water supplies and Ground Water is 30% Wetland, which includes Marshes and Swamps comprises 0.3% Lakes 0.3% and Rivers 0.06%.
- UN estimated over **10 Million People die each year from Water Borne diseases in the world**.
- Less Developed Countries, 80% of Transferable Diseases are related to the Water and each year roughly 3 Million people mostly Children (under age 5) die from water related diseases and some 2.5million die diarrheas diseases associate with inadequate Water Supply, Sanitation and Hygiene.
- 1.8 billion People in the World still lack access to the Safe Drinking Water. Fresh Water is One of the Human’s most Precious and Threatended Resources.
- **Pakistan stands 3rd largest Country in the World in terms of Death of under age 5 year Children due to Water Borne Diseases i.e. Diarrhea-related diseases etc**.
- In Pakistan **58% of Schools going Children don’t have access to the Safe Drinking Water and Toilet Facility where as in terms of Rural School going Girl’s scenario the situation is more pathetic**.
- **UNICEF Pakistan reported that 88% of diseases were attributed due to Contaminated Water, lack of Sanitation and poor Hygiene accounting 1.5 million Diarrhea-related cases in children every year.**
- **In Pakistan about 108 million people has lack access to Safe Drinking Water which are segregated to 84 million people in Rural Pakistan and 24 million People in Urban including Sub-Urban areas.**
• In Pakistan Cost associated with Diarrhea related diseases alone is estimated to range from Rs. 80billion to Rs. 100billion per year.
• Approximately 52% by an average Pakistani; has access to the Safe Drinking Water where as in Rural Pakistan the situation is worst as only 30% has access to the Safe Drinking Water.
• Water borne diseases will continue to grow and some of the diseases which have been eradicated from Pakistan will resurface again such as
  1. Guinea-Worm disease
  2. Intestinal Infestation
  3. Typhoid
  4. Infectious Hepatitis (Jaundice)
  5. Different type of Dysentery
  6. Gastro Enteritis
  7. Diphtheria
  8. Piles
  9. Cholera
  10. Malaria etc

Pakistan’s Safe Drinking Water Scenario:

As per the National Safe Drinking Water Policy 2008;

• Safe Drinking Water; a Fundamental Constitutional Human Right of every Citizen.
• To recognize the key role that Women play in the Drinking Water Sector and ensure their participation in decision making for sector at all level.
• To recognize that access to Safe Drinking Water is the Basic Human Right of every Citizen and that it is the responsibility of the State to ensure its provision to all Citizens.
• To provide Safe Drinking Water almost 93% of the Population by 2015 (according to MDGs).
• The technical specification will be based on provision of a minimum 20 liters per capita per day for rural households and 40 liters per capita per day for urban areas.
• **Almost 48% of the populations have no access to the Safe Drinking Water**, and they are compelled to drink the same water which has been used by the Animal in Open Muddy Pounds especially in the Rural and Far-flung Area of the Pakistan.
• As per WHO’s Pakistan reported, about 55-60% of all Hospitals admission is connected to Water-Borne Bacterial and Parasitic conditions, which 65% of Infant Deaths caused by Water Infections. The long term effects on Human Health of Pesticides and other Pollutants includes Colon and Bladder causes, Miscarriage, Birth Defects, Deformation of Bones and Sterility.
Water Purification:

Water Purification is a process of removing undesirable Chemicals, Materials, and Biological contaminants from Raw Water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (Drinking Water) but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacology, chemical and industrial applications. In general the methods used include physical process such as Filtration and Sedimentation, Biological Processes such as Slow Sand Filters or activated Sludge, Chemical process such as Flocculation and Chlorination and the use of Electromagnetic Radiation such as Ultraviolet Light.

Sources of Water:

1. **Groundwater**: The water emerging from some deep ground water may have fallen as rain many decades, hundreds, thousands or in some cases millions of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity before the treatment plant. Such water may emerge as Springs, Artesian Springs, or may be extracted from Boreholes or Wells. Deep Ground Water is generally of very high Bacteriological Quality (i.e., Pathogenic Bacteria or the Pathogenic Protozoa are typically absent), but the water typically is rich in Dissolved Solids, especially Carbonates and Sulfates of Calcium and Magnesium. Depending on the strata through which the water has flowed, other ions may also be present including Chloride, and Bi-Carbonate. There may be a requirement to reduce the Iron or Manganese content of this water to make it pleasant for Drinking, Cooking, and Laundry use. Disinfection may also be required. Where Ground Water recharge is practised; a process in which River Water is injected into an aquifer to store the water in times of plenty so that it is available in times of Drought; it is equivalent to lowland surface waters for treatment purposes.

2. **Upland Lakes and Reservoirs**: Typically located in the headwaters of River Systems, upland reservoirs are usually sited above any Human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and Pathogen levels are usually low, but some Bacteria, Protozoa or Algae will be present. Where uplands are forested or peaty, Humic Acids can colour the water. Many upland sources have low pH which requires adjustment.

3. **Rivers, Canals and Low Land Reservoirs**: Low Land Surface Waters will have a significant Bacterial load and may also contain Algae, Suspended Solids and a variety of Dissolved Constituents.

4. **Atmospheric**: Atmospheric Water Generation is a New Technology that can provide High Quality Drinking Water by Extracting Water from the Air by cooling the Air and thus Condensing Water Vapor.

5. **Rainwater**: Rainwater harvesting or Fog Collection which collects Water from the atmosphere can be used especially in areas with significant Dry Seasons and in areas which experience fog even when there is little rain.
6. **Desalination**: Desalination of Sea Water by Distillation or Reverse Osmosis Technology. This Technology is very Costly and only afforded by the Highest Developed Nations including USA, France.

**Water Treatment Methodologies:**

The processes below are the ones commonly used in Water Purification Plants. Some or most may not be used depending on the scale of the plant and quality of the water.

**Pre-Treatment:**

1. **Pumping and Containment** - The majority of Water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.
2. **Screening** - The first step in purifying Surface water is to remove large debris such as Sticks, Leaves, Trash and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.
3. **Storage** - Water acquired from Rivers may also be stored in bankside reservoirs for periods between a few days and many months to allow Natural Biological Purification to take place. This is especially important if treatment is by Slow Sand Filters. Storage Reservoirs also provide a buffer against short periods of Drought or to allow water supply to be maintained during transitory pollution incidents in the source river.
4. **Pre-Conditioning** - Water rich in hardness Salts is treated with Soda-Ash (Sodium Carbonate) to precipitate Calcium Carbonate out utilizing the Common-Ion effect.
5. **Pre-Chlorination** - In many plants the incoming water was Chlorinated to minimize the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects, this has largely been discontinued.

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

**pH Adjustment:**

Distilled Water has a pH of 7 (neither Alkaline nor Acidic) and Aea Water has an average pH of 8.3 (slightly alkaline). If the water is Acidic (lower than 7), Lime, Soda Ash, or Sodium Hydroxide is added to raise the pH.

For somewhat Acidic, Alkaline Waters (lower than 6.5), forced draft degasifiers are the cheapest way to raise the pH, as the process raises the pH by stripping dissolved carbon dioxide (carbonic acid) from the water.
Lime is commonly used for pH adjustment for municipal water, or at the start of a treatment plant for process water, as it is cheap, but it also increases the ionic load by raising the water hardness.

Making the water slightly alkaline ensures that coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and lead solder in pipe fittings.

Acid (HCl or H$_2$SO$_4$) may be added to Alkaline Waters in some circumstances to lower the pH. Having alkaline water does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water but as a generality, water with a pH above 7 is much less likely to dissolve heavy metals than water with a pH below 7.

**Flocculation:**

Flocculation is a process which clarifies the water. Clarifying means removing any turbidity or colour so that the water is clear and colourless.

Clarification is done by causing a precipitate to form in the water which can be removed using simple physical methods. Initially the precipitate forms as very small particles but as the water is gently stirred, these particles stick together to form bigger particles - this process is sometimes called flocculation.

Many of the small particles that were originally present in the raw water adsorb onto the surface of these small precipitate particles and so get incorporated into the larger particles that coagulation produces.

In this way the coagulated precipitate takes most of the suspended matter out of the water and is then filtered off, generally by passing the mixture through a coarse sand filter or sometimes through a mixture of sand and granulated anthracite (high carbon and low volatiles coal). Coagulants / Flocculating agents that may be used include:

1. **Iron (III) Hydroxide.** This is formed by adding a solution of an iron (III) compound such as Iron (III) Chloride to pre-treated water with a pH of 7 or greater. Iron (III) Hydroxide is extremely insoluble and forms even at a pH as low as 7.
2. **Aluminium Hydroxide** is also widely used as the flocculating precipitate.
3. **PolyDADMAC** is an artificially produced Polymer and is one of a class of Synthetic Polymers that are now widely used. These polymers have a high molecular weight and form very stable and readily removed flocs, but tend to be more expensive in use compared to inorganic materials. The materials can also be Bio-Degradable.

**Sedimentation:**

Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin.
It is a large tank with slow flow, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between does not permit settlement or floc break up.

Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer—that furthest from the sediment—exits. The amount of floc that settles out of the water is dependent on basin retention time and on basin depth.

The retention time of the water must therefore be balanced against the cost of a larger basin. The minimum clarifier retention time is normally 4 hours. A deep basin will allow more floc to settle out than a shallow basin. This is because large particles settle faster than smaller ones, so large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom.

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant.

The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

**Filtration Process:**

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc. The following filtration methods are highly useful.

**A. Rapid Sand Filters:**

The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles.

Effective filtration extends into the depth of the filter. This property of the filter is key to its operations: if the top layer of sand were to block all the particles, the filter would quickly clog.

To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called *backflushing* or *backwashing*) to remove embedded particles. Prior to this, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as *air scouring.*
This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant. Some water treatment plants employ pressure filters. This work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

**Advantages:**

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2-5 atmospheres.
- They can be cleaned (back flushed) and reused.

Membrane filters are widely used for filtering both Drinking Water and Sewerage (for reuse purposes). For Drinking Water, membrane filters can remove virtually all particles larger than 0.2 um—including *giardia* and *cryptosporidium*.

Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for Industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream.

**B. Slow Sand Filters:**

Slow "artificial" filtration (a variation of bank filtration) to the ground. Slow Sand filters may be used where there is sufficient land and space as the water must be passed very slowly through the filters.

These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand with the coarsest sand, along with some gravel, at the bottom and finest sand at the top.

Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the Zoogleal layer or Schmutzdecke, on the surface of the filter.

An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution system with very low disinfectant levels thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products.

Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth. A specific 'large-scale' form of slow sand filter is the process of bank filtration, in which natural sediments in a
riverbank are used to provide a first stage of contaminant filtration. While typically not sufficiently clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river water taken directly from the major streams where bank filtration is often used.

C. Lava Filters:

Lava Filters are similar to Slow Sand Filters and may also only be used where there is sufficient land and space.

Like Sand filters, the filters rely on biological treatment processes for their action rather than physical filtration. Unlike slow sand filters however, they are constructed out of 2 layers of lava pebbles and a top layer of nutrient-free soil (only at the plant roots). On top, water-purifying plants (such as Iris pseudacorus and Sparganium erectum) are placed.

Usually, around 1/4 of the dimension of lavastone is required to purify the water and just like slow sand filters, a series of herringbone drains are placed (with lava filters these are placed at the bottom layer).

Ultra filtration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

1. **Ion exchange**: Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of $\text{Ca}^{2+}$ and $\text{Mg}^{2+}$ ions replacing them with benign (soap friendly) $\text{Na}^+$ or $\text{K}^+$ ions. Ion exchange resins are also used to remove toxic ions such as nitrate, nitrite, lead, mercury, arsenic and many others.

2. **Electro-De-Ionization**: Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electrodialysis. The water is often pre-treated with a Reverse Osmosis unit to remove non-ionic organic contaminants.

Other Mechanical and Biological Techniques:

In addition to the many techniques used in large-scale water treatment, several small-scale, less (or non)-polluting techniques are also being used to treat polluted water. These techniques include those based on mechanical and biological processes. An overview:
• Mechanical Systems: Sand filtration, Lava Filter systems and Systems based on UV-Radiation
• Biological Systems:
  o Plant Systems as constructed wetlands and treatment ponds (sometimes incorrectly called reedbeds and living walls) and
  o Compact Systems as activated sludge systems, biorotors, aerobic biofilters and anaerobic biofilters, submerged aerated filters, and biorolls

In order to purify the water adequately, several of these systems are usually combined to work as a whole. Combination of the systems is done in two to three stages, namely primary and secondary purification. Sometimes tertiary purification is also added.

Disinfection:

Disinfection is accomplished both by filtering out harmful microbes and also by adding disinfectant chemicals in the last step in purifying drinking water. Water is disinfected to kill any pathogens which pass through the filters. Possible pathogens include viruses, bacteria, including *Escherichia coli*, *Campylobacter* and *Shigella*, and Protozoa, including *Giardia Lamblia* and other *Cryptosporidia*.

In most developed countries, Public Water Supplies are required to maintain a residual disinfecting agent throughout the distribution system, in which water may remain for days before reaching the consumer. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage - often called a contact tank or clear well to allow the disinfecting action to complete.

Chlorine Disinfection:

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide.

Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions.

A solid form, calcium hypochlorite exists that releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated.

The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine. All forms of chlorine are widely used despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products trihalomethanes (THMs) and haloacetic acids (HAAs), both of which are carcinogenic in large quantities and regulated by
the United States Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK.

The formation of THMs and haloacetic acids may be minimized by effective removal of as many organics from the water as possible prior to chlorine addition.

**Chlorine Dioxide Disinfection:**

Chlorine dioxide is a faster-acting disinfectant than elemental Chlorine, however it is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

**Chloramine Disinfection:**

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it won't form THMs or haloacetic acids.

It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is used a nutrient for bacterial growth, with nitrates being generated as a by-product.

**Ozone Disinfection:**

O$_3$ is an unstable molecule, a "free radical" of oxygen which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms.

It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens.

Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products (in comparison to chlorination) and the lack of taste and odour produced by ozonisation.

Although fewer by-products are formed by ozonation, it has been discovered that the use of ozone produces a small amount of the suspected carcinogen bromate, although little bromine should be present in treated water. Another of the main disadvantages of ozone is that it leaves no disinfectant residual in the water.

Ozone has been used in drinking water plants since 1906 where the first industrial Ozonation Plant was built in Nice, France. The U.S. Food and Drug Administration has accepted ozone
as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods.

**Ultraviolet Disinfection:**

Ultraviolet light is very effective at inactivating cysts, as long as the water has a low level of colour so the UV can pass through without being absorbed. The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water.

Because neither ozone nor UV radiation leaves a residual disinfectant in the water, it is sometimes necessary to add a residual disinfectant after they are used. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very little of the negative aspects of chlorination.

**Hydrogen Peroxide Disinfection:**

It Works in a similar way to ozone. Activators such as formic acid are often added to increase the efficacy of disinfection. It has the disadvantages that it is slow-working, phytotoxic in high dosage, and decreases the pH of the water it purifies.

**Various Portable Methods of Disinfection:**

Available for disinfection in emergencies or in remote locations. Disinfection is the primary goal, since aesthetic considerations such as taste, odour, appearance, and trace chemical contamination do not affect the short-term safety of drinking water.

**Solar Water Disinfection:**

One low-cost method of disinfecting water that can often be implemented with locally available materials is Solar Disinfection (SODIS). Unlike methods that rely on firewood, it has low impact on the environment.

One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide.
Pakistan National Standards for Drinking Water Quality

INTRODUCTION:

In Pakistan, there are several potential sources to contaminate Safe Drinking Water;

A. Bacteriological contaminations are attributed due to leakage of Piped water with Sewerage, Pollution through canal irrigated water by the overdosing of pesticides or Industrial Wastage, Intermittent Water supply and stagnant water.

B. Ground water contaminations are attributed in Irrigated and Industrial area by Chemical Pollution from toxic substances due to Industrial Effluents, Textile Dyes, Pesticides, Nitrogenous Fertilizers, Arsenic and other Chemical reaction e.g. Herbicides, Fungicides, Untreated Municipal Waste, Sewerage breakdowns and Coastal Water Pollution due to Waste Discharge and Oil Spills are extremely hazardous for safe drinking water.

C. Hand / Machine pumps or well contaminations are due to underneath water tables containing naturally Arsenic, Florid, Zinc, Sulpher and Beta Emitters etc which are highly Toxic to the Human beings.

Generally water having bad taste, brackish, foul smell, turbidity or mix coloring is not considerable for drinking purposes.

Approximately 52% by an average Pakistani; has access to the Safe Drinking Water where as in Rural Pakistan the situation is worst as only 30% has access to the Safe Drinking Water.

National Standards for Quality Drinking Water in Pakistan

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<thead>
<tr>
<th>Parameters</th>
<th>Pakistan Standard</th>
<th>WHO Standard</th>
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</thead>
<tbody>
<tr>
<td>All water intended for drinking (E.Coli or Thermo tolerant coli form bacteria)</td>
<td>Must not be detectable in any 100 ml sample</td>
<td>Must not be detectable in any 100 ml sample</td>
</tr>
<tr>
<td>Treated water entering the Distribution system (E.Coli or thermo tolerant coli form and total coli form bacteria)</td>
<td>Must not be detectable in any 100 ml sample</td>
<td>Must not be detectable in any 100 ml sample</td>
</tr>
<tr>
<td>Treated water in the distribution system (E.Coli or thermo tolerant coli form and total coli form bacteria)</td>
<td>Must not be detectable in any 100 ml sample. In case of large supplies, where sufficient samples are examined, must not</td>
<td>Must not be detectable in any 100 ml sample. In case of large supplies, where sufficient samples are examined, must not be present</td>
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be present in 95% of the samples taken any 12-Month period. in 95% of the samples taken throughout any 12-Month period.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
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<tbody>
<tr>
<td>Color</td>
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<td>Taste</td>
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<td>Non-Objectionable / Acceptable</td>
</tr>
<tr>
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<td></td>
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<td>TDS</td>
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<td>&lt; 1000</td>
<td>&lt; 1000</td>
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<tr>
<td>pH</td>
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**Essential Inorganic**

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<td>Antimony (Sb)</td>
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<td>&lt;0.005 (P)</td>
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<tr>
<td>Arsenic (As)</td>
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<td>Barium (Ba)</td>
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<tr>
<td>Boron (B)</td>
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<tr>
<td>Cadmium (Cd)</td>
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<td>Chloride (Cl)</td>
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<td>Chromium (Cr)</td>
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<tr>
<td>Copper (Cu)</td>
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**Toxic Inorganic**

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<td>Cyanide (CN)</td>
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<td>Fluoride (F)</td>
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<td>Lead (Pb)</td>
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<td>Manganese (Mn)</td>
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<td>&lt;3 (P)</td>
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<td>Selenium (Se)</td>
<td>mg/liter</td>
<td>0.01(P)</td>
</tr>
<tr>
<td>Residual Chlorine</td>
<td></td>
<td>0.2-0.5 at consumer end 0.5-1.5 at source</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/liter</td>
<td>5.0</td>
</tr>
<tr>
<td>Phenolic compounds</td>
<td>mg/liter</td>
<td>-----</td>
</tr>
<tr>
<td>(as Phenols)</td>
<td></td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Polynuclear Aromatic</td>
<td>g/liter</td>
<td>-----</td>
</tr>
<tr>
<td>Hydrocarbons (as PAH)</td>
<td></td>
<td>0.01 (by GC / MS method)</td>
</tr>
<tr>
<td>Alpha Emitters bq/L or pCi</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Beta Emitters</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Phenolic compounds (as Phenols) mg/L
Polynuclear Aromatic Hydrocarbons (as PAH) g/L
Alpha Emitters bq/L or pCi
Beta Emitters
PHYSICAL PARAMETERS

WHO’s COLOR OF WATER STANDARD!

Color is detectable in a glass of water above 15 True Color Units (TCU). Levels of color below 15 TCU are acceptable to consumers.

PAKISTAN STANDARD: Color parameter ≤ 15 TCU/Hazen Units.

Color of water is one of the most important and conveniently observed indicators of its quality. The highest quality drinking water should be colorless. Potential inorganic, organic and bacteriological contributors of color to natural water are:

(1) Inorganic constituents such as dissolved iron;
(2) Dissolved organic substances like holmic or folic acids, organics from anthropogenic sources such as dyes; and
(3) Suspended particulate matter such as plant debris, phytoplankton and zooplankton. Some of these contributors may be harmless but others are definitely harmful.

Suspended organic matter may itself be harmless but may harbor bacteria and viral contaminants. Trihalomethanes (THM’s) that are generated in the post filtration disinfection stage of water treatment are considered carcinogenic. Organic materials pass through coagulation and filtration and are exposed to chlorine acting as a disinfectant. Holmic materials which give a tea like appearance to water are an ideal example of compounds which may serve as THM precursors. Presence of color in water may, therefore, indicate the presence of organics and if organics are there and the water has been subjected to chlorination, the chances of the existence of THM’s are considerable. Traditionally, the colors of liquids, including drinking water are classified according to the Alpha/Hazen/Pt-Co color scale. One alpha, hazen or Pt-Co color unit is produced by a solution having a concentration of 1mg/L of Platinum. To determine that a sample of water has no color, a visible light (400 – 850nm) is passed through it. If there is little or no attenuation, it implies an absence of light absorption, reflection, or refraction (the three main mechanisms that give color to an object). By comparison with color of solutions having different concentration of platinum and hence colors, one can determine the color units of drinking water. It is practically observed that below 15 Hazen, color of water in a clear glass container may not be detectable. Most drinking water standards, the world over therefore require that the color parameter may not exceed 15 Hazen.
THE MICROBIAL STANDARDS FOR DRINKING WATER

Total coli form bacteria are collection of relatively harmless micro organisms that live in large numbers in the digestive systems and intestines of human beings and warm- and cold-blooded animals.

These micro organisms aid in the digestion of food and can be found in humans and animals wastes.

Soil and decaying vegetable can also be a source of the coli form bacteria. Some coliform bacteria known as faecal coliforms are only present in faecal material. The most common member of this group being Escherichia coli (abbreviated as E. coli) in the Family Enterobacteriaceae named Escherichia (Genus) coli (Species).

These organisms may be separated from the total coliform group by their ability to grow at elevated temperatures and are associated only with the faecal material of warm blooded animals.

Approximately 0.1% of the total bacteria within an adult's intestines are represented by E. coli. Although, in a newborn infant's intestines E.Coli, along with lactobacilli and enterococci represent the most abundant bacterial flora. There are other disease causing bacteria, or viruses present in human waste.

If such a waste finds its way to a water source it would contaminate it and such waters would definitely become a vector for that particular disease.

Some of the most common, microbes linked to drinking water contaminated by human waste and associated diseases are:

• Campylobacter species are believed to cause 5-14% of cases of Diarrhea Worldwide. The most commonly isolated species of Campylobacter is C. Jejuni, an organism that causes Gastroenteritis.

In developing countries the illness occurs primarily in the children under 2 years of age. There is a high association between use of un-chlorinated water and campylobacter infection. In a safe drinking water, there should be no such organisms.

• Vibrio cholerae is the causative organism of cholera. However, Vibrio cholerae 01 spreads through food / water borne route and through the street vendors. The disease causes massive Diarrhea, Dehydration and Electrolyte imbalance.

• Shigella Sonnei and other related Shigella strains are often responsible for the diarrhea diseases (shigellosis) that occur under adverse conditions.

Once infected with Shigella, the patient develops diarrhea, fever, and stomach cramps starting a day or two after the exposure to the bacterium. The diarrhea is often bloody. Untreated surface or even well water may result in shigellosis in the areas where unhygienic conditions prevail.

• Escherichia coli can cause a variety of syndromes and is notoriously responsible for diarrhea episodes, most common being the “Traveller’s diarrhea”. Water and food are the common vehicles of the transmission of the E. coli.
• **Giardiasis**, a diarrhea illness, is caused by *Giardia lamblia*. Giardia is a microscopic parasite that inhabits in the intestine of humans and animals. The parasite is passed in the stool of an infected person or animal.

• **Hepatitis A and E** are the Waterborne viral illnesses that are the most common ones to occur as an outbreak in a defined population. The water borne Hepatitis Epidemics are common.

Coliforms are also present in the soil and plant material. If a water supply is found to contain coliform bacteria it may be contaminated by sewerage or manure, and there is a risk of exposure to water-borne disease.

In particular, the presence of faecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the faecal material of human beings or animals. Water supplies must be tested for faecal coliform bacteria.

According to WHO guidelines, the *E. coli* and *faecal coliform* bacteria **must not be** detectable in any 100 ml sample of all water intended for Safe Drinking Purposes.

### TASTE AND ODOR

**WHO STANDARD:** Non-objectionable/Acceptable

**PAKISTAN STANDARD:** Non-objectionable/Acceptable

Tastes and odors in water supplies can generally be attributed to two different causative elements: the actions of human beings upon the aquatic environment and natural forces within the environment occasionally affecting each other.

Actinomycetes (bacteria) and Algae are two important groups of organisms that produce taste and odor related toxins in drinking water. Actinomycetes are mould like bacteria that produce strong smelling chemicals with earthy and mouldy odors. Actinomycetes and other bacteria can grow as biofilms on the inner surfaces of pipes in the distribution system and cause odors in the household water. Many organisms impart taste and odor to the aquatic environment due to their defense mechanism by releasing repellents and other organic compounds to even kill their predators.

These compounds are naturally very obnoxious. In heavily polluted waters, say near the effluent outlets, or where there are high nutrient levels from Domestic, Agricultural or Industrial fertilizers, excessive plant and algal growth can degrade the water quality and are a very visible cause of the taste and odor problem.

During the death of this material, bacterial action can produce a variety of unpleasant odors (putrid, sulphurous, sharp, rancid, methane, etc.). These can be particularly intense where the decay occurs under the oxygen depleted anaerobic conditions. Diatoms which are very
common in surface waters, and high numbers of these algae can also result in strong source-water odor.

Diatoms store polyunsaturated fatty acids (PUFAs) in their cells, and a process similar to the one that is the cause of the development of rancid odors in foods containing saturated fatty acids such as fish and vegetable oil etc. works here whereby the fatty acids in diatoms are broken down by cell enzymes into odorous compounds.

As far as the human cause of taste and odors in drinking water is concerned, probably the most common cause of consumer complaints is chlorination in the water treatment plant. When low dosages of chlorine are added to water that contains phenols, chlorophenol compounds are formed and impart an objectionable medicinal taste to the water. In general, however, the medicinal odors frequently encountered in treated waters, originally contaminated by industrial wastes, may be due to a variety of other chlorinated organic compounds.

Because of the various combinations of inorganic and organic compounds that cause tastes and odors in water supplies, no simple treatment is cost effective for all taste and odors but generally some form of oxidation is usually effective and potassium permanganate and chlorine dioxide are commonly used.

Levels of taste- or odor-causing contaminants are quantified in a gross manner through threshold odor or taste tests. The water to be examined is diluted with taste- and odor-free water in a series of dilutions and presented in order of highest to lowest dilution to a panel of selected persons.

The sample average at which odors or tastes are just detected determines the threshold number according to the following formula:

\[
\text{Threshold Number} = \frac{A+B}{A}
\]

Here ‘A’ is the volume of the sample tested and ‘B’ is the volume of pure water (which is totally free from any taste and odor) used for dilution.

Thus, if a 100-mL sample is diluted with 100 mL of odor free water and odor is just detectable in the resultant sample, the Threshold Odor Number (TON) is 2. Ideally the drinking water should have a TON value of 1 (no dilution required and B has a value of zero!)

In practice however, a specific TON may have to be fixed with a certain statistical spread. In a country like Pakistan, it may be difficult to go through this exercise and the subjective parameter of consumer satisfaction may have to be relied upon.

Thus if the drinking water is generally acceptable to the community being served, with other parameters meeting the standards, it should be considered to be acceptable.
TURBIDITY:

WHO STANDARD:
Ideally median turbidity should be below 5 Nephlometric Turbidity Units (NTU).

PAKISTAN STANDARD: Below 5 NTU.

Turbidity (muddy aspect) in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton and other microscopic organisms. The particles that cause turbidity in water range in size from colloidal dimensions (approximately 10 nm) to diameters of the order of 0.1 mm.

Originally, turbidity was measured in terms of a Jackson turbidity unit (JTU). In this case the height of the turbid water column, sufficient to make invisible a standard candle flame, when observed vertically, gave a measure of the turbidity of the water sample; obviously, the longer the column the lower the turbidity and vice versa.

A column of 21.5 cm was assigned a value of 100 JTU. The Jackson candle turbid meter measuring turbidity is applicable only to turbidity values greater than 25 JTU and, as such, has limited applicability to the monitoring of drinking water.

The current method of choice for turbidity measurement, the world over, is the Nephelometric method. In this method the intensity of light scattered at 90° to the path of the incident light is measured.

Suspensions of formalin polymer have generally been adopted as the primary turbidity reference standard. Commercially prepared suspensions of polymeric beads are also available for this purpose.

A suspension of formalin formed by the reaction of hydrazine sulphate (50 mg/L) with hexamethylenetetramine (500 mg/L) has a defined turbidity of 40 NTU. Standard Nephelometers are able to respond to changes of about 0.02 NTU at turbidity values below 1 NTU and the practical lower limit of the standard nephelometric method, therefore, is about 0.1 NTU.

Levels of turbidity in raw water can range from less than 1 to over 1000 NTU and control of turbidity in public drinking water supplies is important for both health and aesthetic reasons.

Excessive turbidity makes the treated water not pleasing to look at. It can also interfere with disinfection processes and the maintenance of chlorine residual.

In fact chlorination of water containing turbidity, due to organic matter, can produce carcinogenic Trihalomethanes.
The removal of turbidity is achieved by filtration and, by a combination of coagulation, sedimentation and filtration.

Filtration is carried out through sand beds or other single-, dual- or mixed-media granular filters. This treatment process is capable of producing water with a turbidity of 1 NTU or less.

Following filtration, turbidity in a water treatment plant may be affected by a number of mechanisms, such as post-flocculation of coagulants, oxidation of dissolved metals, bacterial and other growths, resuspension of deposited materials or pipe corrosion etc.

Because of the ease of analysis and relative inexpensiveness of the equipment, it is a very useful tool to assess the drinking water quality, in general and of monitoring the treatment processes and the public water delivery systems, in particular the relationship between high turbidity, in both raw and filtered water, and taste and odor is well known.

As shall be seen later, algal growths, actinomycetes and their breakdown products contribute to taste and odor problems. A positive correlation between serious epidemics of infectious diseases and increased turbidity has been recorded.

Particulate materials in water are usually not in themselves potential hazards, but they may have indirect effects. The concentrations of heavy metal ions and biocides are usually much higher in suspended solids than in water.

The adsorption capacity of suspended particulates can lead to the entrapment of undesirable compounds and pesticides like DDT, and Herbicides such as 2; 4-D, parquet and diquat have shown twenty fold increase in solubility in waters with raised turbidity values.

When such contaminated particles enter the stomach, through drinking water, the release of the pollutants could occur, with possible deleterious effects. Similarly, the presence of turbidity can have significant effects on both the microbiological quality of drinking water and the detection of bacteria and viruses in the water.

Microbial growth in water is most extensive on the surfaces of naturally occurring particles and inside flock formed during coagulation. For many countries the value of 5 NTU has been set as the allowable limit for drinking water at the point of consumption.

In Pakistan, health issues related to infected water are of critical importance and the turbidity being an easily measurable parameter, even down to 0.1 NTU, should be used as a strong indicator for screening of the potable water.

In fact this committee feels that, in absence of any other information, the turbidity value in combination with a negative faecal coliform result could serve as the deciding factor for declaring water fit for drinking or not. In view of this it is proposed, that a value of 1 NTU may be adopted as the drinking water standard for Pakistan.
pH OF DRINKING WATER

WHO STANDARDS: Most raw waters lie in the pH range of 6.5 to 8.5.

PAKISTAN STANDARD: pH range from 6.5 to 8.5.

No health based guideline value is proposed for pH, but it is one of the most important operational water quality parameters.

The pH of a solution is the negative logarithm of the molar hydrogen ion concentration which indicates its acidic character. pH = -log [H+].

It is a measure of acid-base equilibrium in natural water. An increased concentration of carbon dioxide will lower the pH and vice versa. Careful attention to pH control is necessary at all stages of water treatment and distribution system to ensure satisfactory water clarification and disinfection and also to minimize the corrosion of water mains and pipes in household water systems.

If this is not done, contamination of the drinking water may result manifesting itself in the form of taste, odor and appearance changes.

At pH less than 7, for example, corrosion of water pipes may be accelerated releasing metals into the water; this may be a cause of concern if the concentration of such metals exceeds the permissible limits. The direct effects of exposure of humans and animals to extreme pH values (below 4 or above 10) for extended periods of time may result in irritation to the eye, skin and mucous membranes. In sensitive individuals gastrointestinal irritation may also occur, however, occasional pH changes may not have any direct impact on water consumers.

CHEMICAL PARAMETERS

Aluminum (Al):
Aluminum is the most abundant metallic element and constitutes about 8% of the Earth’s crust. Aluminum is iatrogenically introduced in drinking water through the treatment process.

The high concentration has been linked to the development of Alzheimer Disease. However the population-attributable risk could not be calculated, but it is imperative to be on the safe side. Following good standard operating procedures, concentrations of aluminum of 0.1mg/l or less are achievable in large water treatment facilities.

Problem may arise among the small facilities (serving less than 10,000 people), in attaining the desired level due to the small size of the plant that could provide little buffering for fluctuation in operation.

Other limitations rest in the availability of resources and capacity to tackle with the specific operational problems. For such small facilities, 0.2 mg/l or less is a practicable level for
aluminum for the deliverable water. Same is applicable for adaptation for Pakistan i.e. less than 0.2 mg/l.

**Antimony (Sb):**
The daily oral uptake of antimony appears to be significantly higher than exposure by other route. The common source of antimony in Drinking Water appears to be dissolution from metal plumbing and fittings. It appears that antimony leached from antimony containing materials would be in the form of the antimony (V) oxo-anion, which is less toxic form.

Antimony trioxide is genotoxic due to its low bioavailability. Potassium antimony tartrate is most soluble form of antimony. The chronic exposure to it may not be associated with an additional carcinogenic risk.

For Pakistan, in order to cautiously contribute towards reducing the burden of chronic diseases, a provisional value of less than or equal to 0.005 mg/l is set as standard.

**Arsenic (As):**
Arsenic is a metal-like substance found in small amounts in nature. Drinking water containing high levels of arsenic may cause health problems.

There are two main ways arsenic can get into the drinking water. Mineral deposits in some areas naturally contain high levels of arsenic.

Groundwater flowing through these deposits can dissolve arsenic from the minerals. This can increase the amount of arsenic in the well water.

Arsenic has no smell or taste, so it is not possible to tell that the drinking water contains arsenic or not unless it is tested in the lab.

Adverse health effects of arsenic depend on the type and amount of arsenic that has entered the body, the length of exposure time and the response of the exposed body. Unborn babies, young children, people with long-term illnesses and elderly people are at greatest risk due to arsenic exposure.

Studies in other countries have shown that drinking water containing elevated levels of arsenic can cause the thickening and discoloration of the skin. Sometimes these changes can lead to skin cancer, which may be curable if discovered early.

Numbness in the hands and feet and digestive problems such as stomach pain, nausea, vomiting, and diarrhea can also occur due to the elevated levels of arsenic.

Some recent investigations in the Punjab and Sindh provinces show elevated concentrations of arsenic in drinking water. Keeping this in view the value for the standard for Pakistan has been set at less than or equal to 0.05 mg/l.
Barium (Ba):
Barium is normally found as a trace element both in igneous and Sedimentary rocks. It is also used in various Industrial applications.
Food is considered to be the primary source of intake for the non-occupationally exposed population. There is no evidence that barium is carcinogenic or mutagenic but the toxicological end-point of greatest concern to humans appears to be its potential to cause hypertension.

Its value has been proposed to be 0.7 mg/l for Pakistan in confirmation with WHO guidelines.

Boron (B):
Boron in surface water is frequently a consequence of the discharge of treated sewerage effluent.
It is also naturally found in the edible plants and general population obtains it through the food intake.
Conventional treatment processes do not take Boron out and the special procedures should be adopted to remove Boron from the drinking water.
The methods such as ion exchange and reverse osmosis may enable the substantial reduction. These processes are expensive too. Blending with low-boron supplies may be the only economical method to reduce boron concentration in waters where these concentrations are very high.
The value for Boron for Pakistan is 0.3mg/l in confirmation with WHO guidelines.

Cadmium (Cd):
Now-a-days Cadmium compounds are widely used in the batteries. There is a vast use of Cadmium in the Steel and Plastic Industry.

It is released to the environment through the wastewater and diffuse pollution is caused by contamination from fertilizers.

The drinking water may get contaminated by impurities in the zinc of galvanized pipes and solders and some metal fittings.
Food is daily source of exposure to Cadmium. Smoking is a significant additional source of cadmium exposure.

Cadmium accumulates primarily in the kidneys and has a long biological half-life of 10-35 years, in humans. For Pakistan a value of 0.01 would be appropriate, which is in accordance with the standards for most developing nations in Asia.

Chloride (Cl):
Chloride in drinking water comes from Natural Sources, Sewerage and Industrial Effluents, urban runoff containing de-icing salt and saline intrusion.
The main source for humans comes from the edible salt. The high dose of chloride may result in detectable taste at 250mg/l but no health-based guideline value is proposed. However, less that 250 mg/l would suffice as a Pakistani standard for Chloride.
**Chromium (Cr):**
The toxicological database for chromium carries uncertainties. Total chromium concentrations in drinking water are usually less than 2μg/liter, although the concentration as high as 120μg/litre has been reported.

In some epidemiological studies, an association has been found between exposure to chromium (VI) by the inhalation route and lung cancer. The cautious guideline for chromium has been proposed that is 0.05 mg/l in drinking water.

**Copper (Cu):**
Copper concentrations in the drinking water vary widely. Along with the manufacturing of the Commercial Appliances, it is also used as the copper sulphate pentahydrate for the control of algae.

Copper concentration in the treated water often increases during distribution, particularly in the systems where an acidic pH exists or in the presence of high-carbonate waters with an alkaline pH. The guidelines are derived on the basis to be protective against the gastrointestinal effects of copper.

**Cyanide (CN):**
The cyanide is occasionally found in the drinking water, especially among the developing countries.

Cyanide has acute toxic effects. Undesired effects on thyroid gland and the nervous system were observed in some populations as a consequence of the long-term consumption of inadequately processed cassava containing high levels of cyanide.

Pakistan needs to have a closer watch over the values of Cyanide levels in the drinking water being served to the masses on account of its acute toxicity, as also true for the microbiological contamination.

In this proviso, a value of less than or equal to 0.05 is set as standards for Cyanide in drinking water for Pakistan keeping in view what other Asian countries are also following and on expert inputs.

**Fluoride (F):**
Fluoride is present in the Earth’s crust and forms a part of number of minerals. The exposure of the human population depends upon the geographical location of the inhabitants.

Daily consumption is from food mainly, and less from the drinking water and toothpastes. In some northern areas of Pakistan it is found high amounts in the run off water that is consumed by the people living over there and has led to the discoloration of the teeth (dental fluorosis).

Epidemiological evidence shows that fluoride primarily affects the skeletal tissue. A few recent incidences of fluoride in drinking water resulting into skeletal deformation (e.g. among in children in Lahore, Manga Mandi), pose strict monitoring of fluoride in drinking water and value for Pakistan has been tightened than the WHO’s one i.e. less than or equal to 1.5 mg/l.
Iodine:
Iodine, as iodide, occurs normally in water. Iodine is also used for the water treatment in the emergency situations. Iodine is an essential element in the synthesis of thyroid hormone. Lack of Iodine in drinking water and food, leads to the thyroid diseases.

However, some recent studies from China also suggest that an excess of iodine in drinking water may also lead to thyroid diseases.

Lead:
Lead is used in lead-acid batteries, solders and alloys. The organ lead compounds tetraethyl and tetramethyl lead have also been used as anti knock and lubricating agents in petrol. This use is now in a decline and the exposure from the air is declining but source from drinking water constitutes the major proportion.

Lead is a general toxicant and accumulates in the skeleton. The placental (vertical) transmission in humans occurs as early as 12th week of gestation.

Young children absorb 4-5 times as compared to the adults. Lead is toxic to both central and peripheral nervous systems. The cross sectional epidemiological studies have shown that there is statistically significant associations between blood lead levels of 30μg/dl and more and intelligence quotient deficits of about four points in children.

Results from prospective (longitudinal) epidemiological studies suggest that prenatal exposure to lead may have early effects on mental development that do not persist to the age of 4 years. This has been supported through the research on primates that the significant behavioral and cognitive effects were observed following postnatal exposure resulting in blood lead levels ranging from 11 to 33μg/dl.

Most of the lead in drinking water arises from the plumbing systems in the buildings. The measures to control the corrosion may reduce the amount of lead in drinking water.

Considering drastic effects of Lead, for Pakistan the value has been set at less than or equal to 0.05 mg/l. This also is in agreement with values followed by most of the Asian developing countries.

Manganese:
Manganese is naturally occurring, one of the most abundant metals in the Earth’s crust. Usually it occurs along with Iron. It levels in fresh water ranges from 1 to 200μg/litre. Higher levels in aerobic waters are usually associated with industrial pollution. Manganese is an essential trace element too. 20% of TDI allocation to the drinking water is required usually for an adult of weight of 60 kg which consumes 2 liters/day of drinking water. The high amounts may also result in the discoloration of drinking water and become objectionable for the consumer.

The value for Pakistan is proposed to be less than or equal to the WHO’s one.
**Mercury:**
Mercury is used in electrolyte production of chlorine and also used in gold mining. It is used in the thermometers and their spill can cause exposure to mercury.

Mercury in uncontaminated drinking water is thought to be in the form of $\text{Hg}_2^+$. Food is main source of mercury in non-occupationally exposed population.

The mean dietary intake of mercury in various countries ranges from 2 to 20μg/day per person. The value for Pakistan is proposed to be less than or equal to the WHO’s one.

**Nickel:**
A metal usually used for making alloys and producing stainless steel. Normally water is minor contributor to the total daily oral intake but if there is heavy pollution or use of certain types of kettles, of non-resistant materials in wells or of water that has come in contact with nickel- or chromium-plated taps, the nickel contribution from water may become significant to the total daily oral intake.

There is lack of data and evidence that the oral intake of Nickel might lead to cancer. However, the inhalation may lead to risk of developing cancers among humans.

**Nitrate and Nitrite:**
Nitrate is mainly used in inorganic fertilizers and nitrite is used in food preservatives. The nitrate concentrations normally remain low in ground and surface water but can reach to high limits as a result of run off or leaching from the agricultural land.

The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinemia, also known as “blue - baby syndrome”.

The nitrate is reduced to nitrite in the stomach of the baby and it oxidizes the hemoglobin (Hb) to methaemoglobin (metHb) that is unable to transport oxygen within the body.

The methaemoglobinemia causes cyanosis and ultimately leads to asphyxia, if left untreated. The normal metHb levels in infants less than 3 months of age are less than 3%.

The consequences manifest themselves when the concentrations reach 10% or more. Nitrate and nitrite in drinking water is the main source and also where there is relatively high intake in relation to body weight.

**Selenium:**
Selenium, like magnesium, is an essential trace element. Foods like cereals, meat and fish are principal source of selenium.

The recommended daily intake for humans is 1μg/kg of body weight for adults. Selenium compounds have been shown to be genotoxic in *vitro* systems with metabolic activation, but not in humans.
However, in humans, the toxic effects of long-term selenium exposure are manifested in nails, hair and liver. Different studies have given data on such effects with daily intakes ranging from 0.24 mg/day to 0.7mg/day.

**Total Dissolved Solids (TDS):**
The inorganic salts (Magnesium, Calcium, Potassium, Sodium, Bi-Carbonates, Chlorides and Sulphate) and small amounts of organic matter comprise TDS.
Concentrations of TDS in water vary too much extent due to the variability in the geographical locations. There is no reliable data available on the health effects of the TDS in drinking water.

**Zinc:**
Zinc, like magnesium and selenium, is also an essential trace element. It is found in all foods and potable water.
The levels of zinc in surface and ground water normally do not exceed 0.01mg/liter and 0.05mg/liter, respectively.

Concentration in tap water may increase due to dissolution from the pipes. The daily requirement for an adult man is 15-20mg/day.

A value 5 mg/l may be appropriate for Pakistan although up to 3 mg/l is usually acceptable for consumption for consumers. This value takes into account what is being followed at the regional level i.e. most Asian countries.

A number of metallic and ionic species existing in water, beyond keratin limits can be the cause of serious health issues. For any water to qualify as potable, these constituents must be below the specified limits. Metals in water are determined with the standard atomic spectroscopy (atomic absorption, flame emission, plasma emission) techniques.

**RADIOACTIVE MATERIALS:**
Radio nuclides are radioactive atoms that disintegrate to smaller atomic mass atoms, releasing energy in the process. The energy is primarily released in one of the three forms:

1. **Alpha particles** consisting of the Helium Nuclei with two protons and two neutrons and thus bearing a charge of +2
2. **Beta radiation**, consisting of electrons hence carrying a charge of -1
3. **Gamma radiation** which has a true electromagnetic character and hence travel with the speed of light (electromagnetic radiation).

Due to the difference in their constitution, the three types of radiation have different health effects on humans.

Alpha particle travel at moderate speed but due to their size and charge, if ingested, could be very damaging.
Beta particles which travel very fast, near to the speed of light but their smaller size make them less damaging.
Gamma radiation has tremendous penetrating power but is less lethal at lower doses normally to be encountered in drinking water.

Radioactivity in water can be natural or man-made. Naturally occurring radioactivity comes from elements in the earth’s crust or from cosmic ray bombardment in the atmosphere and is not of critical importance in most instances. Radio nuclides whose origin can be linked with human activity may be generated from sources such as mining of ores, nuclear fuel processing, power stations, and radio pharmaceuticals, etc. Evidence exists from experiments on human beings and animals that radiation exposure at low to doses may increase the long-term incidence of cancer. Animal studies give definite clue that the rate of genetic abnormalities increase with radiation exposure and acute health effects of radiation include reduced blood cell counts.

The ‘Bq’ is the standard international unit for radioactivity. The limits for drinking water are indicated both as bq or pCi (10⁻¹² Ci).

A gross alpha test is the first step in determining the level of radioactivity in drinking water. This test serves as a preliminary screening device and determines whether additional testing is required. In order to extend the safety margin it is advisable to take the gross beta measurements as well. Consequently, both standards are frequently quoted in the literature for many drinking water standards.

It is important to fix the upper limit for these parameters as 0.1 Bq/L and 1.0 pCi/L respectively for Alpha and Beta emitters.

**POLYNUCLEAR AROMATIC HYDROCARBONS (PAH’S):**

Poly-Nuclear Aromatic Hydrocarbons (PAH’s) are a class of organic compounds containing two or more fused aromatic rings of Carbon and Hydrogen atoms of which benzo[a]pyrene (BaP) is an important representative. Studies involving inhalation and skin exposure have generated clear evidence that mixtures of PAHs are carcinogenic to humans.

Most PAHs enter the environment via the atmosphere from a variety of combustion processes. Owing to their low solubility in water and high affinity for particulate matter, they are not usually found dissolved in water in significant concentrations.

PAH levels in uncontaminated groundwater are usually in the range of 0 – 5 ng /liter. In highly turbid waters however, the solubility may increase many fold due to absorption.

On the particulate matter concentrations in contaminated ground water may exceed 10 mg/liter.
The main source of PAH contamination in drinking-water is usually the coal-tar coating of drinking-water distribution pipes that are used to protect the pipes from corrosion.

The presence of significant concentrations of BaP in drinking-water in the absence of very high concentrations of fluoranthene indicates the presence of coal-tar particles, which may arise from seriously deteriorating coal-tar pipe linings.

Typical concentration range for sum of selected PAHs in drinking-water is from about 1 ng/liter to 11 mg/liter.

Although the contribution of PAHs from drinking water may be insignificant as compared to inhalation and food ingestion in order to underscore the importance of keeping our water as pure as possible it is necessary that a very stringent limit may be imposed.

The detection limit of the compounds by the standard by GC/MS technique is 0.01 mg/liter which may form a very good base for defining the maximum permissible limits in drinking water. It is recommended therefore that the concentration of PAHs in drinking water may NOT exceed the detection limit of GC/MS.

**PESTICIDES, HERBICIDES, FUNGICIDES, ETC:**
The number of these chemicals in use in Pakistan is so large, and every day new chemicals are continuously added so that it is difficult, in fact impossible, to identify specific limits for each single one of these.

It is recommended therefore that wherever the presence of any particular compound is thought to exist, the water should be analyzed, specifically for it and, declared fit for drinking only if the concentration is found to be below the detection limit of the analytical technique under the standard method for each.

**Strategy to Implement the Solar Water Disinfection Methodology**

As per the initiative of the Swiss Federal Institute of Aquatic Science and Technology (SODIS) technique has been implemented in low income group of Countries. SODIS is a method of disinfecting water using only sunlight and plastic PET bottles. WHO recommended for household water treatment and safe storage.

- No access to good quality drinking water leads to a high risk of water-borne diseases eg. Diarrhea, Cholera, Typhoid, Fever, Hepatitis A, Amoebic and Bacillary Dysentery and other Diarrheal diseases.
- Each year 1.5 million people die in Pakistan from diarrheal related diseases mostly children
• Exposure into sunlight has been shown to deactivate diarrhea-causing organism in pullulated under the age 5 in developing countries like Pakistan. It is equivalent to child dying in every 15 second or 20 Jumbo Jets crashing every day.
• The death represents approximately 15% of all children death under the age of 5 in developing countries.
• Frequent Diarrhea is a cause for children’s malnutrition, while again increases the likelihood for children to die from infectious diseases such as Diarrhea or an acute respiratory illness.
• UV-A interferes directly with the metabolism and destroy cell structure of bacteria.
• UV-A (wavelength 320-400m) reacts with oxygen dissolved in the water and produces highly reactive form of oxygen (oxygen free radicals and hydrogen peroxides) that are believed to damage pathogens i.e. viruses, bacteria and parasites etc.
• Infrared radiation heats the water. If the water temperature rises above 50 C, the disinfection process is 3 time faster.
• At a water temperature of about 30 C (86 F) a threshold solar radiation intensity of at least 350nm - 400nm or 500w/m2; corresponding to about 6 hours of mid-latitude midday summer sunshine.
• Colorless, transparent PET water bottles (1.5 liters) with few surface scratches are chosen for use.
• Water from contaminated sources are filled into the bottles. To improve oxygen situation, bottles can be filled 3 quarter, shaken for 20 seconds (with the cap on) then filled completely and recapped.
• Filled bottles are then exposed to the sun placed on CGI sheet on slop for good results.
• The simple act of washing hands with soap and water can reduce diarrheal disease transmission by 30%.
• SODIS’s efficiency to kill protozoa is dependent on the water temperature reached during solar exposure.

SODIS is a Water Treatment Technology; depends on the following factors:

- Improve the microbiological quality of drinking water.
- Does not change the taste of water.
- Is applicable at household level.
- Is simple in application.
- Relies of local resources and renewable energy.
- Is replicable with low investment costs.
- It eliminate the bacteria vibrio cholera, shigella, salmonella and different pathogenic strains of E. Coli are the most important water borne pathogens.
- Gastro intestinal diseases caused by the bacteria can be serious and treatment is required.
- Dehydration as a result of profus diarrhea which is frequent in under 5 year old children.
- An infection with protozoa may cause chronic digestion problem which leads to malnutrition.
- Public health intervention addressing water quality issues and hygiene education are requirement when viral infection occurs on a large scale.
**Water Turbidity:**

- Suspended particles in the water reduce the penetration of solar radiation into water and protect microorganism from being irradiated.
- SODIS requires relatively clear raw water with a turbidity of less than 30 NTU. (Nephelometric Turbidity Unit)

**Advantage of PET:**

- Low weight and Low costs
- Relatively unbreakable
- Transparent
- Neutral in taste
- PET burns more easily than PVC.
- If PVC is burnt, the smell of the smoke is pungent, while the smell of the PET is sweet.
- Chemically stable etc

**Shape of Containers:**

- UV radiation is reduced at increasing water depth. At a water depth of 10cm and a moderate turbidity of 26 NTU, UV-A radiation is reduced to 50%.
- PET bottles don’t exceed a depth of 10cm when horizontally being exposed to the sun.
- PET bottles are easily available at low cost.
- Field tests confirmed the results from lab in which a 3 log reduction of faecal coliform is achieved. This means that under normal conditions, SODIS shows an efficiency of about 99.9%.

**Training:**

- 2 week training program shall be executed on participatory approach, such as participatory community appraisal would be launched in the training curriculum.
- Modus operandi of training is as:
  - Lectures
  - Working in groups
  - Role playing
  - Practical exercise

**Training Material:**

- Flipchart posters
- Explanatory Technical sheet
- Video on solar disinfection
- Practical demonstration
The Role of Hygiene Education in Society:

- Good health depends not only on access to clean drinking water, but also on the right hygiene behaviour of the society.
- Consuming water of pure quality helps to reduce the number of diarrheal illness, field studies revealed that:
  1. An improvement of the drinking water quality ought to be the 1st intervention and it reduces the diarrheal morbidity by 20% in the society.
  2. By washing hands with soaps could reduce the occurrence of diarrheal disease up to 30%.
  3. The safe disposal of excreta also accounted for approximately 305 reduction.
  4. Further improvements can be achieved by other practice of household hygiene, such as washing vegetable, fruits and dishes with clean water, safe disposal of household waste etc.
  5. The hygiene education / training should cover the following topics:
     - General household and community hygiene
     - Water supply hygiene
     - Latrin use, hygiene and maintenance
     - Hygienic disposal of other waste.
     - Use and maintenance of facilities etc