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HYGIENE

OF

WATER AND WATER SUPPLIES.

BY

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To the

MEMORY

of the late

Dy. Surg.-Genl. D. B. SMITH, M.D., F.R.C.P., Lond.,

Professor of Military Medicine,

Army Medical School, Netley,

BY HIS GRATEFUL PUPIL,

THE AUTHOR.

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PREFACE.

IN a country in which WATER forms almost the universal beverage, it would appear necessary that every inhabitant should be acquainted with the dangers associated with the consumption of it in an impure state, and with the means of rendering its supply as free as possible from impurities. They should also be familiar with the various means by which water-supplies are contaminated, and with the manner in which these polluting processes may be obviated, remedied, or, at least, abated. With the object of furnishing some general information on these points, the following pages have been written; and one is vain enough to think that a careful perusal of what is herein communicated may not be unprofitable to district officers, inspecting officers, *zamindars* and others.

I have to express my indebtedness to many authorities on hygiene, especially to Professors Parkes and De Chainmount, Drs. P. Frankland, G. Wilson, F. R. S. E., Newsholme, Willoughby,

Attfield, King, McNally, Surgeons-General J. M. Cunningham and Furnell; and to many engineering authorities, especially to Professor Rankine, Eassie, Rogers Field, Baldwin Latham, Captain Strahan, R.E., and Sir Robert Rawlinson, K.C.B.

I take this opportunity of thanking my friend Mr. E. A. Seaton, B.A. (Oxon.), for his kindness in looking over the "proof" sheets, and correcting their many literary errors.

P. H.

HYDERABAD, DECCAN,
1st *July*, 1890.

THE HYGIENE

OF

WATER AND WATER SUPPLIES.

INTRODUCTION.

THE absolute necessity of an abundant supply of pure water to populous towns is a matter that has been recognised almost as far back as history extends. This statement is borne out by what we know of the large storage reservoirs and aqueducts of the Greeks and Romans—works which were of excellent construction, and served the purpose of water-supply to towns in an admirable manner. Many of the water works of the people of ancient times have left their traces. Alexandria, Carthage, Herculaneum, Nineveh, Rome, Jerusalem, and many other cities had a complete system of water works. Timocrates, writing of Jerusalem B.C. 340, tells us that "the whole city was artificially flooded with water, so that even the gardens were irrigated by the overflowing waters of the city." The importance of prohibiting the defilement of drinking water was fully apprehended by the ancient Hindoo writers. Such a profound philosopher as Menu could not leave unnoticed a matter of such vital significance as that of water supplies to communities.*

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* *Vide* section on "*Laws against Pollution of Water.*"

Works of water-supply have an ancient history in India. We have only to look at some of the magnificent old tanks that surround many of the larger towns to recognise, that the question of a sufficient supply of wholesome water formerly received no small share of attention. The *devotees* of past times constructed tanks, discovered springs, and made wells for the use of the people. Many of the large tanks seen scattered throughout India, although mainly used for purposes of irrigation, still form part of the water-supply to the people either directly or indirectly. In the Deccan there are to be seen the ruins of many excellent water works that were constructed during and after the Mahomedan conquest. As the Mahomedan conquered a place, he converted it into a town, and wherever possible, instituted some form of public water-supply. In and around the City of Hyderabad may be seen the disintegrating ruins of water works of an extensive nature—*bunds* with tunnels, aqueducts and open conduits, and large reservoirs exist in several places, indicating that the water-supply in days gone by received considerably more attention than it has in more recent times. The high store placed on water has been handed down to some classes of the people of India, who revere, and even worship, certain rivers, springs and wells. Pilgrimages are regularly made by certain sects of Hindoos to various rivers, *e.g.* the Ganges at Hardwar and Gangootri, and at its junction with the Jumna at Allahabad. To such waters as these have been attributed supernatural virtues. Yet we shall see that even such sacred rivers are in no way exempt from wholesale defilement.

No person will doubt that civilisation has advanced since the time that the large tanks above alluded to were constructed, yet in this particular of water-supply, there appears to have been a retrogression on the part of the last few generations.

Although from ancient times to the present date the water-supply to large communities has engaged so much attention, at no previous period of history was such importance attached to it or such interest manifested in it as in our own times. This is partly due to practical experience, but particularly to the scientific investigations of those who have devoted much time and skill to the elucidation of the ultimate causation of disease.

Daily increasing evidence shows the intimate relation between impure water and disease. The rapid strides made in that branch of sanitary science that has for its object the investigation of disease-causes, place us in a position to state that the nature and quality of the water used by a community is a matter of vital significance. There is no factor that plays such an overwhelming part in the preservation of the public health as that of water-supply. Instinct taught this to the ancients, but prolonged and sad experience, together with developed science, have demonstrated it to us. It is really no exaggeration to affirm, that the unrestricted supply of water in a pure state is the first essential of decency, of comfort, and of public health. Without such a supply the poorer classes are bound to remain in a low stage of civilisation. Any great limitation to its use in towns, cities, and municipalities must keep the mass of the people in a condition of the most unwholesome filth and degradation. To the people of India the quality of their water-supply is perhaps more important than it is to any nation in existence, for they are the greatest water-drinkers known. It may in fact be considered their universal beverage. No greater improvement to a locality can be made than that of supplying each household, and each inhabitant, with wholesome water. Every occupied house of a town, municipality, or village should have, within a convenient distance, an available supply of wholesome water, sufficient for consumption and for domestic purposes. Such limitation of its use as we see in the bustees of Indian towns is necessarily associated with a condition of material and unwholesome filth.

With regard to the necessity of an abundance of pure wholesome water, Sir John Simon remarks :—*

"The doctrine in general terms, that a vast influence is exercised over the health of communities by the quality of the water-supply which they consume, is one which, as far back in literature as any reference to such questions could be expected to exist, may be seen to have universal medical consent in its favour, and during long ages of history the common instincts of mankind were even surer and stronger than undeveloped science. Of the many invaluable additions and improvements which medical knowledge has received during the last quarter of a century, scarcely any can, in my opinion, be compared for practical importance to the discoveries which have given scientific exactitudes to parts of the above stated general doctrine, and have enabled

* HEALTH REPORTS, edited by E. Seaton, M.D.

us definitely to connect the epidemic spread of bowel infections in this country (England) with the existence of certain faults of water-supply. Not only is it now certain that the faulty public water-supply of a town may be the essential cause of the most terrible epidemic outbreaks of cholera, typhoid fever, dysentery and other allied disorders, but even doubts are widely entertained whether these diseases or some of them can possibly attain general prevalence in a town, except where the faulty water-supply develops them. "

Water is one of the prime necessities of life. Deprived of it for some days, the functions of the living economy come to an end. This holds good with all animal and almost all vegetable life. The importance of water as a necessary condition for the existence of animals and plants cannot be exaggerated. This is at once apparent when we consider that protoplasm, "the physical basis of life," has water as one of its primary constituents. A few of the lowest *fungi*, especially the germs of some diseases, such as small-pox and anthrax, retain in the dessicated state a latent vitality, but in their dried condition, the power of multiplication is removed. They cannot be resuscitated in the absence of some form of moisture. We may state that all living organisms carry out their functions in water, and are constantly bathed in watery fluids.

At the present day the absence of a good supply of wholesome water forms one of the worst features in the sanitary arrangements of almost all towns and villages in India. Bad as the water-supply is, it is rendered worse by the habits of the people.

Words would fail to adequately represent the immeasurable importance of the *rôle* of water-supply in the public health. We shall, in the following pages, produce enough evidence to uphold the dictum—that wherever a permanently unfailing source of pure water can be assured to a community, nothing should interfere with such a source being utilised. The single fact that the mortality of many of the inland towns in India ranges from 40 to 60 per thousand of population per annum, instead of being about 20, is sufficient reason for all Municipalities undertaking to provide the people with abundance of wholesome water. "It must be obvious to every moderately educated and reflecting person, that a general mortality of 53 per cent. and an infant mortality of 33·3 per cent. together with the establishment of cholera as an endemic scourge, are facts which justify extensive and costly remedial measures on the part of responsible authorities." With regard to water-supply in England, we find that the shallow and deep wells of by-gone periods, which ran parallel with cesspits and in close proximity to midden heaps, have been replaced by public water works in all large towns with the most salutary results. This example has been followed in a few towns and cities in India, and is not unworthy of general imitation.

The sanitary aspect of the question of water supplies is an extensive subject, but we shall confine our remarks to the most salient points in connection with it. We have in the following pages endeavoured to enumerate the chief sources of pollution of ordinary water supplies in India. We know them to be many, and dread to attempt to represent statistically the actual annual mortality created throughout this vast Empire by impure water. It is high time that some organised method should be adopted to prevent this wholesale contamination. The existing laws in this respect are sufficiently definite, and their observance should be universally enforced.

COMPOSITION OF WATER.

Water by the ancients was thought to be an element, that is, a body which could not be split up into a simpler form. Some Greek writers went so far as to state that water was the beginning of all things. In so far as animal and vegetable life is concerned, in the light of their knowledge, the ancient writers were not altogether so far wrong as some modern critics and satirists would have us suppose. By advancing chemical science, however, the immature ideas of Grecian philosophers were subverted. In 1781, Cavendish and James Watt simultaneously and independently demonstrated that water was a compound of hydrogen and oxygen. But this, like all important scientific discoveries, was the culminating point of a number of revelations. Priestly had discovered oxygen and the combustible gas hydrogen, while Lanoisier, the founder of modern chemistry, showed that oxygen was capable of forming compounds with other bodies.

We are now able to show, both by synthesis and analysis, that absolutely pure water is a true union and condensation of two gases, oxygen and hydrogen, in the proportion by volume of two of the latter and one of the former, and by weight, eight of oxygen and one of hydrogen. Its weight in the gaseous state relative to hydrogen is 9, and its chemical formula H_2O.

IMPURITIES OF WATER.

The term "pure" as applied to water is used in two distinct senses,—one in which the water is *chemically* pure, and in which it contains nothing but water; the other in which it is *hygienically* pure, and in which, although certain foreign constituents are dissolved or contained in the water, they are not in sufficient quantities to produce any deleterious effect on the human economy. The extraneous constituents of a hygienically pure water are not only harmless, but are actually beneficial. A chemically pure water is not desirable as a beverage.

Chemically pure water is unknown in nature, and can only with difficulty be prepared in the chemist's laboratory. Distilled water is rarely free from foreign constituents.

Gases in Water.—Water is an active absorbent of many gases, and from this property both innocuous and injurious gases may gain access to it.

Rain water, and all other natural waters, are more or less charged with the gases of the air. These are chiefly oxygen, nitrogen, and carbonic acid gas. Twenty-five gallons of water will contain about five pints of these gases. In ordinary air the proportion of *oxygen* to nitrogen is about 1 to 4; but as oxygen is more soluble than nitrogen in water, water contains more of it. The carbonic acid gas of the air is also dissolved in rain water, but in comparatively small amounts. Twenty-five gallons of tank water seldom contain more than a quarter or half a pint of dissolved *carbonic acid gas.* This gas is very soluble in water, but as only four parts of it are contained in 10,000 parts of air, rain water contains but a small amount of it. Ordinary river and well waters contain considerable quantities of carbonic acid gas. This is accounted for by the fact that in the decomposition and oxidation of the organic matter which gains access to rivers and wells, carbonic acid is generated and dissolved. Water falling on the ground, finds its way to the animal and vegetable matter in the soil. The oxygen already dissolved in the water, oxidises the organic matter, and carbonic acid is given off in the process of decomposition. The water, deprived of its oxygen, absorbs a fresh supply from the air, and the formation of additional quantities of carbonic acid gas is repeated; so that the water becomes more and more saturated with it. Such is the main source of carbonic acid of water.

It is the existence of this carbonic acid gas that gives good water the pleasant briskness, freshness and sharpness to the palate.

There is yet another source of carbonic gas in water that traverses the soil, *viz.*, the air of the soil itself. The air in the surface soil contains a considerable amount of carbonic acid gas (about 200 times as much as ordinary air, the proportion increasing as the depth increases). This carbonic acid gas has likewise been formed by organic decomposition. The water in its passage through the soil carries much of this carbonic acid with it, and this carbonic acid dissolves out any minerals met with that are soluble in a carbonic acid water. Chalk is thus dissolved, and oxide of lime and soda are converted into carbonates.

The presence of *sulphuretted hydrogen* is usually indicative of considerable deterioration of water. This gas is known by its odour. It is frequently found in superficial wells and in drying up tanks. It is formed in these by the deoxidation of sulphates of metals, and this deoxidation is effected by plants undergoing decay. The oxygen of the basic sulphates combines with the carbon of the organic matter to form carbonic acid, and the sulphate combines with hydrogen to form sulphuretted hydrogen.

Minerals Matter in Water.—The *calcareous and magnesian salts* are the most frequent mineral matters met with, and of these the sulphates and carbonates are the chief to be dealt with.

Chalk (or carbonate of lime) is only soluble to the extent of two or three grains to the gallon in chemically pure water; but it is readily dissolved by the carbonic acid present in all natural waters. Ordinary limestone and marble are varieties of carbonate of lime. Gypsum, alabaster, and selenite are varieties of the *sulphate* of the same metal. The sulphate is far more soluble than the carbonate, but is less diffused in the soil, and so is not met with in similar quantities. The amount of lime salts in water varies from one-third of a grain to the gallon in lakes surrounded by siliceous mountains, to 15 or 20 grains per gallon in many well waters, specially those in chalky districts. It has been supposed that the lime salts of water contribute to the formation of bone of animals, but it is usually in such small quantities as to have no material effect in this respect; and, further, Nature furnishes in ordinary food a much more convenient and suitable method of bone formation, than this. Even in places where large amounts of salts of lime are met with, no conspicuous influence is seen in the consumers—either the people become accustomed to the water, or the quantity of lime in it has no particular effect.

The *magnesian salts* are met with almost as commonly as the calcareous. Well water usually contains about 2½ or 3 grains to the gallon. It occurs as a carbonate with smaller quantities of the sulphate. These quantities have no effect on health. Some of the aperient mineral waters contain large quantities of sulphate of magnesia or Epsom salts.* Excess of sulphate of lime and magnesia (10 to 20 grains to the gallon) may constitute an impurity.

Chlorides.—Chlorine in small quantities occurs in all waters. An undue quantity, unless explained by its coming from a saline spring, or from near the sea, should arouse suspicion. The chlorides in water are important as indications of the existence of human excremental contamination, and sometimes they form a guide as to the channel by means of which sewage gains access. Hence the importance of estimating the amount of chlorine in quantitative chemical analyses.† Excess of chloride of calcium and magnesium may give rise to diarrhœa. In the instance quoted at p. the cause of diarrhœa was the excess of chloride and sulphate of magnesium, sodium and calcium in the water distilled from the sea.

* *Vide* section on *Mineral Waters*.

† *Chloride of sodium* or common salt is specially important in this respect, as it is the chief mineral constituent of the urine.

Many authorities hold that certain mineral ingredients, especially the alkaline carbonates (those of calcium, magnesium, sodium and potassium, and even the chlorides of these metals) may exist in large quantities without producing any deleterious effect on the animal economy; and we may state that a small excess of mineral constituents in water is of subordinate importance. On the other hand the majority of hygienists consider that very great excess of mineral impurities of any kind in water is capable of producing various forms of disease.

Of the *metallic salts* constituting impurities in water, *lead*, *iron*, and *copper* are the most important. Copper is rarely met with, and when found is usually derived from copper cooking-utensils which have not been properly tinned. Neglect in this respect is sometimes serious. We have seen several cases of slight copper-poisoning arise in this way. The possibility of this would be obviated by the use of properly enamelled cooking utensils or block steel vessels. *Iron* may be derived either from the original source of the water, the water passing through a stratum containing hæmatiteore, &c., or, in the case of public water supplies, it may be dissolved out from the pipes. The smallest quantity, even $\frac{1}{4}$ grain to the gallon, is recognised by the palate. Such water is injurious to plethoric people, giving rise to ringing in the ears, headache, &c.

The most common and important metallic impurity is *lead*. This in the case of public water works is usually derived either from the service pipe or house cistern. An extremely small quantity of lead in the water may give rise to dangerous symptoms, if the consumption of the water is long continued. Prof. Parkes stated that any quantity over $\frac{1}{10}$ grain per gallon should be considered dangerous, and some persons have been affected by even smaller quantities.

Nitrates in Water:—Almost all waters contain a certain amount of either nitrate of sodium (cubic nitre), or nitrate of potassium (saltpetre), or nitrate of lime (calcareous nitre). Nitre is an oxidised product of decomposed dead animal and vegetable matter In the quantities in which it is usually found, it is not only not harmful, but probably beneficial to man and animals using the water, and it forms part of the food of all plants, the juices of which invariably contain some of it.

When water comes into contact with decaying animal and vegetable matters, then carbon, as we have already said, is oxidised to carbonic acid gas, and their nitrogen is oxidised to nitrates, which are dissolved in the water. When this oxidation of organic matter is incomplete in wells, tanks, &c., the water is impure and may be very dangerous to use. Partial oxidation results in the production of *nitrites*. The presence of nitrites in water is always looked upon with suspicion. They are usually contained in water that is deficiently aërated. When water is undergoing proper aëration, the nitrogen evolved out of organic matter is oxidised into nitrates, and the nitrates into ammonia, with very little formation of nitrites. An increase of nitrates and nitrites is evidence of *previous* contamination of a dangerous kind, but not proof of existing danger. On the other hand any noteworthy increase of oxidisable organic matter calls for grave apprehension.

There should be practically no *nitrogenous organic matter* in water, the limit of albuminoid ammonia being ·035 of a grain to the gallon, and if there be much *free ammonia*, even this amount of albuminoid ammonia should be viewed with suspicion.

Animal matter should always be regarded as injurious to the quality of a water, especially if human excrement is the source of the animal matter.

It is most important that all drinking water be free from decomposing organic matter. In such a state organic matter is invariably associated with micro-organisms, which when introduced into the body may give origin to such diseases as cholera and enteric. This is particularly liable to occur if the excrement of persons suffering from these diseases gains access to the water, and we know that there are many ways in which this can occur.

It may be useful to possess some standard as to the admissible limit of the various constituents of a *first class water*. With reference to such a standard we would state that only slight traces of the following substances are admissible in a water of first quality :—Nitric and nitrous acids and ammonia salts, metallic salts, organic matter, alkaline sulphides and sulphuretted hydrogen. It is extremely rare to find all of these substances absent, yet any thing beyond a trace should be looked upon with suspicion. The admissible limit of other agents is as follows :—

Chlorine under 2 grains to the gallon.
Ammonia „ 3 or 4 „ „

Total solids under 8 grains to the gallon.
Volatile „ „ 1 „ „ „
Free ammonia under ·0014.
Albuminoid „ ·0056.
Oxygen for oxidizable organic matter ·035.
Fixed hardness under 2°.

No drinking water should contain an excess of *solids*, especially when these solids consist of lime and magnesium salts. As above stated eight grains to the gallon is the limit in a first class water, and one grain of this alone should be dissipated on heating. Should the solids consist chiefly of chalk, not more than 14 grains should be present. Some authorities, however, permit of a much larger amount of solids when they are purely of a mineral nature.

With the foregoing remarks on the impurities of water, and with the tables given in another section, we are placed in a position to interpret the result of chemical analyses conducted by qualified analysts.

LIVING ORGANISMS IN WATER.

Living organisms of all sorts and description, both vegetable and animal, are frequently met with in water. Their very presence naturally indicates the existence of a suitable food, which food is chiefly organic. They do not of themselves, however, entitle us to absolutely condemn the water in which they are found, yet a water containing an abundance of life must be regarded as inferior and less desirable than one that is clear and comparatively free from living organisms. The microscopical examination, therefore, forms an important supplement to the physical and chemical examination of water. "Just as the mineral debris could afford us a clue to the nature of the strata *of soil through which the water* may pass, so the known habitat of certain organisms *detected, should enable us, in a general way, to determine whether the water has been taken from a* river, stream, *lake*, pond well or other source. Indeed, if we were perfectly acquainted with the natural history of the forms occurring in a sample of water even in the absence of more definite information, we would have little difficulty in forming a conclusion to the source from whence the water was derived."*

We have already referred at sufficient length to the *animal* organisms most commonly met with in water. Of the *vegetable* organisms *fungi* are the most important, requiring the microscope for their detection. The chief forms of fungi met with in water as far as public health is concerned are, bacteria, bacilla, vibrios (minute chained rods), micrococci (spherical particles singly or in clusters), all of which require as food organic carbonaceous matter, nitrates which they reduce to nitrites, a trace of phosphates, and usually oxygen. Many organisms, however, flourish better in the absence of oxygen. No natural water is free from these vegetable germs.

The number of micro-organisms in different kinds of water varies considerably, but on the whole corresponds with, and gives an approximate estimate as to the degree of impurity. Some important investigations carried out by Dr. Percy Frankland pointed out that the unpurified water of the Thames

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* A Guide to the Microscopical Examination of Drinking Water by J. W. MacDonald, M.D., 2nd edition.

contained about 1,000 micro-organisms *to the drop*, but after passing through the filters of the water companies, the same quantity contained on an average only 20 micro-organisms. The actual number of germs in a water is of importance also from the fact that in their multiplication they generate poisonous bodies called *ptomanies*. Ordinary putrefactive bacteria, vibriones, and cocci may not in themselves be harmful, yet their presence in any numbers in water points to the probability of the existence of dangerous organic matter, this organic matter serving as a pabulum upon such micro-organisms feed and multiply. They are the most pernicious of all impurities in water, for some forms of these microphytes produce disease in man. It need scarcely be said that they are invisible, some often requiring the highest powers of the microscope for their detection.

Yet all vegetable germs in water are not harmful: some indeed exercise a purifying influence by feeding on, and bringing about a disintegration of, the organic impurities contained in the water. Certain forms of micro-organisms split up the nitrogenous (animal) matter and convert it into ammonia, nitrites, and later on nitrates.

Some germs are related to ordinary decomposition processes; whilst others, and we cannot distinguish which, may be the seeds of specific diseases. That certain forms of micro-organisms being about specific diseases, such as enteric fever, cholera, &c., is now a generally recognised fact. These germs are the least readily determinable of all impurities, evading all chemical examination.

The injurious action of water contaminated by the specific poisons of disease is said by many to be unlimited both as to time and space—that once a water receives even a small specific contamination, it is ever afterwards dangerous, no matter how long or far it may flow or percolate. This is a very sweeping statement, and is contradicted by the fact of the proved wholesomeness of many waters that have been specifically contaminated. Indeed, were such an extreme view as this to be true in India, we should for ever be in danger of falling victims to fatal disease, for almost all rivers and wells are so contaminated.

With regard to the origin of certain diseases said to be due to these fungi, it is quite possible that it is only when a water containing these germs is undergoing progressive deterioration, and exposed to certain conditions of weather capable of bringing about the multiplication of the germs that these diseases arise.

Another important test is that of making *cultivation experiments* to ascertain the nature and number of the micro-organisms present. These are carried out by placing the microbes in suitable nutrient media, in which they can germinate and multiply.

Biological science has not as yet sufficiently advanced to enable us to put a definite interpretation on the result of such experiments; still we think that it may be asserted with regard to a given water, that its wholesomeness corresponds with the number of vegetable germs present. This is not always so however. Flowing water with abundance of specific germs may be less unwholesome than stagnant water with fewer such germs. This may explain, in a manner, the discrepancy existing between the different opinions on the subject—the immunity in some and the susceptibility of other waters to produce specific diseases. One point comes out prominently in the foregoing statements, and that is, that the most dangerous impurities of water are not those that are visible : the potent agencies in the production of diseases from water are germs, and these from their minuteness cannot be determinedby any known chemical tests. A knowledge of the method of conducting a microscopical examination of water is then a matter of the greatest importance to those who have to decide as to the potability of water.

In making an ordinary microscopical examination of water, we place a drop of the water on a cover glass, and allow it to evaporate (preferably under a bell glass). This may be examined at once, or passed through a flame three or four times, and then stained with one of various aniline pigments.

The microscopical examination of water before and after filtration is of some importance, and the result is well shown in the analysis given in the Appendix.

When a water is much discolored from impurities, there is no difficulty in obtaining enough of the sedimentary matter for microscopical examination.

But sometimes the sediment is so small in amount that several slides may have to be examined before anything is met with. When this is the case, a long narrow cylindrical glass, thoroughly cleaned, should be filled with the water to be examined, allowed to stand for 24 hours, and then the water to within

$\frac{1}{4}''$ from the bottom should be siphoned off, and preparations made from it in the ordinary way.

The Microzyme Test for water is one that was originally introduced to ascertain whether micro-organisms were present or not, but we now know that germs are present in all ordinary waters, and even in ice. The test consists in adding two or three drops of the water to be tested to 2 c.c. of *Pasteur's nutrient fluid*, the latter having been previously boiled in a steralised test tube. If any bacteria, bacilli, &c., or their spores are present, the fluid in the test tube in a few days becomes milky owing to crowds of bacteria. This test is of little value to hygiene, although it tells us roughly the number of bacteria present, and enables those who follow this method of research to study the bacteorological and morphological characteristics of the germs. "The importance of the thorough acquaintance with the life history of the individual micro-organisms cannot be too strongly insisted upon. For example, by such means, the sperillum of Asiatic cholera can be distinguished from other comma-shaped organisms, and inasmuch as its presence may be an indication of contamination with choleraic discharges, such water should be condemned for drinking purposes, even though we may not yet be in a position to affirm that the microbe is the cause of the disease."

In most running, and in many stagnant waters, we also have a large number of the higher vegetable forms as *algæ* and *diatoms*. Their presence, as a rule, does not contraindicate the use of the water; in most cases, in fact, they effect a beneficial and purifying influence by oxidising the organic matters present. It is to be remembered, however, that they exist in many bad waters.

Of the animal kingdom, the *Rhozopoda* and *Infusoria* are abundantly represented in pools, tanks, and rivers. They are themselves harmless, but point to an existing pabulum of organic matter in the water, which in many cases is in such quantity as to lead to serious contamination. *Hydrozoa* and *Rotifera* are frequently present in good water. *Namatodæ* are often found in impure water. In this order are included the round and thread worms (which may inhabit the alimentary tract of human beings), the embryo of the guinea-worm, and the parasite of the human blood, * which plays such an important part in the production of elephantiasis and the disease called "milky urine." These latter animal parasites are met with in the water of certain areas in which the affections created by them are endemic. The ciliated embryo of broad tapeworm passes through its first stage of development in the alimentary canals of certain fishes (eels and pike). *Leeches* are frequently met with in water. They are often dangerous from the great bleeding they may cause from the throat or stomach when they gain access to those organs. The absence of fish and molluses in perennial rivers and tanks denotes very bad water. Water fleas (*cypris*), *cyclops*, *daphnea*, &c., are found in apparently good water.

Water containing an abundance of life must be regarded as inferior and less desirable, than one that is clear or comparatively free from living forms.

* *Filaria sanguinis hominis* first discovered by the late Dr. T. R. Lewis, F.R.S.

GEOLOGICAL RELATIONS OF WATER.

The nature of the geological strata through which the subterranean water feeding a well (or other sources of water-supply) flows, has an important bearing upon the mineral constituents of that supply.

The following list shows the general character of a water-supply, according to the geological stratum from which it is derived.

Alluvial Waters are those from a mixture of sand and clay. They are generally more or less impure, and exceedingly variable in quality, and in constituents. They are generally contaminated by human excrement and vegetable organic matter. The total amount of solid matter varies from 30 to 180 grains to the gallon, and consists chiefly of carbonate and sulphate of lime, sulphate of magnesia, carbonate and chloride of sodium, traces of iron, and some organic matter.

Chalk Waters are clear, wholesome, and sparkling (being charged with carbonic acid gas) and generally very pure. They are chiefly characterised by the solid matter, consisting of carbonate of lime (5–20 grains to the gallon), carbonate of magnesia, and small quantities of common salt. They are hard, but the hardness is removeable by boiling, which drives off the carbonic acid gas holding the excess of carbonate of lime in solution.

Limestone and Dolomite Waters.—Wholesome and agreeable, bright and sparkling as a rule, but characterised by a larger amount of total solid matter than chalk water, and by the presence of a great quantity of sulphate of lime and magnesia; they are hard waters, and this hardness is much less affected by boiling than the chalk waters. Such waters may possess purgative properties.

Millstone-Grit, and Hard Oolite Waters.—Generally very pure, the solid constituents small, not exceeding eight grains to the gallon, and consisting chiefly of the sulphates and carbonates of lime and magnesia, with a little iron.

Soft and Stone Rock Waters.—Very variable in quality, so that no average can be drawn. Their total solids range from 25–80 grains per gallon, and consist of carbonate, sulphate, and chloride of sodium, small quantities of lime and magnesia, and a large amount of organic matter.

Granite, Metamorphic, and Clay Slate Formations, Trap-Rock.—These waters are generally very pure and wholesome, and containing small quantities of solid constituents, mainly carbonate of soda, and chloride of sodium, with a little lime and magnesia.

Lias Clays.—Yield water of variable composition, but it usually contains from 80 to 220 grains of mineral matter, with a small quantity of organic.

Loose Sand and Gravel Waters are occasionally very pure, especially those from *green* sand. As a rule, however, they contain much mineral matter derived from the sand (chiefly calcium, magnesium, and sodium salts), as well as considerable quantities of organic matter. They are often of alkaline reaction. They are occasionally very impure in consequence of the ease with which surface water may permeate the surface soil to reach the water-bearing stratum below.

Selenetic Waters are unwholesome. They are hard, containing excess of sulphate of lime. They give rise to dyspepsia and to constipation, alternating with diarrhœa.

From the above list we see that in respect of the influence of geological formation in rendering water sparkling, colorless, palatable, and wholesome, by percolation, the following-water bearing strata are the most efficient in their order:—chalk, oolite, green sand, granite, metamorphic and trap rock, conglomerate sand stone.

The power of water to dissolve out mineral constituents from the soil and the geological strata is well seen by scanning the *composition* of a few of the most popular *mineral waters.*

16 ounces Troy of Hunyadi Janos (Hungary) contain:—

	Grains
Sulphate of magnesia	122·8
,, ,, soda	122·1
,, ,, potash	·65
Chloride of sodium	9·98
Bicarbonate of soda	6·11
Carbonate of lime	7·16
Oxide of iron and alumina	·03
Carbonic acid free and combined	4·00

This is a bitter mineral aperient imported from Hungary (Buda-Pesth) used for constipation, and to aid aperient pills in their action.

Carlsbad (Bohemia) Water.

16 ounces contain:—

	Grains.
Sulphate of soda	19·96
Carbonate of soda	9·06
Chloride of sodium	8·72

	Grains.
Sulphate of potash	·36
Carbonate of lime	2·02
„ „ magnesia	·4
„ „ iron	·03
Phosphate of alumina	·21
Silica	·1

Drunk for obstinate constipation, affections of liver, gout, rheumatism, and diabetes.

Friedrichshall.—This is likewise a bitter water, used in diseases of the stomach, liver and urinary organs.

16 ounces contain :—

	Grains.
Sulphate of soda	46·51
„ „ magnesia	39·55
Chloride of sodium	61·10
„ „ magnesium	30·25
Bromide of magnesium	·37
Sulphate of potash	1·52
„ of lime	10·34
Carbonate of lime	·11
„ „ magnesia	1·16
„ „ silica	·33

Seltzer. (Nassau). Furnishes the well-known Seltzer water.

16 ounces contain :—

	Grains.
Bicarbonate of soda	9·77
Chloride of sodium	17·22
„ „ potassium	·28
Sulphate of soda	·26
Phosphate of soda	·26
Bicarbonate of lime	2·66
„ „ magnesia	2·55
„ „ iron }	Traces.
„ „ manganese }	Traces.
Bromide of sodium }	Traces.
Silica	·25

HARD AND SOFT WATER.

Waters are sometimes classified as "hard" and "soft." A *hard* water is one with which soap does not at once form a lather, but produces instead, a deposit of a curdy nature. Hard water presents a peculiar roughness to the touch. Hardness is referred to as—

TOTAL { *Temporary*, removed by boiling.
{ *Fixed*, not affected by boiling.

The hardness of unboiled water is called *total* hardness, while that of boiled water is called *permanent* hardness.

There are a few diseases brought about by the consumption of hard water: goître or bronchocele; stone in the urinary passage; dyspepsia; and diarrhœa, alternating with constipation.

In certain parts of Oudh, such as Ghurwal, Kamaon, &c., about 33 per cent. of the inhabitants are said to suffer from goître; yet, in the water-bearing stratum consisting of clay-slate, only 5·4 per cent. of the population are affected, and with granite only 2 per cent. Here the chief mineral impurities are lime and magnesium limestone. We have seen the inmates of one girls' school in a Himalayan station become affected with goître, while those of other schools not remotely situated from it, were free from this disease. The only apparent difference was the existence of magnesium limestone in the water consumed by the former, and the absence of this mineral in the latter.

It is curious, however, that there are many places in which lime or magnesia exists in excess in water, and no goître is found. This is the case in certain parts of Ireland and Scotland. In Rheims and Avergne in France, limestone forms the water-bearing stratum, and no goître is seen. This has led to some dispute as to the actual agent that gives rise to the disease, and of late years, it has been customary to speak of sulphide of iron as the cause of the disease, although the proofs in support of this hypothesis are as yet somewhat slender.

Much has been written about the comparative wholesomeness of hard and soft water. It is generally found that districts and towns supplied by hard water have a lower mortality-rate than those supplied by soft water. Yet an important fact must not be overlooked, and that is, that the water-bearing strata of four-fifths of the world consists of lime, or contains salts of lime which impart hardness to water; therefore the vast majority of people living, use hard water. Usually people become accustomed to the water of the place in which they live, and only recognise the difference on leaving it. The effects of this difference in hardness of water should be remembered in ordering patients away for a change on account of ill-health.

There are many disadvantages associated with the use of hard water, the chief of which are :—

1. The waste of soap in washing clothes.

2. The difficulty of cooking food, especially vegetables, in it. Tea can be but imperfectly infused in hard water.

3. The precipitation of the lime salts on the interior of vessels in which such water is boiled ; or upon clothes or other material coming into contact with the water. It is a well-known fact that

crude carbonate of soda is used in some laundries in England, and in certain places in India, to lessen the hardness of water, and it is further known that this saturation of clothes with soda decreases the durability of the fabric of clothes. Hard water results from the originally soft rain water falling on, or coming into contact with, limestone rocks, or from the water percolating through strata containing lime, magnesia, iron, and various sulphates, all of which impart hardness to water. Hardness due to carbonate of lime and magnesia kept in solution by excess of carbonic acid, is removed on boiling. The boiling drives off the carbonic acid which kept these salts in solution. This is particularly the case with chalk waters, for on boiling the chalk is precipitated: the hardness it causes is temporary. The sulphates of these salts are not affected in this way.

ESTIMATION OF HARDNESS.

The hardness of water is estimated by shaking the water with a standard soap solution, the result being the formation of a lather when the hardness has been reduced by the alkalinity of the soap. The actual hardness is spoken of as so many degrees, each degree corresponding to the amount of soap that is destroyed by a known quantity of water.

By *degrees* of hardness we signify that a definite quantity of water decomposes a certain number of cubic centimetres of a standardised soap solution. Thus 10 degrees of hardness means that 10 c. c. of the standard soap solution have been used; that is, each c. c. solution of = 1 degree of hardness. (Frankland's scale.) Each degree of hardness causes the destruction of 2½ oz. of soap in 100 gallons of water used for washing clothes.

A rough means of judging the relative degree of hardness of any sample of water, consists in placing a small quantity in a test-tube, and adding to it a few drops of a standard solution of soap in alcohol, when a white turbidity will make its appearance, the intensity of the turbidity depending upon the degree of hardness.

Fourteen degrees of hardness is the allowable limit in waters used for drinking and cooking purposes. Some authorities hold that water having anything beyond 8 or 9° of hardness ought not to be used without being softened; others consider that even as much as 40° is harmless if the hardness arises from chalk only.

The causes of hardness may be thus tabulated :—

Total Hardness due to	1. Carbonate of lime and magnesia.	
	2. Carbonic acid.	
	3. Calcium fixed salts.	
	4. Magnesium salts.	
Fixed Hardness due to	1. Calcium fixed salts.	
	2. Magnesium salts.	
Temporary Hardness due to	1. Carbonate of lime and magnesia	in solution.
	2. Carbonic acid	

The chief causes of hardness are then, carbonates of lime and magnesia, acids, and iron.

The carbonates at times are fixed salts (as in trough water). But when we speak of fixed hardness, we usually mean sulphate of lime and magnesia. The white deposits frequently seen on the interior of kettles and engine boilers consist of precipitated carbonate of lime and magnesia. The only acid usually present is carbonic acid in the gaseous state. This helps to keep the carbonates of lime and magnesia dissolved in the water. By boiling, the carbonic acid gas is driven off, and the lime and magnesian carbonates are precipitated. The same precipitation takes place if ordinary oxide of calcium is added to this water. It is useful to know to what agent the hardness is due, for such knowledge points to whether the water can be rendered fit for domestic purposes or not. Water from natural sources contains a varying amount of lime, magnesia and other salts. In accordance with the quantity of these salts is the hardness or softness of water. Hardness is then generally due to excess of carbonate of lime and magnesia held in solution by excess of carbonic acid gas.

Scales pointing out the degree of hardness or softness are arbitrary. Clarke's standard is the one usually employed. Each degree of it corresponds with one grain of carbonate of lime to the gallon. Frankland's is equally correct and easier to work. Any water below 9° is considered soft; any above this is said to be hard. A soft water contains from 4 to 9 grs. of carbonate of lime and magnesia to the gallon, while a hard one contains from 9 to 40.

Waters according to their degree of softness may be classified as follows :—

1. Rain water.
2. Upland surface water.
3. Surface water from cultivated land.
4. River water.
5. Spring water
6. Deep well water.
7. Shallow well-water.

DISEASES ASSOCIATED WITH IMPURE WATER.

In a preceding section we dealt with the various impurities giving rise to disease. In this we shall make a few remarks regarding the manner in which these diseases are brought about.

Impure drinking water produces disease in various ways, of which the chief are : (1) By its containing organic matter, vegetable or animal, living or dead, including in this, suspended parasites, their ova, or spores ; and (2) by having dissolved in it excess of certain saline bodies, such as chlorides, carbonates, and sulphates of lime and magnesia, &c.

The *organic* impurities are by far the most important constituents of water, and they are the most powerful in producing disease. The *saline* bodies, when in excess, are not without their injurious effects, but when found they are more or less constant and unvarying, can be determined with accuracy, and the diseases they bring about can be readily and with certainty connected with them. Dead organic matter may give rise to diarrhœa, dysentery, malarial fevers, &c., but living organic matter in the form of specific micro-organisms may bring about specific diseases, such as cholera and enteric fever.

The chief diseases brought about by impure water are :—Cholera, typhoid or enteric fever, dysentery, diarrhœa, "malarial" fevers, ague, remittent (including the various forms of so-called "jungle fever"), parasitic diseases from animal and vegetable parasites, goître and urinary calculus.

CHOLERA—ITS RELATION TO WATER.

Cholera is endemic—that is, it is always present to a greater or less extent—in Lower Bengal. It has there occasional epidemic outbreaks; but an entire cessation of the disease occurs only for a few months of the year. In several of the large towns and municipalities of India, it is also endemic, as in Calcutta, Bombay, Benares, Hyderabad and its suburbs, &c. When the conditions favourable to the propagation of this disease are present, and it has once made its appearance, it is liable to disseminate to an unlimited extent. Water is one of the chief means by which the disease is spread. There are doubtless other agencies by which it is diffused, such as air specifically contaminated, foul clothes, food, &c., yet water in most outbreaks plays an important part in this respect. This is shown from the decrease of the disease in all those areas where it was endemic on the establishment of a permanent supply of pure water—Calcutta and Madras for example.

Impure water is the chief means by which cholera arises.

The water-supply of Calcutta was formerly from open tanks and wells, and the Hoogly river. The tanks and wells were constantly subjected to various forms of pollution. Into the Hoogly the night-soil of the city was allowed to flow; and dead bodies (many probably the corpses of deceased cholera cases) were thrown. A new and improved water-supply was started some years ago with the happy result of a decrease in the general death-

Cholera in Calcutta.

rate, and in particular of mortality from cholera. A similar statement holds good of Madras. Sir John Simon writes: "The discharges from the bowels of infected patients, escaping into wells and other water-courses, are indubitably a powerful means of contagion. Water so polluted has been at the bottom of many widespread and decimating epidemics." The whole of the literature of hygiene or preventive medicine is pervaded with thoroughly authenticated instances to prove this.

Personal experience with regard to relation of cholera to impure water.

A few instances that have come under our own observation will serve to show how impure water brings about cholera:—

(1) When in charge of several hundred Indian emigrants on board a sailing vessel in the Indian Ocean, cholera broke out. All the people had up to this time used the drinking water put on board at Calcutta. The issue of this water was at once prohibited and distilled sea-water used instead. But the distilling apparatus got out of order, and we were obliged to return to the Calcutta water. The day we resumed its use several fresh cases of cholera took place. The only conclusion one can come to is that the Calcutta water was polluted in such a manner as to be capable of creating the disease.

(2) In investigating the cause of an outbreak of cholera amongst some *wadders* near the village of Khairatabad,* we discovered that the people attacked procured their water from a putrid pool close at hand. As each person lived separately, there is reason to consider that they were all affected by a

* In Hyderabad, Deccan.

common cause, and that cause we believe to be the poison contained in the foul water they drank; for, on stopping the use of the water, the disease disappeared from the locality.

(3) On another occasion, on the confines of the village of Khairatabad, we saw a woman washing the soiled cloths of her deceased husband (who had succumbed to cholera) in a small tank, from which several people were at the time drawing water for drinking purposes. The tank was, of course, at once closed, but the truth of the astonishing ignorance of the lowest classes of the people remains, and causes us to wonder that a disseminating epidemic has not visited us long ere this. Such facts as these should arouse the energies of every intelligent being to do his utmost to disperse a knowledge of the rudiments of sanitation throughout the length and breadth of this Empire. Cholera prevailed in this village for several days after this.

(4) Last year while seeking the cause of cases of cholera in Begum Bazaar, we entered several huts where patients were suffering from the disease. In one hut we found a man prostrated with cholera. He had passed his stools on the ground around, and had vomited in several parts of the floor, soiling also his cooking utensils and a *lotah*. On making enquiries we found that his wife had just drunk water out of this very lotah. The man recovered, but his unfortunate wife died of the disease, the victim of appalling ignorance.

A direct proof of the contagiousness of the excreta of cholera patients is given in the following often-quoted cases. A small quantity of a cholera stool was mixed by accident in water contained in a *gurrah*. The chatty was exposed to the sun for many hours. Next morning nineteen persons each swallowed a small quantity of this water. Within 35 hours five of them were seized with cholera. Instances of outbreaks of cholera from water specifically contaminated by the excreta of cholera patients abound in medical and hygienic literature; we would add but the few foregoing to the long list already in existence. As we have said before, cholera arises in other ways than through polluted water, but there is a consensus of opinion amongst authorities on the subject, to the effect that impure water is the main factor that brings about its extension. We need not enter into this relation, except in stating that it is now beyond doubt that some of the most appalling outbreaks of cholera have been definitely linked with impure water-supply. In the year 1879 five millions of people died in India, $3\frac{1}{2}$ millions from fever, and 265,000 from cholera. In the Chuddergbaut Municipality in the year 1888 there occurred 736 cases. About $\frac{2}{5}$ths of these proved fatal. Against the polluted water theory of cholera production is the fact, that most of those who drink such water escape cholera. But the same may be said with regard to enteric fever, and to us this portentous exemption indicates that two factors are necessary to the production of cholera—(1) a specific poison (be it a bacillus, or *ptomaine* or animal alkaloid, or organic poison), and (2) a good nidus or breeding ground in the alimentary tract of the individual consuming the water, giving rise to a susceptibility to the disease.

One thing is certain, wherever the use of unwholesome water has been supplanted by a purer supply, there cholera had considerably decreased.

Enteric or typhoid fever.

Enteric or typhoid fever has in a vast number of outbreaks been shown to be due to the contamination of water by the excreta of patients suffering from the disease. This is so well recognised as to need no further insistance here.

Impure water plays an important part also in producing *diarrhœa*. This is especially the case if the impurity arises from decomposing animal and vegetable matter. But sometimes dissolved or undissolved mineral matter also creates the disease, and many observations made on this latter point show that the diarrhœa so prevalent on the hills is due to suspended mica scales, and finely divided particles of silica.

Dysentery.

Dysentery is also caused by impure water, particularly when the impurity consists of decomposing organic matter. Several cases have come under our observation where combined dysentery and ague were caused by drinking marsh water. Ague, although mostly caused by breathing malarial air, is sometimes due to water. That marsh water creates enlarged spleen and ague was as known to the ancients.

Malarial diseases.

Apropos of this origin of ague, we might relate the case of a European officer who recently arrived in India and went on a shooting excursion. On the first day he forgot to convey his bottle of water, and was obliged to drink the impure water of a *jheel*. The afternoon he did so he suffered from a severe attack of ague, and the following morning had symptoms of an attack of acute dysentery.

Parasites—internal and external.

The human being is liable to suffer from several kinds of *worms*. The ova or immature form of these parasites may gain entrance to the alimentary tract through drinking water, as we have already mentioned. In other cases, they attack the surface of the body while washing. In this way we may become the hosts of round worms, thread worms, duodenal worms, flukes, blood filaria (introduced through the medium of the misquito), hydatids, and guinea-worms. We have already mentioned the connection between goitre stone in the bladder and water. As examples of vegetable parasites attacked the skin and tissues through water, we have the germ of ringworm, and that of the *fungus foot* of India.

The high mortality of India is largely due to impure water. By improving the water-supply throughout the country, we believe this death-rate will be greatly lessened. We have said enough to show that the use of impure water is very injurious and often fatal. This fact has been known for ages.

Connection between impure water and epidemic diseases.

So close is the connection between certain epidemic diseases and impure water, that one is almost inclined to hazard the statement that such diseases can scarcely spread widely in a community, without its influence. It is a safe thing to assume that any severe outbreak of bowel-complaints in a community should call the attention of the sanitary authorities to the state of general water-supply.

Short of producing any active disease, the continuous use of foul water may bring about a general impairment of health, a lessened immunity from, and an increased liability to, diseases of all kinds. All these maladies may owe, not only their origin, but also their continuation and propagation to infected water.

THE USES OF WATER.

The uses of water in civilised communities are many.

1. It is an essential part of our daily food. It serves to preserve the fluidity of the blood, aids the excretion of effete products from the body, and helps to lubricate and build up the tissues. By its evaporation from the surface of the body it cools the system. It is really more important than food itself: for without it, food could not be used. It is necessary to aid in dissolving, digesting and assimilating the food, which, through these processes, is so altered as to be rendered fit for circulating through the body. For these reasons alone the vital importance of water in the animal economy is evident. It forms about 70 per cent. of the whole body, or in plainer terms, a man weighing 154 lbs. has in his body about 12 gallons of water, that is, enough to drown him if rightly arranged. It forms one of the chief constituents of the juices and tissues.

2. It is the closest approach yet discovered to the long-sought for universal solvent (of the alchemists).

3. It is necessary for personal cleanliness. This

is perhaps the best place to remark upon the necessity of public bathing ghats. This cannot be too strenuously insisted upon, and the water in these should, if possible, be kept clean by constant removal and periodical cleansing.

4. As a household requirement, it is used for cooking, for cleaning utensils, floors, &c.

5. It is necessary for washing our linen.

6. For public purposes, it is used for watering streets and extinguishing fires. Among the greater advantages of an ample supply of water may be enumerated the cleansing of drains effected by copious daily flushing. The semi-consistent putrid fluid seen sluggishly flowing along drains is no small factor in the production of disease in Indian communities. The great object of surface drains is to remove, with as little delay as possible, the foul refuse fluids of our houses from our surroundings, and this can only be effected by regular periodical flushing.

After the introduction of an adequate public water-supply to towns, were it rendered compulsory, that every house tenant, stable, &c., should be furnished with water from this source, irrespective of private or public wells, it would go far to improve the sanitary condition of the towns, to promote health and lessen disease and mortality.

7. It is required for drinking purposes for horses and other domestic animals, as well as for washing these animals and cleaning carriages.

8. It is also required in manufacturing processes. But its uses do not end here. Taking advantage of its incompressibility in the liquid form, and its elasticity in the gaseous state, we are enabled to

carry out our most powerful mechanical processes. Indirectly we have through it our soil and air purified.

9. The rain clears the air for us by washing it, and finally we have the rain washing the soil.

Water has also its therapeutical uses. In cases of fever, especially those fevers associated with high temperature, it affords a direct means of getting rid of the excessive heat of the body. We need scarcely be reminded that cold water is one of the best available means of reducing local inflammations. It would be out of place to do more than merely mention the part played by the waters of the different Spas of Europe. Its various applicability in these institutions is due, however, in part to the extraneous agents the water contains.

To effect all these purposes, a liberal supply is required, and a really hygienic state of a house, its surroundings and inmates cannot exist without such a supply. A community will, as a rule, be found unhealthy in proportion as its supply of water is scanty. Such scantiness means imperfect cleansing, together with in a great many cases, impurity in quality. Water is a universal drink, and when pure, it is the only one necessary for healthy persons.

QUANTITY OF WATER REQUIRED PER HEAD OF POPULATION.

After giving considerable attention to this subject, the late Professor Parkes arrived at the conclusion that 25 gallons per head, per diem, is the minimum quantity of water that ought to be allowed. In places where sewers are in existence, it is necessary that this amount of water should pass through the house drains into them, in order to guarantee the complete removal of all solid waste and keep the sewers clean. In apportioning this quantity, Dr. Parkes gives the following amounts as required for ordinary house use :—

	Gallons.
Cooking purposes	·75
Drinking	·33
Ordinary ablution, including personal ablution and sponge or shower bath ...	·5
Cleaning up utensils and house-washing ...	·3
Washing clothes	·3
	12·08

But in apportioning the daily allowance for *all* purposes, he has given the following table :—

Domestic supply	12 gallons.
General baths	4 ,,
Water closets *	6 ,,
Unavoidable waste	3 ,,
	25 gallons.
Municipal purposes { Street watering / Extinguishing fires }	5 gallons.
Trade	5 ,,
	35 gallons.

A whole bath requires about 30 gallons. The following quantities are required for the use of the animals specified :—

Horse	6 gallons.
Cow	6 ,,
Elephant	25 ,,
Camel	10 ,,

* Although water closets are not in use in India, except in a few towns, and are not likely to become so generally, when we consider the demands of the large number of domestic animals in use in Indian towns, 25 gallons can scarcely be reckoned excessive.

We should remember that pure water is as necessary for domestic animals as for ourselves, for many of the diseases from which they suffer are attributable to the use of impure water. Professor Rankine gives the quantity of water required as follows:—

	Gallons per head per diem.		
	Lowest.	Greatest.	Average.
Used for domestic purposes ...	7	15	10
Watering streets, extinguishing fire and supplying fountain ...	3	3	3
Allowance for trade and waste ..	7	7	7
Total ...	17	25	20

These quantities represent *average* requirements, and with regard to households, anything short of the amounts stated will render sanitary cleanliness defective. Recently we made two series of observations with regard to the quantity of water used by the lower classes in certain *bustees*, and found that in one case on an average not more than two gallons per head enter each hut, and in the other not more than $2\frac{1}{4}$ gallons, a quantity altogether inadequate to effect the least semblance to cleanliness, personal or domestic. From a sanitary point of view nothing can be more reprehensible than such restriction in water-supply, and there would be no difficulty in tracing a vast amount of sickness to it.

LAWS AGAINST POLLUTION OF WATER.

The pollution of drinking water was strictly forbidden in the early sacred writings of India. The drama of Yajurveda contains the following order : " Do not spit out with retching in the water, do not pass urine or discharge excreta in the water, do not throw any hair, nor nails, nor bones, nor ashes, nor dip any dirty clothes into the water. For to do so is to abuse the precious gifts of the gods and disgrace them." Persons suffering from contagious, skin, or other diseases were forbidden to bathe in tanks or ponds. Menu says : " Let him not cast into the water either urine, or ordure, nor saliva, nor cloth, nor any other thing soiled with impurity; nor blood, nor any other kind of poison." In the days that these laws were given to the people, the fouling of water in any way was thought a great sin.

In Great Britain the Rivers Pollution Prevention Act has done much to improve and preserve the purity and flow of river water. It is applicable to rivers, streams, water courses, canals, and lakes. It enumerates the more serious sources of pollution as follows :—

(*a*) Solid refuse of manufactories, manufacturing processes, or quarries, rubbish, and cinders, and any other waste or putrid matter ; (*b*) Sewage matter, whether solid or liquid ; (*c*) Poisonous, noxious or polluting liquids proceeding from factories, and manufacturing processes ; (*d*) Solid or liquid matter from mines, which is poisonous, noxious, or polluting or interfering with the flow of water.

In the present day we find that the *Indian Penal Code*, and all properly organised Municipal Corporations prohibit the contamination of water by the public. Indian Penal Code says: "Whoever voluntarily corrupts or fouls the water of any public spring or reservoir, so as to render it less fit for the purpose for which it is ordinarily used, shall be punished with imprisonment of either description for a term which may extend to three months or with fine which may extend to Rs. 500, or with both." We may here refer to the stringent provision in all existing sanitary laws with regard to contamination of water.

We abstract the following from the Bengal Municipal Act, sections 208 and 209:—"All streams, channels, water courses, tanks, reservoirs, springs, and wells, not being private property, shall, for the purpose of this Act, be under the directions and control of the Commissioners.

"The Commissioners may, by order published at such places as they may think fit, set apart convenient tanks, parts of rivers, streams, or channels, not being private property, for the supply of water for drinking and for culinary purposes; and may prohibit therein all bathing, washing of clothes and animals, or other acts calculated to pollute the water set apart for the purposes aforesaid; and may similarly set apart a sufficient number of the same for the purpose of bathing, and a sufficient number for washing animals and clothes, or for any other purpose connected with the health, cleanliness, or comfort of the inhabitants."

The penalty for contravening these sections is a fine up to Rs. 50.

In the case of water derived from an impure well, or some other polluted sources in compounds, the Municipal Acts enforce that the source of supply be purified or closed. We may likewise quote the following bye-laws from the two municipalities in juxtaposition, but working independently :—" The Committee may, by notice, require the owner or occupier, of any land or building to clean, repair, cover, fill up fence, or draw off any private tank, well, reservoir, pool, or excavation therein, which appears to the Committee to be injurious to health or offensive to the neighbourhood."

Sanitary regulations and bye-laws have for their object the preservation of the health of the community. There is no known people that have attained such a degree of sanitary perfection as to need no controlling influence to be placed over their actions. There is, in a large number of the population, an utter indifference to dirt in all forms. I do not make this statement against the higher caste people. They are, as a rule, exemplary as to the cleanliness of their persons and the interior of their houses. But amongst these the exterior of their abode is often found neglected as to its sanitation.

The authorities upon whom devolve the responsibility of proper administration in connection with water-supplies should be alive to the gravity of the task that is theirs. They should keep constantly in mind the serious consequence that might arise from contamination of water, and they should enforce the most rigid obedience to the law of the land regarding such contamination. We are convinced that nothing short of the most uncompromising insistance with regard to municipal laws will prevent the dangerous contamination of wells, tanks and other water supplies in the interior of towns and municipalities of India.

GENERAL SOURCE OF WATER.

The natural sources of water-supply are rivers, streams, lakes and springs, but the general sources of all fresh waters are the seas and oceans. The ocean covers about $\frac{7}{8}$ of the earth's surface, but we cannot use its salt water. Nature effects a distillation for us, whereby this salt water is converted into "sweet" water. From the oceans the heat of the sun effects a vaporisation of water into the air, in the same way that the water disappears from a tumbler if exposed to radiant heat. A vast quantity of water is drawn up from the sea in this way in the form of vapor which mixes with the air. In the invisible form, water is conveyed by the air over the land, re-condensation takes place, and it is precipitated as snow, hail, rain but chiefly as rain. The wind blows this hot and moist air to a cooler place. This results in the formation of clouds and a fall of rain. Air at any particular temperature can only hold a certain minimum quantity of water in the form of vapor. When the air gets below this temperature, clouds form, the little particles of water join together and descend—that is it rains. The air always contains some of this watery vapor or steam, a fact we daily observe when ice is put into a glass of water. The outside of the glass first becomes covered with a haze, and then we see droplets of water on it. The cold glass has cooled down the air surrounding it, and caused the water in the air to condense into drops. On reaching the surface of the earth the rain is disposed of in various ways : a portion is evaporated, another portion flows in the direction of the inclination of the surface, and a third portion percolates or sinks into the soil. The amount of rain that evaporates depends upon the temperature and degree of humidity of the air,—the higher the temperature and the dryer the air, the greater the evaporation. When the inclination of the surface is but slight and the soil very permeable, a large part of the rain sinks into the earth ; but if the soil is not porous, the greater part of the unevaporated water flows down the incline. This is the portion that helps to swell streams and rivers. A small share of the percolated rainwater is absorbed by the roots of trees, vegetables and grasses, but most of this is subsequently evaporated from green leaves. When it rains heavily, the greater part of the water finds its way to the large rivers, and finally into the seas and oceans once more, after subserving the great offices in supporting animal and vegetable life.

A constant circulation of water is taking place between the earth, the air, and the ocean. In some countries during the winter the air is so cold that the particles of vapour are converted into snow before they touch the earth. This is the case also in the higher Himalayan mountains. This snow not melting at once, forms blocks or sheets of ice. In the intervals between the rainy season, our large rivers are supplied chiefly by water from the melting of these extensive blocks or fields. In precisely the same way as water evaporates in the case of oceans, watery vapour arises from all exposed sheets of water, rivers, tanks, wells, marshes, and pools. We know that in the hot weather, many tanks and small rivers dry up, even when the water is not used.

Of the rain which reaches the earth, then, some flows at once into rivers, some of it sinks into the ground, and some of it goes into wells and tanks. That part of it which sinks into the earth feeds the wells, tanks and rivers in the intervals between the rainy seasons. We now see why the water of the globe does not decrease in quantity. A change of form is constantly taking place, but no reduction in quantity. Rain water before it touches the earth is pure and fit to drink: it is *distilled* water. As soon as rain water comes in contact with the earth, however, it dissolves out the soluble salts contained in the soil as well as the soluble organic matter. In all populated places the soil contains a large amount of decaying vegetable and animal impurities. In coming into contact with these, rain water is rendered impure. The rain in passing through the lowest layer of air, washes out the bad products of the atmosphere, and carries them with it.

SPECIAL SOURCES OF WATER.

THEIR CAUSES OF POLLUTION AND REMEDIES.

Recollecting the number of diseases that owe their origin to impure water, and water specifically contaminated, it behoves us to exercise the greatest care with regard to the source whence we are supplied. We shall therefore devote a few pages to a consideration of these sources, the many causes of this contamination, and point out, as we proceed, how these polluting agencies might be either entirely removed, or minimised.

As special sources of water in Indian towns and villages we have :—

(1) *Wells*, superficial and deep, either public or private.

(2) *Tanks*, large and small, natural (or lakes) and artificial.

(3) *Rivers and streams.*

(4) *Ponds, ditches, effluent from irrigated land, and marsh water.*

(5) In a very small minority of cases *Public Water Works.*

In general terms it may be stated that all of these waters except (5) are more or less impure, and that without previous boiling and filtration, are unfit to use for drinking purposes. All are subject to various forms of pollution.

The comparative merits of the various waters in respect of wholesomeness, palatability, and general fitness for drinking and cooking, is given in the following table.*

Wholesome	1. Spring water ...	Very palatable.
	2. Deep well water ...	
	3. Upland surface water ..	Moderately palatable.
Suspicious	4. Stored river water ...	
	5. Surface water from cultivated land ...	Palatable.
Dangerous	6. River water to which sewage gains access ...	
	7. Smaller well water ...	

POLLUTION OF RIVER WATER.

River water is usually soft, containing a limited quantity of mineral matter, which consist chiefly of lime and its salts. The quantity of this mineral matter varies, however, from a few grains (in excep-

* Sixth Report of the Rivers Pollution Commissioners of London.

tionally pure) to 150 grains to the gallon, according to the amount of impurity to which the water is exposed. It contains about $\frac{1}{25}$ of its volume of gases, which are evolved on boiling or freezing.

When people begin to build a village or town, they usually select a site in proximity to a reliable water-supply. The banks of a river are most frequently chosen. In gathering together in communities, large or small, they pollute the river water. If many such towns or villages are on the banks of a river, the water arriving at the lowest of them will be poisoned to some degree. We need scarcely dwell on the fact that when large masses of people are congregated in towns and villages, a sort of artificial existence arises in which the collective habits of the community affect the individual, and that in accordance with the nature of these habits, the *air*, the *soil*, and the *water* of the soil, are variously contaminated. These three factors (air, soil and water) are so correlated that they react upon one another. An impure soil means that all shallow wells sunk in it will contain impure water. The influence of such contamination is not selective in its effects, the rich and the poor are alike acted upon. Notwithstanding the strict laws that have been laid down in the sacred books of the Hindus against the pollution of water, we find the lower classes systematically disobeying them. Let us imagine ourselves on the banks of a river close to any large town or city, making a few observations. We note the people using the margins of the river as a latrine, subsequently rising and washing themselves in its water. Were contamination from human excremental matter to be an absent factor, the water of most rivers would be fit for use after filtration. Excremental contamination is the worst form of pollution to which any water source can be subjected, and this fact cannot be too widely known. We have seen the margins of the bed of a river covered with manure, including human excrement, horse dung, &c., for the growth of crops of melons. We need scarcely remark that such an outrage against sanitary principles should be stringently and permanently prohibited. There are various other causes of pollution at work. We see people washing clothes in the river. Now we know that these soiled clothes contain some of the waste matters from the body. These clothes may have just been worn by patients suffering from infectious or contagious disorders—small-pox or cholera for instance. It is clear that, if the germs of the disease are washed into the water, the inhabitants lower down the river using it, are liable to be affected by such germs. If dhobies *must* wash clothes in rivers, they should have a part of the river allotted to them, situated below the habitations of the people. The bodies of people who have died of cholera, small-pox, &c., are often thrown into rivers. Crowds of human beings are seen spitting in the river water and subsequently drinking it. Cattle, horses, elephants, and other animals, are taken to the river to be washed, their droppings and urine pollute the water, as do also the foul matters washed off the surface of their bodies. *Gowlies* will, if allowed, select a residence close to the banks of a river, to render the labour in connection with the care of their buffaloes the easier. In small rivers and streamlets these practices are so injurious to health as to be a matter of danger to life itself.

All the *nullahs* and ditches around inhabited places during the dry seasons are used as latrines, the consequence being that the first outburst of the rains washes into the rivers the accumulated refuse of the previous dry period together with the decaying vegetable matter that abounds in such places. The water of streams which pass through malarious places may, if used, bring about malarial fevers. We have seen natural water channels connected with main drains emptying their foul contents into rivers.

One frequent site of Hindoo burial grounds is the banks of rivers. We have seen bodies buried within nine feet of a running stream, and the same stream when running at its high water level submerge the graves, and on receding bring into view the bodies of the deceased, the superficial earth-covering having in the meantime, been washed away. The products of the putrefaction of human remains thus find access to the water, and are consumed by those living lower down the stream. We have seen corpses float down rivers, and this when epidemic cholera prevailed. It is no uncommon thing to find the rags and pillows, &c., of cremated Hindoos left on the brink of the rivers or near tanks. Enough has perhaps been said to support the statement that river water should be thoroughly purified by artificial means, before being consumed, and if other sources of supply are available, river water should not be used. It is worth while remembering that *deep* wells sunk near a river, frequently yield an exceedingly wholesome water.

During the monsoons rivers look muddy. At that period they flow with greater rapidity, and stir up the solid matters from the bottom. The rain water conveys into the rivers a considerable quantity of earth and organic matter. But a muddy water may not be altogether undrinkable. By letting it stand for a time, in a tall vessel, the mud gradually precipitates. We can hurry the process of this deposit in many ways—by the addition of a little alum, or, as is often done in Bengal, by using the clearing nut (*strychnos potatorum*).

We are acquainted with several towns in India, where the drains of the town have been specially constructed to convey the drainage into rivers.

We have inferred that the water of large rivers is, as a rule, purer than that of smaller ones. In large rivers, the poisons are in a more dilute form, the flow is more rapid, and the water mixes with a greater quantity of air—the oxygen of the air acting as a purifying agent. Much requires to be done to maintain the purity of river water in India, and thus lessen sickness and the death-rate. The very magnitude of the evils to be counteracted in any attempt to maintain this purity has caused a postponement of the application of the required remedies.

If the public thoroughly understood and rightly interpreted the dreadful effects of the reprehensible practice of converting rivers and tanks into modified sewers, we feel convinced that no expenditure of money or time would be thought too great to put an end to a system, so disgusting, so revolting, and so destructive to the health and lives of the community at large, but more especially to those whose daily calling necessitates their living exposed to and dwelling in the midst of these pernicious influences. If these monstrous and suicidal evils be not stayed, it need not be surprising to find the most fearful epidemics of cholera and even pestilences depopulating cities and muncipalities in which they are permitted to continue.

Many authorities hold that running water has an intrinsic power of purification, that the oxygen of the air dissolved in the water, is sufficient to oxidise and render harmless all the organic matter contained. Were the impurities limited, doubtless this would hold good, but on the banks of all large rivers, towns are situated one below the other, so that there is scarcely time for one source of contamination to be rendered innocuous, before others are added. Upon this point an interesting experiment was carried out (if we remember rightly by Dr. P. Frankland) to show the fallacy of such a view. Distilled water, to which a varying quantity of sewage was added, was caused to circulate automatically in a specially constructed small circular metal drain. After it had traversed the drain a number of times representing a distance greater than that of any river in England, he found the water to be still impure.

The same erroneous notion with regard to the self-purifying power of the water of rivers prevails with regard to all large bodies of water, such as those of tanks, lakes, and large reservoirs. We would here state that no ordinary source of water-supply has such self-purifying power inherent in it.

When once a river or stream is contaminated by human excrement, it is almost impossible to state when its water becomes once more pure and fit to drink.

Although river water is seldom even approximately pure, it may usually be safely imbibed when the experience of those who have used it for a long time has proved its general wholesomeness. But absolute reliance should not be placed on this good reputation, for under special circumstances river water may become dangerously contaminated. In some instances, and at particular seasons, this is specially the case with large rivers. The smaller the stream, the more jealously should it be watched, and the more carefully should it be protected from contamination.

Drying up rivers and streams occasionally become the means of the propagation of disease from their having been infected at a higher level.

The decomposing vegetable matter washed into rivers by the rains is a frequent source of "malarial" diseases.

Streams close to their sources, passing through land not cultivated, and devoid of human dwellings are good sources of water-supply; but streams and rivers passing through cultivated valleys, with towns and villages on their banks, furnishes water which must invariably be regarded as suspicious in quality, and in point of fact such waters are often dangerously polluted.

Spring-water is, as a rule, very pure, and that from deep springs is the best of all potable waters, being a naturally filtered water. It is only when springs are superficial, or within reach of contamination, that there need be any apprehension of their creating or transmitting disease. Fountains are imitations of natural springs. Just as water rushes or springs from any artificial fountain that is supplied through pipes from a reservoir at a higher level, no matter how far distant the reservoir may be, so water naturally springs from any crevice or porous spot in the ground that is supplied through the underground channels with rain-water which falls on a higher level, no matter how far distant that higher gathering ground may be. A *spring* of this kind may be met at or near the surface of the ground, or at a considerable depth, and the same physical law is at work here as in the case of Artesian wells. In *quality*, the water of springs is much the same as that of deep wells, and it contains usually the same kind of gases and solids.

Spring water usually contains an abundance of mineral matter. This mineral matter is formed from the deposition of rain from the air permeating a soil containing much carbonic acid gas. This gas dissolved in the water percolating with it through the soil, dissolves out certain amounts of alkaline earths and metals, which appear in solution as *bicarbonates* (of lime and magnesia chiefly).

The running water of a river usually contains much less mineral matter than spring water. The surface water of a river rapidly gives off its carbonic acid gas, whereby certain mineral constituents, especially those of lime, are precipitated.

Spring water contains much carbonic acid and but little oxygen, the former gas giving to such water its fresh, brisk, taste. Vegetable organisation flourishes in it, but animal bodies which require abundance of oxygen, are but sparingly represented in spring water.

Certain spring waters contain finely divided particles of *silica* and *mica* scales; especially is this so in certain springs in the Himalayas, and it is to these constituents that "hill diarrhœa" has been attributed by some authorities.

The volume of flow or discharge of a stream of water is expressed in units of volume per unit of time.

Of different units of time the second is the most convenient in mechanical calculations; the minute is the customary unit in stating the discharge of streams; the hour, the day, and longer periods are used in calculations as to drainage and water-supply.

The mean velocity of a stream at a given cross section is found by dividing the discharge, or volume of flow by the area of cross section, and is most conveniently expressed in feet per second. In ordinary cases the least, mean, and greatest, velocities may be taken as bearing to each other nearly the proportion of 3, 4, and 5. In slow currents they are as 2, 3 and 4.

There are three ways of measuring the discharge of a stream: by weir-gauges, by current metres, and by calculation from the dimensions and declivity.

The use of weir-gauges is the most accurate method, but it is applicable to small streams only.

The weir is constructed across the stream so as to dam up a nearly still pond of water behind it, from which the whole flow of the stream escapes through a notch, or other suitable sharp-pointed orifice, in a vertical plate or board, the elevation of still or nearly still water being observed on a vertical scale in the pond, when zero point is on a level with the bottom of the notch, or with the centre of a round or rectangular orifice.

RAIN-WATER.

We have elsewhere remarked that the original source of all supplies of water is the rainfall. The rain-water which escapes evaporation and also absorption by vegetables either runs directly from the surface-soil into streams, or where it sinks deeper into the ground, flows through the crevices of porous strata, and escapes at their outcrop in springs, or collects in such porous strata from which it may yield water through wells.

In the matter of water supplies the actual measurement of the rainfall is of the utmost importance. To arrive at this two factors are required: area of the district, called the drainage area, catchment basin, or gathering ground, and the depth of the rainfall in a given period.*

In order to measure the area of a catchment basin,

* A drainage area or catchment basin is, in almost every case, a district of country enclosed by a ridge or water-shed line continuous except at the place where the waters of the basin find an outlet. It may be, and generally is, divided by branch ridge-lines, into a number of smaller basins each drained by its own stream into the main stream.

a plan of the country is required, which either shows the ridge-lines or gives data for finding their positions by means of detached levels or of contour lines. When the gathering ground is large, it is preferable to measure the several smaller basins of which it consists. In some cases the boundary of a drainage area is not a ridge line on the surface of the country: this is so when the rain water sinks into a porous stratum until its descent is stopped by an impervious stratum, and in which consequently one boundary at least of the drainage area depends on the figure of the impervious stratum, being in fact, a ridge-line on the upper surface of that stratum instead of on the ground, and very often marking the upper edge of the outcrop of that stratum. If the porous stratum is partly covered by a second impervious stratum, the nearest ridge-line on the latter stratum to the point where the house stratum crops out will be another boundary of the drainage area. In order to determine a drainage area under these circumstances, it is necessary to have a geological map and sections of the district.

The depth of the rainfall in a given time varies to a great extent at different seasons, in different years, and in different places. The rainfall in different parts of a given country is, in general terms, greatest in those districts which lie towards the quarter from which the prevailing winds blow.

For practical purposes the most important *data* respecting the depth of rainfall in a given district are:—

1. The least annual rainfall.
2. The mean annual rainfall.

3. The greatest rainfall.
4. The distribution of the rainfall at different seasons, and especially the longest continuous drought.
5. The greatest flood rainfall, or continuous fall of rain in a short period.

In the question of water-supply, the least annual rainfall and the longest drought, are the most important facts to ascertain.

To obtain these data with accuracy, the daily rainfall of a given district for a period of 20 years is necessary. But observations over such a prolonged period are rarely to be had. Under these circumstances, the most reliable records of rainfall in the nearest station are to be obtained and calculated from.

It may be stated as the result of experience, that the proportions of the least, mean, and greatest annual rainfall at a given station or place usually lie between those of the numbers 2, 3 and 4 and those of the numbers 4, 5, and 6.

The *available* rainfall of a district is that part of the total rainfall which remains to be stored in reservoirs, or carried away by streams after deducting the loss through evaporation, through absorption by plants, and by the ground, &c.

The proportion borne by the available to the total rainfall varies very much, being affected by the rapidity of the rainfall and the compactness or porosity of the soil, the steepness, or flatness of the ground, the nature and quantity of the vegetation upon it, the temperature and moisture of the air, the existence of artificial drains, and other circumstances.

The following are examples:—

Ground.	*Available Rainfall.*
Steep surfaces of granite, gneiss, and slate, nearly	1
Moorland and hilly pasture	from ·8 to ·6
Flat cultivated country	from ·5 to ·4
Chalk	0

Deep seated springs and wells yield from ·8 to ·4 of the total rainfall.

Such data as the above may be used in roughly estimating the probable available rainfall of a district, but a much more accurate and satisfactory method is to measure the actual discharge of the streams (if there be any) at the same time that the rain-gauge observations are made, and so to find the actual proportion of available to total rainfall. The rain water penetrating the strata of the land from springs flowing out at a lower level, gives rise to brooks, rivers, and lakes. The rain water condensed from the ocean, is pure, soft, and does not contain mineral impurities. This soft water, however, is a powerful solvent, and on reaching the earth dissolves some and combines with other minerals with which in its onward progress it comes into contact, such as lime, magnesian salts, certain sulphates, chlorides, and a few gases.

Rain water is not altogether to be depended upon for larger towns, for its supply is somewhat uncertain, the quantity falling is small in proportion to population, and it is not very palatable.

In some places stored rain-water forms the only means of supply. Under these circumstances some special arrangement has to be made for its collection. This is sometimes done by preparing a large surface of ground in an exposed situation, the surface of which is rendered impermeable by a covering of asphalte, slates, or hydraulic cement. This prepared surface is sloped towards an outlet pipe or pipes which carry the water to a reservoir or tank. In other places the roofs of houses are used as collecting surfaces. "The first portion of rain which falls and descends from the roof should be rejected, as it is liable to be much polluted with soot, vegetable matter (leaves), and animal matters (excrement of birds, &c.), washed off from the slates or tiles. After the first washing, the remainder of the water may be collected and stored. Roberts' Rain-water Separator effects this purpose by allowing the first portion of water that passes through the apparatus to run to waste through a pipe at its base. After a certain time, the apparatus, which is balanced on a pivot, cants over, owing to its centre of gravity being altered when nearly full of liquid, and the water escapes through the outlet below into another pipe, which conducts it to a storage cistern. Rain-water should always be stored in as pure a condition as possible; otherwise the storage receptacle becomes coated with foul matters, which putrify and poison the water."*

Rain-water is potable, but it often becomes impregnated with dead animal matter and fungoid growths from the roofs and gutters where it falls, and is then passed into cisterns in a state far from pure. In these vessels it precipitates some of those organic impurities, which form a decaying sediment at the bottom. Rain-water contaminated in this

* *Hygiene and Public Health.* By LOUIS PARKES, M.D., 2nd Ed., p. 6.

manner if used for drinking purposes should always be filtered. The cistern should be thoroughly cleaned before the rain water enters it.

Rain water that has fallen on corrugated iron or zinc roofs should not be used for drinking purposes.

The water of *jheels* and *marshes* is one of the most unwholesome that can be used. It is decidedly impure, containing an abundance of decaying vegetable matter (from 10 to 40 grains per gallon), although it sometimes has the appearance of being pure. This vegetable matter, in combination with heat and moisture, is the cause of "malarial diseases"—ague, remittent (including "jungle") fever, enlarged spleen, dysentery, diarrhœa, anæmia and sometimes neuralgia. Such water should never be drunk. If compelled to use it, we should first give it a series of boilings and then filter it.

The water of *ditches*, pools and ponds, is likewise excessively impure, especially if they are close to human habitations. It is usually stagnant, foul, and full of organic matter, including living organisms, animal and vegetable. Its consumption is always associated with great danger to health, and if its use is unavoidable, it should be filtered, repeatedly boiled, and filtered again before being used for drinking purposes. In this case there must be two filters. We have seen villages depending entirely for their water-supply, on ponds and the water contained in shallow excavations.

The *effluent* from *irrigated land*, particularly that from rice-fields, is exceedingly impure and dangerous to use for drinking purposes. In some agricultural districts, this water forms a principal source of supply. These fields are regularly manured and contain decaying vegetable and animal matter. The combination of putrefying animal and vegetable organic matter in such water is most pernicious to the well-being of those who drink it.

WELL WATER.

There are three varieties of wells, *shallow* or *superficial*, *deep*, and *artesian*. The waters of these wells vary much in quality. The last mentioned may be considered a variety of deep wells, and we will dispose of it with a few words, for the reason that artesian wells have, up to date, served no practical purpose in Indian town, or village hygiene. Artesian wells are made by boring into the ground until a layer of water is come upon, which layer has in some other place a higher level. The water is forced up and spouts out as a permanent artificial spring. The water of these wells is *very* good and the supply abundant; but it lies so far below the surface as to be too costly to get at.

A *deep well* is one that passes through the first impermeable stratum of the soil, which stratum usually consists of stiff clay, but occasionally of rock. The ordinary depth of such a well is from 40 to 50 feet. Sometimes these wells have a much greater depth.

The water of deep wells owes its characters to the rock formations through which it has passed. As a rule, it is pure and free from contamination from organic matter. The quality of deep well water varies therefore in accordance with the nature of the geological formations through which the water flows before entering the well. Local experience is generally sufficient to indicate what the quality of the water ought to be.

Deep well water is much harder than river water. The hardness is chiefly due to lime salts, especially the carbonate, held in solution by excess of carbonic acid. The water is usually cooler, and contains less organic matter than superficial wells, and even if subsoil water does find its way to it, that water has to pass through a greater depth of earth, with the result that almost all the organic matter is removed by natural filtration.

Shallow or superficial wells usually have a depth of 20 or 30 feet. They do not extend below the first impermeable layer of the earth's crust.

Such water is therefore exposed to pollution owing to the presence of the many impurities contained in the surface layer of the soil. Water from such wells is almost always unwholesome, and of very suspicious quality.

The water of all wells and springs is derived from rain. The rain-water percolates through various surface soils until stopped by an impermeable stratum of clay or a layer of rock. In the impermeable strata the water collects, rendering them water logged up to a certain level, the line of this water-logging corresponding with the lowest level of the natural outlet through which the underground water is escaping to rivers, streams, &c. Beneath the soil, then, we have an extensive subterranean reservoir, and it is this reservoir that is tapped when a deep well is sunk through stiff clay or rock.

From the foregoing statements with regard to wells, we see that the water they yield may be good or bad. If a well is deep, the water it supplies is probably good, provided that the flow of surface drainage into it is prevented. On the other hand a shallow well, as a rule, contains impure water. We mentioned a subterranean lake as existing at a variable depth from the surface. The water from this source is always pure.

Nearer the surface, we have the *subsoil water*. Water from this source is, as a rule, of suspicious quality, for it dissolves out the impurities, animal, vegetable, and mineral, contained in the subsoil.

We find that the level of the subsoil water alters very much during the year. It is supposed by Prof. Pettenkofer that epidemic outbreaks of both enteric fever and cholera are coincident with changes in the water level of the soil. This he considers especially the case in loose or gravelly soil, and when well water is used, which has been taken from wells sunk into such soil, which has been contaminated by human excrement. According to this authority low water under these conditions, or a rapid rise in the water line after being low, or any great or sudden change in the water level, is sure to be followed by an epidemic of enteric fever. It appears that a process of development of matters excreted from the human body is necessary, in order to secure the evil results arising from excrementitious pollution of water, and this development in part takes place in contact with the soil; or certain organic changes occur in the soil, which could only be secured by a change in the water level.

The fluctuating water line simply acts mechanically in furthering the processes of nature. We are of opinion that without the fluctuation in the water in the water level, excremental pollution appears to be inoperative in producing epidemic disease. In India, cholera produces the greatest mortality at a time coincident with the lowest levels of the subsoil water. A fluctuating water line alone, however, is not the cause of disease, as we can well understand; that water may fluctuate and produce the most healthful results by promoting an aeration and purification of the soil. Disease is the result of excremental pollution of the soil, favored by certain descriptions of soil and variation in the subsoil water level within that soil. Those who design systems of sewers or drains will do well to remember when water is met within the soil, that this water may become a destructive agent to health and life by reason of its contamination by leaky sewers, the evil effects of which may be carried to considerable distances. All subterranean water must be looked upon not as so much inert matter, but as always on the move ready to carry the influences of pollution in the directions of its flow. It has often been observed that on sloping ground disease due to excremental pollution occurs only on the lower side of a street, under the houses of which the underground current of water is poisoned by a leaky sewer, or other receptacle of fæcal matter, while the houses located above the sources of pollution are healthy.

Those who have had much to do with municipal work in India will be familiar with the following history of the origin of a large number of superficial wells. In erecting a new hut or house, the builder excavates the soil from the ground around the area to be built upon, the soil being used for building purposes. The builder after digging to a depth of 4, 6, or more feet, finds that he has come upon a water-bearing stratum of soil—the subsoil water is reached. The more he excavates, the larger and more continuous the supply of water. He imagines that he has come upon a permanent supply of good water, and with a little further deepening he has constructed his *bowrie*, which henceforth and for generations is the only source of water-supply to his family.

POLLUTION OF WELLS.

The vast majority of the people of India have to depend on wells for their water-supply. This universality of use of well water, together with the fact that the water of wells is in a large number of cases impure and unwholesome, render a consideration of this form of water-supply very important. We have alluded to the habits of the people as being instrumental in effecting pollution of water-sources generally. These habits act more banefully on the limited quantity of water contained in wells. Wells sometimes receive the subsoil drainage water from swamps, cesspools, graveyards, vaults, &c., rendering the water unfit for use. The chief cause of the pollution of superficial wells, however, is the flow of surface drainage and subsoil water into them. By surface drainage we mean the flow of all refuse water of the soil before it finds its way to a proper water-course or channel. This surface water in passing over and through the filthy ground around habitations, carries with it many poisonous matters. We see, therefore, that in the case of superficial wells, the quality of the water they supply depends upon the nature of the soil through which the subsoil water flows. This soil has, as a rule, been contaminated by the organic impurities of years. Now, until all the vegetable and animal organic matter of the soil is oxidised (a process that takes years to complete), the water from superficial wells remains impure : but in the absence of proper soil and surface drainage, the pollution of the soil is constant and progressive, and therefore this oxidation of organic matter is never completed. The water of some of the superficial wells we have analysed is really a form of dilute sewage. This form of contamination is preventable to a considerable extent, by constructing a proper parapet wall around the mouth of the well. All wells should be protected by being lined for a depth of 15 feet at least, with a thick layer of hydraulic cement. Even shallow wells would be improved by this means. If the subsoil water sinks below the level of this lining, it has at least been filtered through 15 feet of soil before entering the well. As an additional precaution against direct contamination by surface and subsoil water, the soil around the tube of the well should be puddled to as great a depth as possible. In steining a well, the earthenware well-rings (or *tikras*) may be used.* The original

* One objection to the use of earthenware tubes or *tikras* is, that in drawing water by means of a windlass and bucket, the swinging of the bucket is liable to break the rings.

excavation should exceed the diameter of the well by 3 feet, to allow of thoroughly well worked puddle being rammed down. This puddle must be impervious, and the best form of earth for puddle is a light loamy soil with a small share of sand. Surface alluvial soil is useless. From the outside of the basement of the parapet wall, there should be a smooth, sloping, pavement, extending for a distance of 5 feet or so, and this should be surrounded by a masonry channel lined with good cement. This channel should convey all refuse water to a cistern, from which latter it could be periodically cleaned out; or better still, the drain might lead to one of the public drains. But lining the upper part of a well with cement does not *permanently* prevent the access of subsoil water impurities. The soil around the well may act efficiently as a filtering medium for a time, but eventually its powers in this respect, like those of all other filtering media, become exhausted, and when this stage is reached, all the soil surrounding the well is contaminated. The result then is, that instead of removing the impurities of ordinary subsoil water, it adds further to them, by giving up some of those which it had previously removed. Before sinking a deep well, it would be prudent to ascertain the direction of the flow of the subsoil water, for then the sinking might be carried out in such a way as to cut off the access of the subsoil water. If any difficulty is experienced in ascertaining the direction of the flow of the subsoil water, we may be guided by the general rule, that it flows with the natural inclination of the ground. The area of soil drained by a well, roughly corresponds to a circle, the centre of which is the well itself, and the radii from four to eight times the depth of the well. In some cases, however, the area drained is considerably greater than this, the diameter of the drained area being 200 yards or more. It will thus be seen that no source of pollution should be permitted to exist within 100 feet of a well, and even this distance is, in many cases, insufficient to prevent contamination. For a well to afford a permanently wholesome water, it must be sunk below the first impermeable geological stratum, and be fed by the subterranean lake that exists there. This deep supply is rarely reached at a depth less than 50 feet.

Municipalities are more or less constantly constructing parapet walls around, deepening and cleaning out the silt and decomposing filth that accumulates at the bottom of wells. Without seeing and smelling the matter that is removed from the bottom of some shallow wells, it is difficult to imagine that such filth could be deposited. The poor and unfortunate people of *bustees* are daily drinking this material in a dilute form. If surface wells are indispensable, they ought to be cleared of silt periodically. It would be a great improvement were the people to draw water from wells by means of a metal bucket which should be kept at the well. Caste prejudice comes in here, but this might be overcome by using separate buckets for different castes. The employment of a pump would obviate these difficulties. These provisions prevent the introduction of private utensils which are often unclean.

No trees should overhang wells, or be allowed to grow into or through their walls. An important item obviating many difficulties would be the placing of a wooden cover over every well. This, in addition to keeping out birds and their droppings, insects, decaying leaves, &c., would remove the possibility of the people otherwise fouling the water. Another advantage would be to have the mouth of the well as small as compatible with convenience.

That a well is popular as a source of drinking water is no guarantee to the purity of its water. The water of wells containing organic matter undergoing decomposition frequently has a peculiar, but not unpleasant taste, and the slightly sparkling appearance given to it by the carbonic acid formed in the decomposition of the contained organic matter, gives it the specious characters of a good water, and induces people to seek a particular well in which this process is going on.

When much water is removed from a deep well, the level of the water in it descends below that of the subsoil or ground water. The subsoil water now directly feeds the well and flows towards it in such a way, that the area of soil draining its water into the wells forms a sort of pyramid with the apex downwards, the apex corresponding in size with the calibre of the well itself. The result is that all the soil that is embraced in the area covered by the base of the pyramid drains its water into the well. Further, the impurities of any foul ponds, and filth deposits within its reach, are washed into the well. In the case of some wells the larger the quantity of water drawn from them the larger the base of the drained area, the greater the amount of subsoil water entering it, consequently the greater the degree of contamination.

This is one of the reasons why in the sinking of a well the direction of the flow of subsoil water currents is so important, for should they pass beneath houses, near well-privies, &c., the well they feed, may become the means of pestilence and death, instead of serving the functions of life and health. The surface soil in India is chiefly of a loamy character, and therefore permits of free percolation of water, which water, as we have before stated, carries with it the impurities of the soil. The descent of the water beyond a certain level is stopped by a layer of clay, but the water oscillates upwards and downwards, and this oscillation helps to increase the degree of saturation with impurities, which are conveyed with the subsoil water to any wells which this subsoil water may feed. Before being opened for use, the water of all newly-dug wells should be analysed by some competent person, and this analysis should be repeated from time to time to assure the consumers of its continued purity, or inform them of any deterioration that may have taken place. It appears to be legitimate to presume that well-water is impure and unwholesome, until it is proved by analysis to be otherwise.

A cesspool or *sundass* should not be co-existent with a well in a compound: as we have stated, the loamy character of the soil of most Indian towns permits of free percolation from the former to the latter, and we have more than once seen a direct leakage from a sundass occur in this way. We have come across localities in a thickly-populated municipality and city in which the ground around wells was honeycombed with *sundasses*. The effects of this on the quality of the water of superficial wells can easily be imagined. That such a condition is coincident with excessive disease-rate needs no verification,—it is self-evident. Deep well water is not so liable to contamination as that of superficial wells, but even in these there is always the possible risk of pollution by percolation from cesspools, sundasses, and deep drains. As such wells are frequently sunk in the vicinity of houses, this danger is not an imaginary one. If there is any known infiltration from a cesspool or sundass through surrounding soil, the well should be filled up, unless the polluted soil can be entirely removed, and the source of its contamination sought out and got rid of. The deepening of a superficial well always lessens the degree of impurity, as it causes the feeding water to be filtered through a greater depth of earth.

In the case of some superficial wells situated in the heart of populous localities, any material improvement of the quality of the water they yield is practically impossible. The ground around is so saturated with organic impurities, that it will continue to add its quota of poison, as long as the well exists. Such wells should be permanently closed, preferably by filling them with earth, and if necessary they should be replaced by deep wells sunk in clear ground, remote from sources of pollution.

It may appear unnecessary to state that wells should not be sunk in graveyards; yet we have counted no fewer than 19 instances of this in one municipality. The organic products from decomposing human remains gaining access to water is highly pernicious, and if the possibility of disease germs being washed into the well by the subsoil water in its onward flow to the well be added, the closing of all such wells needs no further insistence.

It has come within our experience to find a well situated on the margin of a highly polluted river yield a comparatively pure water. During a threatened water famine in Hyderabad, the bed of the supplying river having dried up, tube wells were sunk to a depth of 20 feet. The yield was infinitely purer than that of the wells situated within bustees, notwithstanding that the river, when running, was frightfully contaminated.

Another source of pollution of wells, streams, and tanks is the washing of nightsoil carts in the water. The possible evils associated with this pernicious practice—the direct spread of cholera, enteric fever, &c.—are obvious. This has on more than one occasion come under our observation.

In all places where trades giving rise to nuisances exist, precautions should be taken that the trade refuse does not gain access to any source of water-supply.

Shallow wells yield, as a rule, notoriously bad water. In their ordinary state the water of the wells afford an excellent breeding place for germs. These wells are supplied by the ground water, and it is supposed by some that the height of the level of this ground water has an important bearing on the prevalence of certain diseases at certain seasons. With regard to the relation between the supply of shallow wells, disease and low ground water, some explain it by stating that it is due to the greater concentration of the impurities in consequence of decreased supply. In reality, however, this is an erroneous view, for analysis has proved the waters at such periods to be purer than when the level of the ground water is high. We should remember that there is decreased fluctuation when the ground water is low, and this decreased motion of water is associated with stagnation, and stagnation with deterioration. We have no hesitation in stating that all shallow wells and surface ponds in the interior of bustees and Indian towns generally should be filled up and permanently closed, as sources of water-supply. Serious contamination is scarcely ever absent. Their continuation as a means of water-supply can only serve to perpetuate the occurrence of many of those diseases we have, in a previous section, associated with impure drinking water. We feel convinced that if municipalities adopted this suggestion, they would be carrying out one of the most important of their duties as guardians of the public health.

It is hopeless to expect to maintain the purity of well water situated in densely populated parts of Indian towns and villages. Unless the water of a well is decidedly unpalatable, the people will not go out of their way to procure it from a better source. We have already mentioned that when the palate recognises impurities, pollution to a dangerous extent has already taken place, and even long before this stage of contamination is reached, the water may be unsafe to use. The poor will often resort for their supply to a shallow pool or excavation close at hand, rather than get water of better quality at a little distance. Instances of this kind come under our observation daily.

A few years ago we were asked to report on the causes of pollution of a certain large well attached to a mosque, and to make suggestions for removal of its sources of pollution. At the well we discovered several persons bathing, others washing their clothes on the parapet walls, others washing their mouths and spitting into the water; some were washing their feet in the water. Many were drawing water for drinking purposes in filthy earthenware utensils. We recommended that the parapet wall be raised to $3\frac{1}{2}$ feet from the ground, and that pipes with stop cocks be let into the wall, and further suggested the construction of a bathing cistern on a lower level in proximity to the well. This well remains in *statu quo*, and the impurities greater than ever. Even if such recommendations as these were carried out, they can effect good in a limited number of cases only; they become impracticable when we have to deal with the water-supply for wells for a community of, say, 100,000 souls. The well above alluded to supplied about 2,000 people with water. We can imagine the effects of its wholesale defilement. From the results of 29 analyses carried out during the last 14 months of waters from different wells in Chudderghat (Hyderabad, Deccan), we found that in three cases only was the water potable. The following is the average composition in these 29 instances:—

Total Solids.	Hardness.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.
25·2	13·5	3·5	·02	·09

All the impurities are in excess of what they should be in even a "usable" water.

There are many points in favour of the total abolishment of wells when a better water-supply is available. The following are a few of these:—

(1) In drawing water from wells, there is great expenditure of time and labour, in consequence of which

(2) An insufficiency will be drawn and used, and as a secondary result, there is bound to be

(3) Defective domestic cleanliness with all its accompanying evils. There appears to be a fixed ruling on the part of the people, that the quantity of water used decreases as the labour expended in procuring it increases; and conversely where facilities for providing it are great, the consumption is large.

We have proved, from special observations made on the subject, that the ordinary bustee occupant does not use more than two gallons of water a day (unless the well is at his very door), a quantity altogether inadequate to effect the least semblance to domestic or personal cleanliness.

Let us attempt to put the matter a little more clearly. To enable perfect cleanliness to be carried out in a household with the average number (about six) of people in it, each person requires about 12 gallons per day, that is, 72 gallons has to be daily conveyed to the house. Say the average distance of the well is 50 yards (many are 200 or 300 yards off) and the depth of the well 30 feet.

One gallon of water weighs 10lbs.; 72 gallons, 720lbs., which raised 30 feet = 21,600 lbs. The same carried 50 yards or 150 feet = 108,000 lbs., or about 48 foot tons, in all there being about 60 foot tons of labour expended. Modern public waterworks aim at altering this by providing water at the doors of the inhabitants.

TANK WATER.

A large proportion of the people of India use tank water for drinking and other purposes. When these tanks were originally constructed, the water was probably more or less wholesome; but the inhabitants in process of time, have by their habits rendered it of doubtful quality. The causes of pollution of tank water are many, and to a large extent similar to those in operation in rivers. The effluent of drains is frequently permitted to enter tanks. We have seen instances where the drains have been purposely constructed to convey their contents into tanks, practically converting the tanks into sewage reservoirs. In one case we observed that one of the best water-supply tanks in the vicinity of a large town formed the catchwater basin of the drainage from the adjoining area. An analysis of the water from this part of the tank showed it to be frightfully impure. We need scarcely write that this is an unmitigated evil, and one that must materially interfere with the wholesomeness of the water. It should be permanently prohibited. By the provisions of nature—dilution, oxidation, animal and vegetable life, the harmful effects of this wholesale nuisance are reduced, but they are insufficient.

The main sources of contamination of tanks are :— The habit of committing a nuisance on the slopes of the tank. This should be absolutely prevented by the posting of peons, watchmen, or policemen along the margins of the tank. The buffalo nuisance is also met with at the tank.

Buffaloes, horses, donkeys, elephants, &c., are regularly brought to tanks to be watered and washed, and deposit their refuse on the brink. Buffaloes may frequently be seen wallowing for hours in the tank water. This could be remedied by railing in the margins a little above the highest water level, or by surrounding it with walls. If necessary to provide for the washing of cattle and horses near a tank, a special trough should be constructed for the purpose. People wash themselves in the water of the tank, after performing the offices of nature close by. Tanks often form a general bathing place for a large part of the community. Special tanks or ghauts should be set apart for bathing. Tanks should only be accessible by steps at one side. No person should be allowed to draw water in a dirty utensil. All vessels used for the purpose should be thoroughly cleaned before being brought to the tank; or better, public buckets might be kept at the tank. People should not wash their feet, hands, or mouth in the tank water, and the disgusting habit of spitting in the water should be strictly forbidden. All these practices are remediable by proper police or peon supervision. Offences of this nature should be made punishable, and notices might be posted in vernacular, pointing out the prohibition of such habits, and the penalty to which offenders are liable. The Indian Penal Code is very clear on this point (sec. 277). Its penalties should be imposed on all delinquents. It should be remembered that tank water deteriorates during the hot weather as a result of putrefactive fermentation, but during the rains, its quality is improved as its impurities become less concentrated. It is always charged with animal and vegetable matter, and swarms with living organisms, especially during the dry weather. It is during this part of the year that the public health suffers so much from its consumption. The water of rapidly drying up tanks is usually very impure. Water of average temperature containing much organic matter, forms an excellent breeding place for germs—in it they acquire increased vitality and rapidly multiply. The water in tanks during this season is a constantly decreasing quantity, whilst its impurities are becoming progressively greater. The gross organic impurities of course subside.

There is another evil which helps to contaminate tank water, and one which may be seen universally. This is the conveyance of the water in unprotected open channels to the tank. For several months of the year the channel is dry. During these dry months, their bed is used as an open latrine. At the first heavy shower of rain, all the accumulated excrement is washed into the tank. This is a matter to which sufficient attention is not given. We have seen such a channel running by a bustee in which epidemic cholera prevailed. We may accept the dictum, that no water but that of the rain which falls directly into it, and that of the feeding channels, should be allowed to enter tanks.

The surface drainage of the ground and the tank should be prevented from flowing into the water, unless such drainage is the absolute means of feeding the tank. The effluent from irrigated land should be prevented from entering tanks. This may be done by raising the banks above the level of the surrounding ground.

The many sources of contamination to which tanks in the vicinity of towns and villages are subjected, render the water always dangerous, without previous purification by filtration, or preferably by boiling and filtration. The larger tanks contain purer water than ordinary rivers. We should remember that a water that has been infected to only a very slight extent, if the source of infection be not removed, may acquire dangerous qualities with a little greater infection, or under more favourable circumstances. Such a water is a perpetual menace to the health of the consumers.

No trees should be allowed to grow near tanks, for the falling leaves are blown into and decay in the tank water. All decayed and decaying plants should be removed from tanks.

Certain plants and almost all fish are useful in purifying tank water when they are not in excess. Plants act chemically in the water by giving out oxygen, and fish feed on the smaller animals contained in the water—crustaceans, insects, and organic matter. It has at times occurred that the purity of large volumes of water has decreased on the removal or killing of fish, and the only successful means of restoring their purity has been the re-stocking with fish. The best fish for stocking tanks are the *ruho or rooi*, *kalla*, *mirgal*, *kalaboas* (of the carp family).

Much care is necessary in selecting ground for the construction of a tank for drinking water. The interior of towns and villages is to be avoided, for the soil of such places has been impregnated with the impurities resulting from the percolation of filth and drainage for years. "Made soil" is likewise specially objectionable as a site for a tank. The vicinity of all filthy pools and ponds is also to be avoided, for they will feed the tank through the medium of the subsoil. This may of course be prevented by having a thoroughly well rammed puddle bottom, and constructing an embankment, the core of which should be puddled.* All this, however, increases the initial expense, and a puddled bottom is not always effectual in preventing percolation from the subsoil. The inside of the embankment of tanks should be constructed of masonry, and the outer face turfed. No trees or shrubs should be allowed to grow on the embankment, for the roots sink into, and split up the core, causing leakage and the formation of rat holes. A new tank should always be dug in new ground, and any foul ponds, cesspits, or superficial wells close by should be filled with earth. The earth dug from the tank will

* Regarding the details of *bund* construction, *vide* section on *Reservoirs*.

be valuable for this purpose. Tanks are fed by natural water channels leading to them, by specially constructed channels from impounding reservoirs or by similar channels without such reservoirs. In some cases tanks form the catchment basin of a large area of ground, specially prepared or not, to receive the water.

In the vicinity of some towns and large villages, there are old dilapidated tanks, the restoration of which, as sources of water-supply, could be effected at comparatively small cost. These might in some cases be used as the settling reservoirs of water works.

Large volumes of standing water, such as those of tanks, lose about 5 feet of water per annum by evaporation and absorption.

Purposes and Capacity of Store Reservoirs.—A store reservoir is a place for storing water, by retaining the excess of rainfall in times of flood, and letting it off by degrees in times of drought. They are used for one or more of the following purposes :—

To prevent damage by floods to the country below the reservoir;

to prevent the evil consequences of droughts;

to increase the ordinary or available flow of a stream by adding to it the whole or part of the flood water;

to enable water to be diverted from a stream without diminishing the average monsoon flow;

to allow mechanical impurities to settle.

The *available* capacity, or storage-room of a reservoir, is the volume contained between the highest and lowest working water-levels, and is less than the *total* capacity by the volume of the space below the lowest working water-level which space is left as a place for the collection of sediment, and is either kept always full, or only emptied when it is absolutely necessary to do so for purposes of cleansing and repair. It is impossible to lay down a universal rule as to how much the space so left, or "bottom" as it is called, is but in some good examples of artificial reservoirs, it occupies about one-sixth of the greatest depth of water at the deepest part of the reservoir. The absolute storage-room required in a reservoir is regulated by two circumstances,—the demand for water, and the extent to which the supply fluctuates.

The best rule for estimating the *available* capacity required in a store reservoir, would probably be one founded upon taking into account the supply as well as the demand.

In order that a reservoir of the capacity prescribed by the preceding rule may be efficient, it is essential that the least available annual rainfall of the gathering-ground should be sufficient to supply a year's water-supply.

The foregoing principles as to capacity have reference to those cases in which the water is to be used to supply a demand for water. When the sole object of the reservoir is to prevent floods in the lower parts of the stream, it ought to be able to contain the ascertained greatest total excess of the available rainfall during a season of flood above the greatest discharging capacity of the stream (consistent with freedom from damage to the country).

Reservoir Sites.—In choosing the site of a reservoir, the engineer has chiefly three things to consider:

the elevation of the site, the configuration of the surrounding country, and the materials for the work, especially those materials which will form the foundations of the embankment, or embankments, by which the water is to be retained.

The elevation of the site must at once be so high, that from the lowest water-level there shall be sufficient fall for the pipes, conduits, or other channels by which the water is to be discharged, and at the same time so low that there shall be a sufficient gathering-ground above the highest water-level.

The configuration of the ground best suited for a reservoir site is that in which a large basin can be enclosed by embanking across a narrow gorge. To enable the engineer to compare such sites with each other, and to calculate their capacities, plans with frequent contour lines are very useful, or in the absence of contour lines, numerous cross sections of the valleys. Of course, the water's edge of a reservoir would itself be a contour line.

After the site of a reservoir has been fixed, a plan of it should be prepared, with contour-lines numerous and close enough to enable the engineer to compute the capacity of all parts of the reservoir from the lowest to the highest water-level, so that when the reservoir is constructed and in use, the inspection of a vertical scale fixed in it may show how much water there is in store.

Care should be taken to observe whether the basin of a projected reservoir site has, besides its lowest outlet, higher outlets through which the water may escape when the lowest outlet is closed, unless they also are closed by embankments.

The figure of the ground at the site of a proposed reservoir embankment must be determined with care and accuracy, by making, not only a longitudinal section along the centre line of the embankment, but several cross-sections of the site of the embankment, which should be at right angles to the logitudinal section, unless there is some special reason for placing them otherwise. One of these cross-sections of the embankment site should run along the course of the existing outlet of the reservoir site, which is usually a stream, and another along the course of the intended outlet.

Materials.—The soil of the site of the intended embankment should be impervious to water, or capable of being easily removed so far as it is pervious, in order to leave a water-tight foundation; and its nature is to be ascertained by borings and trial pits. In some cases it is not sufficient to confine this examination to the site of the embankment; but the bottom and sides of the reservoir-basin must also be examined, in order to ascertain whether they do not contain the out-crop of porous strata, which may conduct away the impounded water. The best material for the foundation of a reservoir embankment is clay, and the next, compact rock free from fissures. Springs rising under the base of the embankment are to be carefully avoided.

The engineer should ascertain where earth is to be found suitable for making the embankment, and especially clay fit for puddle.

Construction of Reservoir Embankment.—1. *General Figure and Dimensions.*—A reservoir embankment rises at least 3 feet above the top water level, and in some cases 4, 6, or even 10 feet. It has a level top, whose breadth may be in ordinary cases about one-third of the greatest height of the embankment; the outer slope, or that furthest from the water, may have an inclination regulated by the stability of the material, such as $1\frac{1}{2}$ to 1, or 2 to 1; the inner slope, or that next the water is always made flatter, its most common inclination being 3 to 1.

Making the Embankment.—The embankment is to be made of clay in thin horizontal layers. The central part of the embankment should be a "puddle wall" of a thickness at the base equal to about one-third of its height; it may diminish to about two-thirds or one-half of that thickness at the top. Great care must be taken that the puddle wall makes a perfectly watertight joint with the ground throughout the whole of its course, and also with the puddle coating of the culvert.

During the construction of a reservoir embankment, care should be taken to provide a temporary outlet for the water of its gathering ground, sufficient to carry away the greatest flood discharge. This may be done either by having a pipe sufficient for the purpose traversing the culvert, or by completing a sufficient bye-wash before the embankment is commenced.

The outer slope is usually protected from the weather by being covered with sods of grass. The inner slope is usually pitched or faced with dry stone set on edge by hand about a foot thick up to above three feet above the top water-level, and as much higher as waves and spray are found to rise. The top of the embankment may be covered with sods like the outer slope; but it is often convenient to make a roadway upon it. In either case it should be dressed so as to have a slight convexity in the middle, like that given to ordinary roads, in order that water may run off it readily.

No trees or shrubs should be allowed to grow on a reservoir embankment, as their roots pierce it and make openings for the penetration of water. For the same reason no stakes should be driven into it.

Appendages of Store Reservoirs.—The waste-weir is an appendage essential to the safety of every reservoir. It is a weir at such a level, and of such a length as to be capable of discharging from the reservoir the greatest flood-discharge of the streams which supply it, so as not to allow the water-level to rise to a dangerous height. The water discharged over the weir is to be received into a channel, open or covered, as the situation may require, and conducted into the natural water-course below the reservoir embankment. The weir is to be built of ashler or squared hammer-dressed masonry; the bottom of the waste channel, directly in front of it, is best protected by a series of rough stone steps, which break the fall of the water. Instead of a waste-weir, a waste pit has, in some cases, been used, that is to say, a tower rising through, or near the embankment to the top water-level; the waste water falls into this tower and is carried away by a culvert from its bottom; but the efficiency and safety of this contrivance are very questionable, for it seldom can have a sufficient extent of overfall at the top.

Water sluices may be opened to assist the waste weir in discharging an excessive supply of water. They may either be under the control of a man in charge of the reservoir, or they may be self-acting.

The bye-wash is a channel sometimes used to divert past the reservoir the waters of the streams which supply it, when these are turbid, or otherwise impure. Its course usually lies near one margin of the reservoir, and is then conveniently situated for receiving the water discharged by the waste-weir.

When erected for purposes of water-supply, the object of a weir is partly to make a small store reservoir, but principally to prolong a high top water-level from its natural situation at a place some distance up the stream to a place where water is to be diverted from the stream to drive machinery, or for some other purpose.*

PUBLIC WATER WORKS.

The subject of providing communities with pure drinking water on a large scale is one that in the present day is attracting no small amount of attention. The people of India are becoming conscious of the immeasurable superiority of a system that permits of drawing pure water from taps and hydrants, to that of a supply from polluted wells and tanks. Every year adds one or more to the number of the towns and municipalities supplied with water on this system. The inauguration of

* The above account of reservoir construction has been abstracted from RANKINE's *Civil Engineering*.

public water works has produced considerable influence in lessening epidemic and endemic disease, such as enteric fever and cholera on the one hand, and "malarial fevers," dysentery, diarrhœa, guinea-worm, &c., on the other. That an impure and insufficient water-supply is coincident with a high death-rate is shown in the following table*:—

Name of town.	Population.	Water-supply, gallons per head.	Death-rate per 1,000.	Remarks.
Christiana ...	122,036	39·7	18·44	Public water works.
London ...	4,000,000	31·25	20·40	
Baltimore ...	408,520	54·00	21·90	
Boston ...	400,000	73·30	22·00	
Philadelphia ...	1,000,000	54·15	22·30	
Genoa ...	137,037	24·50	22·57	
Rangoon ...	134,176	28·00	22·92	
Stuttgart ...	110,000	26·40	23·50	
Rotterdam ...	162,139	22·45	23·50	
The Hague ..	130,000	17·60	23·60	
Chicago ...	560,693	102·50	23·60	
Trieste ...	146,357	4·4	30·00	
Lahore ...	128,000	10·00	31·91	Wells
St. Petersburg ...	929,093	21·30	35·20	Polluted river.
Cairo ...	450,000	...	37·00	Do.
Madrid ...	397,816	3·3	38·30	
Seville ...	132,798	7·26	39·32	Partly river.
Delhi ...	173,393	...	47·86	Wells.
Ahmedabad ...	124,767	...	49·07	Polluted.
Pekin ...	500,000	...	50·00	Subsoil water.
Veramgam ...	18,990	...	61·24	

In an address recently delivered to the Cawnpore Municipal Board, MR. J. B. HUGHES, Sanitary Engineer to the North-Western Provinces, in urging the necessity of establishing a public water-supply in that city, said :—

"There is happily another proposition established by experience, that the causes which produce high mortalities are within the control of local authorities,

* Abstracted from "*Sanitary Engineering for India.*" By R. B. HARRINGTON.

and by substituting pure water for dirty water or suspicious water, and by the prompt removal of filth, an abnormal death-rate may be considerably reduced and made to approximate to normal proportions. It is because this fact has been so thoroughly established, that the law gives large powers to the Local Government of the North-Western Provinces in the N.-W. P. Municipal Act; it is the reason why large powers are given to Municipal Boards themselves, to summarily deal with private rights and interests, in cases affecting the public health.

"I shall be glad to show some statistics, illustrating the effect of water-supply and sewerage work on the public health, to those members of the Board who would like to go deeply into the subject. Some of the *most striking cases are given below*:—

Effect of a Pure Water-Supply.

Name of town.	Population.	Expenditure on water-supply.	Death-rate per thousand.	
			Before introduction of water.	After introduction of water.
		£		
Chester ...	39,569	74,816	30	23·3
Gildersome ...	4,000	2,000	27	16·
Hull ...	149,000	215,000	31	16·
Manchester ...	1,000,000	2,850,000	33	24·7

"The experience in English towns has been reproduced in India, and I would ask your attention to the case of the town of Burdwan, which, acting on my advice, carried out works for the supply of water for domestic purposes which were opened in December 1884. Previous to the construction of these works, the town was notoriously unhealthy, with a death-rate of 42 per thousand, which has now been reduced to 20 per thousand. In the town of Calcutta the death-rate now varies between 25 and 26 per thousand, although much remains to be done to perfect the present system of water-supply and drainage, which is rapidly approaching completion. The death-rate in the suburbs of Calcutta, in which water-supply and sewage works are about to be commenced, is now between 44 and 69 per thousand. The cholera death-rate has been reduced from an annual average of 4,056 to 1,492. The deaths from fever have been reduced in the following proportions :—

Periods of three years.	Total deaths from fever.
1877—1879	16,033
1880—1882	11,180
1883—1885	10,891
1886—1888	9,873

" In all localities and under all heads of disease a steady improvement has followed the introduction of drainage and water works."

In contemplating the opening of a new system of public water-supply, the main points to attend to are :—

1. Whether or not the supply is *permanently* equal to the demand;

2. That the water at its source is pure, and that its purity can be maintained until it reaches the taps and hydrants;

3. The accessibility of the water at its source, but particularly when distributed; and

4. The cost of the scheme, and the expenses associated with its maintenance.

In a large number of cases a public supply is available at a greater or less distance from municipalities and towns, either from rivers, tanks, or deep wells. Some instances offer the greatest facility to opening public supplies, others present great natural barriers. As an instance of the manner in which almost insuperable obstacles may be overcome, we would refer our readers to the LVth Volume of the *Proceedings of the Institute of Civil Engineers*, wherein will be found a paper by Captain STRAHAN R.E., on THE KURACHI WATER WORKS. An instance of this description opens out unbounded hope that in many cases in which the idea of the possibility of obtaining a water-supply source has been entirely relinquished, water may still be found if the natural sources of water are more carefully investigated. In this respect the following abstract on the *search after water* from PARKES' *Practical Hygiene* may prove of some service :—

"Few precise rules can be laid down. On a plain, the depth at which water will be found will depend on the permeability of the soil and the depth at which hard rock or clay will hold up water. The plain should be well surveyed; and, if any part seems below the general level, a well should be sunk, or trials made with Norton's tubewells. The part most covered with herbage is likely to have the water nearest the surface. On a dry sandy plain, morning mists or swarms of insects are said sometimes to mark water below. Near the sea, water is generally found; even close to the sea it may be fresh, if a large body of fresh water flowing from higher ground holds back the salt water. But usually wells sunk near the sea are brackish ; and it is necessary to sink several, passing farther and farther inland, till the point is reached where the fresh water has the predominance.

"Among the hills the search for water is easier. The hills store up water, which runs off into plains at their feet. Wells should be sunk at the foot of hills, not on a spur, but if possible at the lowest point ; and if there are any indications of a water-course, as near there as possible. In the valleys among hills the junction of two long valleys will, especially if there is any narrowing, generally give water. The outlet of the longest valley should be chosen, and if there is any trace of the junction of two water-courses, the well should be sunk at their union. In a long valley with a contraction, water should be sought for on the mountain side of the contraction. In digging at the side of a valley, the side with the highest hill should be chosen.

"Before commencing to dig, the country should be as carefully looked over as time and opportunity permit, and the dip of the strata made out if possible. A little search will sometimes show which is the direction of fall from high grounds or a water-shed. If moist ground only is reached, the insertion of a tube, pierced with holes, deep in the moist ground, will sometimes cause a good deal of water to be collected. Norton's American tube-well gave satisfaction in Abyssinia, although it did not succeed so well in Ashantee. A common pump will raise the water in it if the depth be not more than 24 or 26 feet; if deeper, a special force pump has to be used."

With reference to the maintenance of the purity of water until it is finally distributed, one of the main objects of public water works is to exclude water from the possibility of contamination by the various processes in constant operation, in open or exposed water-supplies. In the pipes (when of good construction and properly jointed) the water is secured from pollution.

The *accessibility* of a water to the people should not be forgotten. A polluted water-supply, situated say 400 yards from a bustee, leaves its inhabitants almost *in statu quo* as to water-supply.

The fourth point is the question of expense associated with the construction of public water works. The initial outlay required for water works is frequently the greatest barrier to their introduction. The expenditure of large sums of money on works of public benefit leading to no immediate return, is not hurriedly undertaken by municipalities. It might be here remarked that any public water works where the supply is limited on the score of expense (and not on that of the general yield of the supply source) are necessarily defective. The experience of some of the large municipalities in India points to the fact, that the more expensive and thorough schemes are much superior to, and eventually more economical than, those which are less costly, but not so complete.

When pure water is supplied to the people at, or close to, their doors, it will be incumbent on them to pay water-rates. The charging of such rates is necessary to defray the expenses initially incurred as well as the cost of maintaining the water works. We need scarcely remark that the introduction of a new tax meets with some opposition, and its collection is effected with some difficulty.

In the assessment of a water-tax there are several points to be considered: (1), the original cost of construction of the works; (2), the means by which the money was furnished; (3), if by loan, the period over which the loan is extended, together with its interest and compound interest; (4), the annual expenses in the maintenance of the water works; (5), the actual population, and (6), the proportion of wealthy to pauper people, *i.e.*, the number by whom house-connections are likely to be made. In an entirely pauper population, or one, say, of a large agricultural village, the cost of maintenance of a constant water-supply system, either with or without the use of machinery for pumping, could not be met by rates, and loss would be inevitable; but where, as is the case in most towns of India, a part of the community is more or less wealthy, there is every facility for carrying out any method of supply that may be deemed expedient.

The following table shows the computed average annual cost per head of supplying water under pressure to the towns of Calcutta, Burdwan, Dacca, and Jeypore:—

Name of town.	Population.	Average supply per head per day.	Original cost of construction.	Cost of annual maintenance.	Computed annual charges, taking 5 per cent. interest on original cost of construction *plus* 1 per cent sinking fund *plus* annual maintenance.	Average annual cost per head.
		Gall.	RS.	RS.	RS.	RS. A. P.
Calcutta ...	400,336	20 3	83,67,489	2,18,390	7,20,439	1 12 0
Dacca ...	69,212	3·2	1,50,000	14,000	23,000	0 5 4
Burdwan...	32,627	3·8	2,31,801	17,000	30,908	0 15 2
Jeypore ...	137,847	2·6	4,75,110	26,253	54,759	0 6 4

The supplies here vary from 20·5 gallons (Calcutta) to 2·6 gallons (Jeypore). If 20 gallons be assumed in each case, the average annual cost per head (cost of construction and maintenance being in proportion) would be :—

		RS.	A.	P.			RS.	A.	P.
*Calcutta	...	1	12	0	Burdwan	...	4	15	10
Dacca	...	2	1	4	Jeypore	...	3	0	8

the average of the four towns being Rs. 3 nearly.

According to Mr. J. B. Hughes, the estimated taxation at Agra, Benares, and Allahabad is from Rs. 1·07 to 1·23 per head per annum.

CONSTANT AND INTERMITTENT SUPPLY.

We may now enter into a consideration of the relative merits of the two systems of supply usually adopted—the *constant* and the *intermittent*. In the *constant* system the mains and service pipes are kept constantly filled under pressure sufficient to raise the water above the highest stories of houses, and there is no actual restriction as to the amount of water that each householder may draw.

In the intermittent system the water is cut off from the smaller mains, except for 20 minutes or half an hour, once or twice a day.

It is a common error to suppose that the constant service means an unlimited supply, and the intermittent a very much restricted one. In the former the supply per head of population depends on the quanti-

*Abstracted from *Sanitary Engineering for India*, by B. R. HARRINGTON, C.E.

ty that can be raised daily and the capacity of the storage reservoirs. As the water is always available, every precaution has to be taken in the constant system to guard against wilful waste, for if such waste were universal, the supply would soon terminate.

Constant Supply.—"All drinking water ought to be drawn direct from the mains, under proper supervision; the waste of water is less in the constant than it is in the intermittent system of supply. These and other advantages have led to the adoption of the constant system in a great majority of British towns."—*River Pollution Commissioners' Sixth Report.* The constant is immeasurably superior to the intermittent, so that unless its inapplicability in any particular case should be decided by competent engineering authorities, it should be adopted as the only method by which the growing necessities of the people can be fully and effectively satisfied. The disadvantages of the constant system are said to be that great waste and extravagance of water is encouraged; but with proper fitting taps, waste water preventers, and waste meters, these could be avoided. The great advantages of a constant system of water-supply, and the practicability of its adoption have been abundantly demonstrated in various towns in India, and these examples are not unworthy of universal imitation.

But the constant system is not always what it professes to be. The quantity of water ostensibly supplied to each inhabitant is, as a rule, not the actual amount which reaches the hydrants, and is used by the people. It has been repeatedly shown that much of the water of mains and sub-mains is wasted through leaks, and that on an average not more than half the amount said to be supplied, reaches the hydrants. What becomes of the rest? It leaks from the pipes (from bad jointing as a rule), keeps the ground moist, saturates the foundations of houses, helps the putrefactive processes already too abundant in the soil and house, and introduces the gaseous products of decomposition into the interior of houses. In the absence of a perfect form of subsoil drainage, this must be productive of results injurious to the public health. The actual quantity available is, as a rule, much too small. The mass of the people in such towns in India as have been supplied with public water works depend for their supply on hydrants alone, and the same would be the case probably in the vast majority of instances in India. Under this system the supply is unequal to the demand. The remedy appears to be to increase the number of hydrants. Mr. Harrington has attempted to demonstrate the insufficiency of the water-supply to the poorer classes in Calcutta by an estimation of the yields of the hydrants calculated on the population, and states that not more than $\frac{3}{4}$ of a gallon is thus provided for each person. Although we have not heard or read of any complaints on this score, we consider that his remarks in this respect deserve the serious consideration of those opening new water works, and especially with reference to the supply to the poorer quarters.

There is no doubt that to cause the constant system to become a source of profit, the same connections should be laid on to all the houses within reach of the mains. By this means the cost of the work is more widely distributed. But we do not want profit in such a matter as water-supply. We desire to provide water, free from danger to public health, at the least possible cost. It has been abundantly proved that the intermittent system is more dangerous to public health than the constant, and the explanation appears to rest in the contamination to which the cistern-stored water in the former case is subjected, together with deterioration due to stagnation. Sir John Simon says: "I consider the system of intermittent supply to be radically bad; not only because it is a system of stint in what ought to be lavishly bestowed, but also because of the necessity which it creates that large and extensive receptacles should be provided, and because of the liability to contamination incurred by water which has to be retained often during a considerable period."

Where house cisterns are indispensable, they are best constructed of well-cemented slate-slabs, which should be thoroughly enamelled inside. A wrought-iron cistern coated with some bituminous compound has been recommended by many. The ordinary iron tank reservoir similarly coated is very useful, although from the absence of fresh air, if it is not thoroughly looked after, the water in it rapidly deteriorates. A cistern of thoroughly glazed and cemented bricks is also a convenient form of construction for house cisterns. Lead cisterns should never be used in a house. Galvanised iron is also objectionable. Another important point is, that the service pipes which convey the water from the mains and sub-mains to the housetops or cisterns, should never be composed of lead or galvanised iron. A safe pipe is a leaden one lined with block tin. *Wooden* cisterns should likewise be avoided, as the wood is apt to decay, to favour the putrefaction of, and impart organic impurity, to the water.

The impurities of house stored water may be lessened to some extent by fitting on to the house cistern, some form of specially made filter, so as to render the water ready for use on domestic delivery.

With regard to house storage of water the Rivers Pollution Commissioners in their Sixth Report remark :—" All storage of drinking water in houses is attended with the risk of pollution. Good water is spoiled, and bad water rendered worse, by the intermittent supply (house storage being inseparable from this form of supply)."

Any water collected in the house for intermittent use during the day should be carefully protected from all possible sources of pollution, and the receptacle for the water should be periodically cleaned.

In some cases, however, house cisterns are a necessary evil, but knowing the dangers associated with such storage, precautions in proportion should be taken to preserve the purity of the water. Storage on a large or small scale undoubtedly accelerates the deterioration of water; particularly is this so in covered reservoirs, where from stagnation, warmth, and limited supply of oxygen, micro-organisms in the water multiply rapidly. Dr. Frankland has shown by experiment that artificial agitation of water retards or stops the multiplication of microscopic vegetable germs. Both putrefactive and pathogenic germs, rapidly multiply in water, under favourable circumstances. In a stagnant water, it does not signify how many micro-organisms are present to begin with, for in a short time it teems with them.

REQUIREMENTS OF A GOOD WATER-SUPPLY.

These may be enumerated as follows :—

1. That every person in the community should get at least 12 gallons of water a day. The nearer the quantity is to 30 gallons the better. These 12 gallons should reach the taps and hydrants. The source of supply should be as distant as possible from human habitations, one situated among distant hills being very desirable. Any source of supply would probably be better than those in general use at present, *viz.*, shallow wells, streams, and rivers.

2. The water should be as free as possible from all organic and inorganic impurities; it should be hygenically pure at its source, and this purity should be maintained till the water reaches the ultimate distributing taps and hydrants. It is with the object of removing from the masses of the people the power of contaminating the drinking water, that we should endeavour to get a supply from a locality where no such polluting influences are in existence. The wells of most towns and villages, originally containing pure water, have, in process of time, been rendered so unwholesome as to be almost dangerous to use, and this is chiefly owing to the foul habits of the people.

It is presumable that the water provided by public water works is fit for use as a beverage direct from taps and hydrants, and as a general rule the presumption is warranted by the result of analysis of such waters; sometimes however they require further purification by domestic filtration. On the other hand we have seen the filtrate from domestic filters more impure than the water from the hydrant itself. Hence the value of periodical analysis of hydrant and tap water. The result of these analyses should be published.

3. That the 12 gallons be available at any period of the 24 hours, *i.e.*, the supply should be *constant.* This is a matter of great importance on account of the liability of stored water to contamination. To keep the stored water of a house cistern pure requires more care and attention, than the ordinary inhabitant is disposed to give. In India this cistern would probably be chiefly represented by large (and often foul) earthenware gurrahs, or brass utensils. We know that water readily absorbs impurities coming into contact with it; but other and more dangerous sources of pollution are only too abundantly present as a rule.

4. There should be no partial dependence for this supply upon wells. Wells, belonging to individual houses whether in use or not, should all be closed, except in cases where the house is too remote from the public water works supply.

5. A less urgent necessity than those enumerated, is, the construction of drinking-water fountains, in various parts of a town or municipality, to yield a drink of pure water to the weary labourer, and worn out beast of burden.

6. The administrative control over this water-supply should be in the hands of the local municipal authorities. It may be considered the duty of every local municipal body to endeavour to provide an adequate supply of pure water for the community. The clauses with reference to this in the various Municipal Acts are unequivocal. The process of supplying water on a large scale, can be most satisfactorily, efficiently and speedily carried out by municipal corporations under the auspices of local governments. Municipal commissioners have extensive powers, and they can levy water-rates and collect them. The large initial outlay is the usual barrier, but most municipalities of any size, are now in a position to borrow money for the purpose of constructing water works. It should be remembered that such money is merely lent, and lent for a very praiseworthy object, that of providing a community with a permanent supply of wholesome water.

The various conditions we have enumerated as necessary for a supply of wholesome water urgently require fulfilment in a large number of towns and municipalities in India. The vast majority of towns are still unprovided with a proper water-supply, notwithstanding that in many of them all these conditions are attainable; and in point of fact, the number in which they cannot be complied with is comparatively small. We have quoted one instance, that of the Kurachi water-works, to show that apparently insuperable obstacles may be overcome in respect of water-supply. This instance is all the more remarkable if we remember, that the average annual rainfall at that station is only about 7 inches.

Early in the history of modern municipal organisation in India, in consequence of caste prejudices, some opposition to general water-supplies on the scientific principles of to-day, was raised by the people. This has practically expired now; the people have assimilated the views of Western civilisation in this, as in other innovations. In towns where sewers and water pipes run parallel, with imperfect house traps to the former, there is said to be a certain amount of risk of water pollution from sewer gases gaining entrance to houses and contaminating the water of cisterns supplied on the intermittent system, or from the waste pipes from such cisterns opening directly into sewers with imperfect traps or no traps at all. But in the constant system of water-supply (which will probably be invariably followed in India, where new water works are opened), no such risk will be run. There are but few towns in India in which sewers are laid, and their possible existence in the future is too remote a contingency to affect the question of public water-supplies in any way. The chief means of removal of refuse house liquids in India is by surface drains, and those who have had experience in the matter know how very difficult it is to keep such drains clean, in the absence of an abundance of water for flushing.

Before leaving this question of public water-supplies, it may not perhaps be out of place to write a few words with regard to Mr. Harrington's proposed plan of supplying water to Indian towns and municipalities. He suggests that *gravitation* alone be used, and that the water be conveyed to separate ghâts for drinking and bathing purposes. Considering that the use of steam for raising water is altogether too costly for an indigenous population, he recommends that the source of the water should be at the highest attainable level, and conveyed to those ghâts in aqueducts by gravitation only. The ghâts are to be distributed over the municipal area to be supplied, and are to be of two kinds—one for drinking water only, the other exclusively for bathing, the two being placed adjacent to one another. The great advantages claimed for this system are that the initial expense is infinitely less than in any other plan, and that no steam power need be employed subsequent to its establishment. The first of the advantages claimed certainly holds good, the cost being not more than one-fourth of that of the ordinary system. Mr. Harrington also claims for his system that there is greater facility for getting water from ghâts than from hydrants, and enters into a calculation to show that a thickly-crowded town could not be properly supplied from hydrants, unless the hydrants were at about thirty feet from each other, his calculations having special reference to Calcutta. We entirely fail to see this, and have the experience of some large municipalities in which the supply is continuous to support us. The atrocious system of "cutting off" the water-supply for a certain part of the day (known as the "intermittent system") does certainly add to the difficulty of supplying everybody with a very liberal supply of water, but with the high pressure system which has been advocated, no such embarrassment as this need be apprehended. Doubtless, Mr. Harrington's plan would, to a certain extent, suit the habits of the people, but from a sanitary point of view, we would unhesitatingly condemn it, for it would serve to perpetuate the evil habits that are constantly effecting a defilement of existing water-supplies. We are positively convinced that any system that in its ultimate distribution permits of direct access to the water by the people, will be a constant menace to the public health.

Among other defects in this system we would mention that (1) ground for such ghâts in crowded towns is not always available; (2) being uncovered they allow the water (*a*) to evaporate rapidly, and (*b*) if the volume be not large to soon become warm; (3) liability to organic contamination from (*a*) droppings of birds and falling of leaves, (*b*) the unclean utensils that would be dipped into the water, (*c*) the splashings and the washings of the feet of the people entering the ghât, (*d*) the possibility of mistaking the drinking for the bathing ghât or *vice versâ*. The two great advantages about it are that it proposes to use gravitation as a force to the exclusion of steam to convey the water to towns, and (2) its comparative cheapness. But the use of pumping machinery is not always a necessity. There are certain towns, such as Calcutta and Kurrachee, supplied entirely by steam pressure.

When the source of water is at a sufficient elevation, it may be supplied by gravitation alone. Steam power is resorted to when the place to be provided with water is at a greater elevation than the supplying river, well, spring, or artificial reservoir—Calcutta, Bombay, and a few other places in India are supplied from impounding reservoirs. Hyderabad and its suburbs are to be supplied by large tanks fed by the water from impounding reservoirs along the Eassie and Moosie rivers, the water reaching the tanks through lengthy channels.

One of the greatest advantages of public water works is the doing away with manual labour in connection with the drawing of water from wells. They reduce this labour practically to *nil*. Carried out in their perfected methods, they give a constant supply of water at any time without any expenditure of physical power on the part of the consumer. They likewise do away with the risks associated with house storage of water.

An ordinary public water works consists of the following :—A large *settling reservoir* in which the gross suspended impurities subside. From this it is passed into the *filters*. These are brick tanks, which, in India, are usually covered. The bottoms of these filters are covered with 4 or 5 feet of sand and coarse gravel, arranged as follows :—A layer of brick or broken stone about 6″ or 9″ deep, then 6″ of gravel, and lastly a layer of sand $2\frac{1}{2}$ feet. On the surface of the sand, the water is 5 feet deep.

From the filter beds, the filtered water flows to the *service reservoirs* (which are covered chambers to protect the water from sun and contamination), whence it is distributed, either by gravitation or by pumping, to the different parts of the town or municipality. The rate of filtration should not be greater than 700 gallons per square yard in the 24 hours, although this amount is often exceeded.

In all modern public water works, the plan of ultimate distribution is much the same—the laying of cast-iron pipes, or masonry channels (covered or uncovered) to convey the water either direct to the filter bed or to a settling tank, from which latter it passes to the filter bed. From these beds it proceeds by mains, sub-mains and service pipes to streets and houses. Attached to the pipes are hydrants, waste water metres, stop cocks and other accessory apparatus. Once the mains are laid, then those who wish, and can afford it, have service pipes connecting the supply with their house, and if necessary with every room and storey of the house.

AERATED WATERS, ICE, MILK, &C.

The various forms of aërated water (of which soda-water may be taken as the type) owe their sharp, characteristic taste, and sparkling appearance, to the air and carbonic acid they contain. The air and carbonic acid in aërated waters do not render these beverages less dangerous, if the water employed is previously impregnated with impurities, and it is well to remember that aërated water manufacturers are not always particular as to the source of the water used.

Aërated water is prepared as follows:—Carbonic acid is generated by the action of sulphuric acid on chalk, sulphate of lime being left behind. The carbonic acid is forced into the water which dissolves about five times its volume of the gas.

It is merely a solution of carbonic acid in water under high pressure. *Real* soda-water has 30 grains of bicarbonate of soda to the pint, and should only be used medicinally.

We have seen an instance in which aërated waters were prepared from the unfiltered water of a marsh pond. An analysis of this water showed an abundance of both animal and vegetable life, as well as disintegrating animal and vegetable debris.

The use of aërated waters, prepared from unfiltered, impure water, is no less dangerous than the use of the impure water itself. We repeat this assertion, as there is an erroneous impression abroad that aërated waters have a self-purifying property. This is a delusion. Aërated water factories should be thoroughly supervised by all local municipal authorities, and the filtering apparatus of these establishments carefully seen to.

We feel convinced that it is much safer to use pure, filtered, drinking water, than the aërated waters generally met with. This may not apply to those of large municipal towns and cantonments, where such manufactories are strictly superintended, but it certainly does to small towns and municipalities, where strict supervision is absent.

In freezing, water loses some of its impurities, and any incorporated vegetable organisms present are temporarily rendered inactive, but on melting, they once more resume vital properties. Where the quality of the water used in the preparation of *ice* is not guaranteed, it is infinitely safer to use the ice as a cooling agent, by placing the vessel containing the beverage to be cooled in it, rather than placing the ice in the beverage. We have more than once analysed ice from large factories and found it to be very impure, containing a considerable amount of organic matter, including micrococci and bacterioid forms. The most dangerous impurities of water are, suspended organic matters. Dead organic matter, if in large quantity, is decidedly unwholesome, but even in small quantities, it is usually dangerous, because it increases the probability of contamination with dangerous living organisms. It is but fair to say, however, that most factory ice is pure.

It is exceedingly important then to ascertain that the water used in the manufacture of the various aërated waters, ice, and in the preparation of *sherbets* and other beverages, is of unimpeachable quality. In all these cases the water should be of unexceptionable purity, and in every instance where filtration fails to effect an approximate degree of purification of the water, we should insist on its being boiled.

As a considerable quantity of artificially prepared ice is consumed in India, it may not be out of place to make a few remarks concerning ice. *Natural* ice results from the freezing or crystallisation of rain water or snow. On melting it yields an exceedingly pure water. During the freezing process it gets rid of the gases and most of the mineral and of much organic impurities contained in the water previously. The absence of gases and all mineral matter renders it insipid, and devoid of that freshness and sparkle so much appreciated in wholesome water. The absence of saline matter renders it soft. Artificially prepared ice may also yield pure water, but should the water from which it is prepared be of doubtful quality, the possibility of contamination should not be lost sight of. Any germs in the water remain in it when frozen.

How to keep Water cool without Ice.—Although it is somewhat doubtful as to whether the general use of ice to cool beverages under ordinary circumstances is an advantage to health, there is no doubt that a draught of cool pure water is exceedingly refreshing to the thirsty in hot weather. Water may be kept cool without the aid of ice by the following simple plan. Place several bottles of water, covered with straw, in a coverless box or basket. Sprinkle water over the straw every now and then, so as to keep the straw constantly damp, and have the box or basket suspended and swung to and fro. The dry heated air, coming into contact with the bottles, causes the sprinkled water to evaporate. In this vaporisation the heat of the water is abstracted or got rid of.

Another item we must notice here is the dilution of milk by *gowlies*. That these men adulterate their milk with water is notorious. But this mere dilution is not the greatest evil associated with the practice. The water chosen is often from some shallow polluted pool, close at hand, or from surface wells. At certain seasons it is positively dangerous to use milk contaminated in this manner, and at such seasons we have no hesitation in recommending the use of condensed milk, in the absence of fresh milk of reliable quality. There are now many instances on record where the dilution of milk with impure water has led to outbreaks of epidemic diseases. The dilution of milk with water that is charged with impurities, particularly if these impurities consist of the specific poison of communicable disease, is an outrage on the public, and every means possible should be taken to prevent it. Even the washing of milk utensils with surface water has been known to bring about enteric fever. Much valuable information on this point might have been gleaned from the letters that appeared in the *Pioneer* during the year 1889, and the recent experiments of Professor D. D. Cunningham, F.R.S., of Calcutta, point to the fact that all milk, the purity of which cannot be guaranteed, should be boiled.

Village Water-Supply.—The question of water-supply is as important in village communities as it is in those of towns, for the actual number of town dwellers bears but a small proportion to that of the inhabitants of villages. Further, towns, or at least the larger ones, may usually avail themselves of special sanitary officers and engineers to deal with the question of water-supply. Villages, on the other hand, have but the headmen or the district officers (whose visits are few and far between) to advise them on sanitary matters. A few remarks on village water-supply may not therefore be out of place. In investigating a village supply, the points to direct attention to are,—the nature of the existing sources, and their means for improvement, the quantity of water available, the methods to be employed in purification, if it be necessary (and it is rarely that it is not), and the mode of distribution.

With regard to the *selection of sources*, it usually lies between deep wells, tanks and upland surface water. In connection with the *stored rain-*

water as a supply, the late Surgeon-Major McNally* remarks: "From this source pure drinking water could be readily obtained in places where well waters are brackish or unwholesome from their hardness, and the presence of magnesium or other mineral impurities, or from organic impurity, and where surface waters are liable to contamination. Such places exist in nearly every district. Large surfaces of rock may sometimes be utilised as collecting areas, the water being received in a channel cut along the lower edge of the surface, and delivering with the intervention of a small filter into the storage tank. If a rock surface is not available, stone or brick may be employed for paving the selected area, or its floors may be puddled and lined with mortar, or what is better, Portland cement. The surface ought to have a sufficient incline to allow the rain to run off rapidly, and thus limit the loss by evaporation. The prepared area must be surrounded by an impenetrable fence or high wall, to prevent its defilement by men, grazing or stray cattle, &c. A prepared surface of this kind is better than a house roof for collecting rain, being more easily inspected and cleaned. A roof is not generally large enough to yield a sufficient supply. It may be found convenient in some cases to use both roofs and ground areas. If it be determined to supply a whole village with rain water, it is much better to have one large properly made surface and storage tank, which can be more easily looked after and kept clean than several small ones."

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* *Sanitary Handbook for India*, p. 69 *et seq.*

The quantity of water required, and the consequent size of the collecting area, will depend upon whether water for all purposes, or only for cooking and drinking, is to be supplied from this source. In places where the rainfall is sufficiently abundant, and where a large collecting surface can be provided, it may supply water for all purposes, at least 5 gallons per head (including children) daily being allowed. In places where the rainfall is scanty, or where long periods of drought are frequent, it may be possible to supply only water for drinking and cooking purposes from it, at least one gallon per head daily being allowed. To calculate the size of the collecting surface required, the first thing to ascertain is the average rainfall, for as long a series of years as possible. If no observations of rainfall have been made at the place itself, the records of the nearest meteorological station may generally be accepted. One inch of rainfall yields a little more than half a gallon (0·5198) for each square foot of surface. The methods of calculation can be best explained by an example. Let us suppose that it is required to obtain a supply of 5 gallons per head daily for a village containing 450 inhabitants, the average annual rainfall of the place being 28 inches. The total quantity of water required in the year will be the population multiplied by the daily amount per head, multiplied by the number of days in a year: or, $450 \times 5 \times 365 = 821250$ gallons. As each inch of rain yields half a gallon per square foot, 28 inches yield 14 gallons in each square foot, and $821250 \div 14 = 58661$, which is the area in square feet necessary to collect the required supply. As an allowance for wastage by evaporation, leakage, &c., 25 per cent. may be taken, thus making the area 73,326 square feet, that is, a square space measuring $\sqrt{73326}$, or nearly 270 feet on each side.

The construction of a *storage* tank for rainwater has already been alluded to: its capacity has now to be discussed. In most parts of India very little rain falls during the first six months of the year: storage for at least six months' supply will therefore be required. The rainfall of the driest year likely to occur may be taken at not less than half the average rainfall, and in such a year only half the usual supply would be collected. It may, therefore, be generally reckoned that a good storage tank ought to have a capacity equal to nine-months' supply —that is, three-fourths of the annual requirements. In the case above supposed of a village with 450 inhabitants requiring 5 gallons each daily, or 821,150 gallons in a year, the storage tank ought to have a capacity of $\left(\frac{821250 \times 3}{4}\right)$ or 615938 gallons, or nearly 98700 cubic feet (*vide* Appendix). A reservoir, —23 feet deep, 23 feet wide, and 172 feet long, would have the required capacity, and it should, if possible, be covered. In any case it should be protected by a fence. Storage tanks ought to be built in two or more compartments, for convenience of cleaning. There are, however, very few Indian villages that could undertake the construction of reservoirs of these dimensions. If drinking water only were to be provided in this way, the construction of smaller reservoirs might readily be undertaken, and under these circumstances, reckoning one gallon per individual, 2,250 persons could be supplied. In cases where villages are unable to meet the expenses at once, the funds could be provided on loan, the repayment being made after a number of years and the work itself carried out by taluq or local fund or municipal boards.

Mr. R. B. Harrington's proposed plan of supplying towns might with advantage be adopted in certain villages, although we doubt its applicability to towns. Of course it may happen that it is not practicable to supply wholesome water to a village at a reasonable cost, or that the supply is so situated as to be ungetatable. Under such specially unfavourable conditions, it is a question as to whether the State should not take the initiative in inaugurating a water-supply, or whether local fund or sanitary boards might not do so.

With regard to *distribution* of water in villages, one of many methods may be adopted. The plan of drawing water in private vessels should be absolutely abandoned, for such utensils are frequently foul, and the suggestions made with regard to town wells apply equally here.

A good plan is to build a cistern at a convenient level, and have it filled once or several times daily from the well or rain reservoir or tank by means of a pump or other mechanical elevator worked by public cattle, or by hand, or water-power or a wind mill. The people could then obtain water from the cistern-tap without any danger of polluting the source. For larger villages the water might be raised at the source, be carried into the village by pipes or an aqueduct, and distributed to one or more public cisterns or fountains placed at convenient centres. A good public supply for villages could thus usually be managed at no great expense, and it would very largely contribute to the health and convenience of the inhabitants. When a public supply is provided, one of the village officials should have charge of it, and be held responsible for its efficiency, and for the periodical cleansing and repairs of collecting surfaces, wells, storage tanks, filters, cisterns, &c.

We would venture to state that there is probably no single factor in the organization of public health arrangements of villages deserving of greater attention than this one of water-supply. We have dealt with it as far as our space allows. We would not pretend to have exhausted the subject, yet we entertain the hope that a careful perusal of the facts herein laid down will lead those concerned to pay more attention to a matter of such vital significance.

EXAMINATION OF WATER.

An accurate opinion as to the wholesomeness or otherwise of a drinking water can only be arrived at after subjecting a sample of it to a complete examination. This consists in an investigation into the physical characters of the water, a chemical analysis (both qualitative and quantitative) and a microscopical examination.

The scheme of such an examination may be represented as follows :—

A. PHYSICAL ... { 1. Color. 4. Lustre. 2. Clearness. 5. Taste. 3. Sediment. 6. Smell. }

B. CHEMICAL.

Chlorine.
Lime.
Magnesia.
Sulphuric Acid as Sulphates.
Phosphoric Acid as Phosphates.
Nitric Acid as Nitrates.
Nitrous Acid as Nitrites.
Ammonia.
Iron.
Lead.
Copper.
Zinc.
Sulphuretted Hydrogen.
Alkaline Sulphides.

(*b*) *Qualitative.*

Chlorine.

Hardness ... { Total. Temporary. Permanent. }

Solids ... { Total. Volatile. Fixed. }

Oxidisable Organic matter.

Ammonia ... { Free or Saline. Albuminoid. }

Nitric Acid.
Nitrous Acid.

Yet after all these processes have been carried out there is a further requirement,—that of an endeavour to cultivate any microscopical vegetable germs that may be present, and ascertain their nature. This is termed the morphological or *biological examination.* When this also has been accomplished, we are placed in a position to give the most reliable and trustworthy opinion as to the quality of a given sample of water. To carry out these processes with accuracy demands that the analyst shall have had a sound chemical training, and that he be familiar with the use of microscopes of high power. Hence the uselessness of lay persons undertaking anything but a physical and simple chemical examination of water. On the other hand in the vast majority of cases, however, a sufficiently trustworthy opinion can be formed as to the quality of a water, after a physical and chemical examination of it has been made by a competent person.

In *collecting water for* an *analytical examination,* much care is required, and for this purpose the following plan may be adopted. Collect the water in a scrupulously clean glass-stoppered bottle, of about half a gallon capacity. The water should be kept in a cool, dark locality, and the examination should be carried out as soon as possible. In collecting the water from a tank or well, the surface impurities should be avoided by immersing the bottle, and removing the stopper, under water. The middle of the stream, river or tank, should be chosen, avoiding the intake of feeding channels. If from a public tap, or hydrant, the tap should be opened for a few seconds before filling the bottle. Make a note of the place, time and period of the year. Remember to wash the bottle out three times with some of the water to be examined, and do not quite fill it.

Trained analysts exercise the utmost caution in expressing their opinions as to the quality of waters analysed by them, for they are conscious of the importance of their decision. It is but fair then, that in sending samples for analysis, such samples should be accompanied by as much information about the water as it is in our power to give. In point of fact many analysts will not express judgment on a water until they are furnished with this information. It is often a waste of time and labour to send six or eight bottles of water marked A, B, C, &c., without any further reference to the water sent.

The chief points regarding which the analyst is concerned are:—

Date and hour of collecting water; its source—from a well, tank, stream or river.

If from a *well*, the nature of the soil and geological strata in which the well is sunk, the depth of the well, and whether it is near or remote from sun-dasses or well-privies, cesspits or drains.

If from a *tank*, the part of it from which the water was removed, and the nature of the various contaminating agencies (if any) at work.

If from a stream or river, the relation of the position from which the sample was taken to the banks.

The analyst should also be made acquainted with any special reason there may be for making an analysis.

A little practice in the physical and chemical examination of water would soon enable us to form a fair opinion of samples of water, or at least familiarise us with the chief characters by which waters may be distinguished as grossly contaminated.

PHYSICAL EXAMINATION OF WATER.

Much may be learnt from a simple physical examination, and as all but experts are obliged to rely on the results of such an examination, it will be well perhaps to make a few remarks under this heading.

From a physical examination of water we ascertain the *colour*, *clearness*, *lustre*, *taste* and *smell* (if any), and the existence or not of any visible *suspended matter* or *sediment*.

Colour.—For this we use narrow cylindrical, clear glass vessels, about 18 inches in height. We fill one with the water under examination, and the other with distilled water for comparison. We place these in a good light, on a white slab, or on some printed paper, and see if we can read the print below. The best and purest waters have no colour when seen through this depth, or only a faint bluish tinge.

Waters are often slightly *greenish*, due to cellular *algæ*, and such waters are not considered impure on this account. Waters of a *yellowish* or a *brownish* colour are to be looked upon with suspicion. A *yellowish* hue is often due to peat, in which case the water, although unpleasant, is innocuous. A brownish or yellowish hue may be due to iron; it then has a chalybeate taste; even one-fifth of a grain to the gallon gives this taste. A similar colour may be due to sewage contamination.

Clearness.—Any water that is not clear and transparent, cannot be reckoned as one of the first order. Dissolved or finely suspended particles of colouring matter will reduce the natural clearness of pure water, as will also finely divided and suspended *mineral matters.* Most of such suspended matters *subside on allowing the water to* stand, but fine particles of calcareous salts, and of mica, &c., may not subside.

Sediment.—To find out the amount and nature of the sediment, the water is to be allowed to stand some time. The general characters of the sediment may now be investigated. It may be investigated microscopically, and in this way its exact nature be discovered. It may also be subjected to the *biological test.**

Lustre.—With regard to *lustre*, the technical terms in use are, *adamantine* and *vitreous* or dull, words which sufficiently express their meaning. The lustre of a drinking water depends on the gases, oxygen and carbonic acid, dissolved in it. Good water has an adamantine lustre ; in other cases it is dull or vitreous.

Taste.—The taste of a drinking water depends, as a rule, on the gases dissolved in it, and not on the mineral salts it contains. It may be said that any water in which the mineral matters in solution are recognised by the palate is unfit to drink. An ordinary drinking water contains from 20 to 25 grains of common salt to the gallon. It requires about three times this quantity to be recognisable by the sense of taste.

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* The *biological* test consists in the cultivation of any germs present in the water by bringing them into contact with sterilised nutrient media. This is a form of examination that has led to much information already, and has opened out a new field for research, and we are convinced that it is capable of yielding excellent results when carried out in its integrity.

Smell.—Any perceptible smell in water should cause us to regard it with suspicion. A smell is usually due to putrefaction, in which the evolution of sulphuretted hydrogen and ammonia compounds is taking place. Any smell in water is best brought out by heating it to about 100° Fahr., and adding a little caustic soda to the water.

The sense of touch requires considerable practice before it can be of use in the physical examination of water.. It is chiefly employed in detecting hardness in water, hard waters giving a roughness to the touch.

If a water gives negative results in its physical examination, we may ordinarily regard it as of good quality. If we are at all doubtful as to its characters, we should have it subjected to both a qualitative and quantitative chemical examination. We would repeat that the senses are unreliable judges in estimating the wholesomeness of a water.

Professor PARKES has classified waters into *pure*, *usable*, *suspicious* and *impure*, in accordance with the amount of impurity met with in these different classes of water.

The following table indicates the chief physical characters of the waters of this classification.

Character or constituent.	1. Pure and wholesome water.	2. Usable water.	3. Suspicious water.	4. Impure water.	REMARKS.
Clearness, lustre, and aëration.	Transparent, sparkling and well aërated.	Transparent, sparkling and well aërated.	Turbid.	Subsoil and not easily purified by coarse filtration.	Turbidity due to very fine aërial matter is sometimes associated with pure waters; thus minutely divided calceum sulphate will not subside in distilled water.
Suspended matter.	Detectable by the eye.	Absent or easily separable by coarse filtration or subsidence.	Considerable.	Large.	...
Colour.	Colourless.	Colourless or slightly greenish.	Yellowish.	Distinctly yellow or any marked colour.	When the impurity is mostly vegetable, the colour may be very marked in good, or at least usable water.
Taste.	Palatable.	Any marked taste.	Any marked taste.	...	...
Smell.	None.	None.	...	...	...

CHEMICAL EXAMINATION.

It is out of the scope of this brochure to give a complete *resumé* of the methods of conducting a chemical examination of water. Those for whom these pages are written will ordinarily not be in a position to make such an analysis, and on the other hand the analyst will have the high authorities of Parkes, Frankland, Blyth, Wanklyn and Chapman, &c., to guide him. We shall therefore deal only with the more salient points in connection with this subject.

In conducting a *qualitative examination of water*, the following table may be of service to those not specially engaged in analytical processes :—

Reaction.—This is determined by litmus and turmeric papers—water of acid reaction giving a red colour to blue litmus paper, alkaline water turning turmeric paper brown.

Water is usually neutral. If there be acidity which disappears on boiling, it is due to carbonic acid gas. On the other hand, if the alkalinity disappears on boiling, it is due to ammonia. Permanent alkalinity is due to carbonate of soda.

Lime.—The addition of a solution of oxalate of ammonia to water containing lime gives a white precipitate—6 grains of lime to the gallon gives a turbidity only; with 16 grains there is a considerable precipitate.

Chlorine.—The presence of chlorine is determined by acidifying water with a little dilute nitric acid, and adding a few drops of nitrate of silver solution. One grain to the gallon gives a haze; four grains give a distinct turbidity, ten grains a slight, and twenty grains a considerable precipitate.

Sulphuric Acid as Sulphates.—The test for sulphuric acid in water is carried out by adding some dilute hydrochloric acid and chloride of barium: $1\frac{1}{2}$ grains of a sulphate give no precipitate until after standing, 3 grains give an immediate haze, and after a time a slight precipitate.

Nitric Acid as Nitrates.—Mix a little of the water with twice its bulk of pure sulphuric acid. This sets free the nitric acid from its combinations; then add a few drops of the solution of brucine—a pink and yellow zone occurs at the junction of the water and acid. The sulphuric acid should be poured down the test tube gently, so as to form a layer beneath the mixed water and brucine solution. Half a grain of nitric acid to a gallon gives a marked pink and yellow zone. This is a very delicate test. Another method is to evaporate down two cubic centimetres of water to dryness, add a drop of pure sulphuric acid and a minute crystal of brucine. The same reaction takes place, and by it ·01 of a grain to the gallon can be easily detected. In the above test, if a solution of pyrogallic acid be employed instead of that of brucine, a pink zone, turning purple, will be observed.

Nitrous Acid as Nitrites.—A solution of pure iodide of potassium, followed by some freshly prepared starch solution is added to the water, and followed by some sulphuric acid. A blue colour is developed. The colour should be immediate. Make a comparative experiment with distilled water.

Ammonia.—For the determination of ammonia, we add a few drops of *Nessler's solution* to the water. A yellow colour or yellowish-brown precipitate occurs, in accordance with the amount of ammonia present. By experience we learn the amount of ammonia present from the degree of colouration produced in this reaction, although for exact analysis the quantitative method must be employed. If the ammonia is small in quantity, several inches in depth of water should be looked through on a white ground.

Iron.—Red and yellow prussiates of potash give a blue precipitate. The red prussiate is used for ferrous, and the yellow for ferric salts.

Sulphuretted Hydrogen.—A solution of a salt of lead added to the water gives a black precipitate. When the water is heated, the smell of sulphuretted hydrogen may be perceived.

Sulphides.—Nitroprusside of sodium gives a black precipitate with lead, but the absence of colour with nitro-prusside shows that the sulphuretted hydrogen is uncombined.

Oxidisable Matter including Organic Matter.—About 250 cubic centimetres of the water is evaporated to dryness in a porcelain or platinum vessel. By further heat, the residue assumes a brown or black colour if much organic matter is present, and if nitrogen is present in the water, the smell of ammonia is detected. A solution of potassio-gold chloride produces a colour passing from rose pink to violet to olive, and ultimately a black precipitate takes place. The water, which should be neutral or feebly acid, must be boiled for 20 minutes with the gold chloride. If no nitrous acid be present, the reaction may be considered due to organic matter. Add to a few ounces of the water, sufficient dilute solution of permanganate of potassium to produce the faintest tinge. In the presence of organic matter, the solution will gradually become decolourised, the rapidity with which it does so depending upon the amount and characters of the organic matter present. In the absence of nitrites, the reaction indicates organic matter; if the *action be rapid*, it is probably animal; if slow, it is probably vegetable.

The presence of micro-organisms in the water may be detected microscopically after allowing the water to stand in a long narrow jar for six hours, and using the lowest ½ inch of water for the purpose.

Lead, Iron or Copper.—Acidify the water with hydrochloric acid and add sulphuretted hydrogen solution. Any brown colour developed, shows the presence of lead or copper. Add ammonia sulphide solution. This produces a dark colour, not cleared up by hydrochloric acid. Place some water (100 c.c.) in a white dish, and stir up with a rod dipped in ammonia sulphide, wait till the blue colour is produced, then add a drop or two of hydrochloric acid. If the colour disappears, it is due to iron; if not, to lead or copper.

Zinc.—Sulphuretted hydrogen gives a white precipitate. This test is not available if there be iron present, or should the water be alkaline. It only holds good for perfectly neutral waters containing zinc.

Hardness.—A roughtest as to the hardness of water may be made as follows: Add a little of the "soap test" solution to the water in a test tube and shake it thoroughly. The degree of turbidity produced will afford a coarse indication as to the degree of hardness.

Waters have been classified by Prof. Parkes for hygienic purposes as,—*Pure* and *Wholesome*; *Usable*; *Suspicious*; and *Impure*. The following table shows the amount of impurities in each case :—

Character or Constituent.	1. Pure and wholesome water.	2. Usable water.	3. Suspicious water.	4. Impure water.	Remarks.
Solids Total.	Under 8 grs. per gal.(=11·4 parts per mil.)	Under 30 grs. per gal. (=42·8 parts per mil.)	Above 30 grs. per gal. (=42·8 parts per mil.)	Above 50 grs. per gal. (=71·4 parts per mil.)	In chalk waters of the 1st class, the solids may reach 14 grains per gallon (=20 parts per million), the greater part being calcium carbonate.
Solids, Volatile (capable of being dissipated by red heat.)	Under 1 gr. per gal=(1·4 parts per mil.) solids on incineration should scarcely blacken.	Under 3 grs. per gal. (=4·3 parts per mil.) solids may blacken a little, but no fumes should be given off.	To 5 grs. per gal. (=7·1 parts per mil.) much blackening on incineration or nitrous fumes given off.	Above 5 grs. per gal. (=7·1 parts per mil.) much blackening and nitrous fumel given off or smell of burnt horn.	In peat waters the incinerated solids may blacken considerably.
Chlorine.	Under 1 gr. per gal.(=1·4 parts per mil.)	Under 3 grs. per gal. (=4·3 parts per mil.)	Above 3 grs. per gal. (=4·3 parts per mil.)	Above 6 grs. per gal. (=8·6 parts per mil.)	Water slightly contaminated with seawater may have a higher amount of chlorine and still be usable.

Character or Constituent.	1. Pure and wholesome water.	2. Usable water.	3. Suspicious water.	4. Impure water.	REMARKS.
Nitrites.	Absent.	Absent.	Present.	Marked.	**These are generally indications of previous animal contamination, but they may occasionally come from vegetable matter.**
Oxygen required for oxidisable organic matter, determined by permanganate in presence of acid.	Under 0·07 gr. per gal. (=1 part per mil.)	Under 0·105 gr. per gal. (=·15 parts per mil.)	Above 0·105 gr. per gal. (= ·15 parts per mil.)	Above 0·14 gr. per gal. (=·2 parts per mil.)	**The amount may be greater in good peat waters.**
Ammonia free or saline.	Under 0·0014 gr per gal.(=·002 parts per mil.)	Under 0·0035 gr per gal. (=·005 parts per mil.)	Above 0·0035 gr. per gal. (=·005 parts per mil.)	Above 0·0070 gr. per gal. (=·01 parts per mil.)	**Frankland's standard for good water is = 2 to 3 parts per million of organic carbon; 0·2 parts per million of organic nitrogen. He also gauges it by the previous sewage contamination as measured by the nitrogen existing as nitrates, about one part per million being the limit of inorganic nitrogen in reasonably safe waters.** ***N.B.*—Frankland's numbers are stated per 100,000 instead of per million.**

Ammonia, Albuminoid or organic.	Under 0·0056 grs. per gal. (=·008 parts per mil.)	Under 0·0070 grs. per gal. (=·01 parts per mil.)	Above 0·0070 grs. per gal. (=0·01 parts per mil.)	Above 0·0105 grs. per gallon.
Hardness fixed.	2 Clarke's scale.	Under 4 Clarke's scale.	Above 4 Clarke's scale.	Above 6 Clarke's scale.
Metallic contamination.	None.	Trace of iron.	Trace of iron.	Any metal except iron.
Hydrogen or alkaline sulphides.	Absent.	Absent.	Absent.	Present.
Microscopic characters.	Mineral matter vegetable forms with endochrome; large animal forms; no organic debris.	Same as No. 1.	Vegetable and animal forms, more or less pale, and colorless, organic debris; fibres of clothing, or other evidence of house refuse	Bacteria of any kind; Fungi numerous, vegetable and animal forms of low types, epithelia or other animal structures; evidences of sewage; ova of parasites, &c.

PURIFICATION OF WATER.

The purification of water may be considered under the headings of *Natural* and *Artificial Purification.*

There are many natural processes at work in bringing about some degree of purification of water. For instance, the water of surface wells is merely the subsoil water that has filtered through the superficial stratum of the soil. Surface well water may not be pure, but as a rule it is more so than the subsoil water itself. It may not be out of place, therefore, to say a few words with regard to the natural processes effecting the purification of large volumes of water, such as those of rivers, tanks, and wells.

By means of *dilution*, *oxidation*, *subsidence*, and by the *action of animal and vegetable life*, Nature endeavours to minimise the harmful effects we have associated with impure water.

Dilution is efficacious only when large volumes of water are to be dealt with, and the contained impurities small in amount. The more concentrated the poisonous or harmful constituents of water, the more injuriously will they affect the consumers. This may appear to be a truism, but it is one that is too often lost sight of, especially in connection with tank and well supplies when these sources are decreasing in volume.

With regard to *oxidation*, we have already alluded to the action of air-oxygen on contaminated waters. All natural waters contain a certain amount of dissolved oxygen. This oxygen has the power of oxidising and rendering innocuous, to some degree, most of the suspended and dissolved organic impurities of water. Water in motion contains more oxygen than that which is stationary. In moving water the impurities are more rapidly and repeatedly brought into contact with atmospheric air.

By the physical process of *subsidence*, the suspended solid matters finding their way into tanks, &c., gradually sink to the bottom. This is one of the most active of the natural purifiers of large bodies of water. The influence of this factor is fully demonstrated by removing a little of the silt and filth from the bottom of a tank, or a large well, that has not been cleared for some years. The water of tanks and rivers, during the rains, contains a large amount of fine clay; this gradually subsides, and in finding its way to the bottom, carries with it much of the suspended organic matter.

Fishes and plants ordinarily take no small share in purifying water, and for this purpose their presence in tanks and reservoirs may be looked upon as a necessity. In all large tanks a moderate amount of living plants is beneficial. They act chemically by aiding the oxidation of any organic matter present.

Tank water improves during the rains by dilution with rainwater, and "the animal and vegetable life in it preserves the proper balance, removes decaying matters, and prevents putrefaction to any great extent; at least this is the case in good tanks." (Dr. David Waldie.)

"Of the water-plants suited for the preservation of tank water, the following are the best known *:—*Nymphœa rubra*, which has long india-rubber like stems, varying with the depth of water, and deep-red or blood-coloured fenners; *vallisneria octandra*, the water-plant used by the Jessore sugar-refiners to cleanse their raw sugars.

In addition to the higher order of plants, there are a large number of cryptoganydous or non-flowering plants, *algœ*, *confervee*, &c., which flourish in water, and generally in tanks or ponds, where they float about in masses, sometimes covering the whole surface with a thin green scum. They are harmless, in most cases in fact beneficial. It is only during its decay that such vegetable matter is injurious to the quality of water. When clearing tanks or reservoirs of weeds, plants, &c., the vegetation should be entirely removed from the vicinity of the tank and not allowed to decay on the banks.

Fishes prevent the overgrowth of vegetable matter, and feed upon the insects and crustaceans, and the dead organic matter present in the water. According to Rankine, destruction of fish contained in large volumes of water has led to increase in the number of small crustaceans on which the fish had lived, rendering the water impure and nauseous. In such cases the remedy is to re-stock the tank or reservoir with fish. "Of fish, the best suited for stocking tanks are the *katla*, *ruho* or *rooi*, *mirgal*, all of the carp family (cyprinidæ), are the most desirable." †

There are very few waters that do not require

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* *Municipal Work in India.* By R. C. STERNDALE (Thacker, Spink & Co., Calcutta).

† STERNDALE's *Municipal Work in India*, p. 167.

some form of **Artificial Purification**, before being used for drinking purposes. Rain-water, if collected pure, water from mountain streams, primary springs, and well-preserved deep wells (if remote from inhabited houses), may be used without any preparation. So may that from the water works of most large towns, the water of these works having been tolerably well prepared by filtration before final distribution. In all other cases the water should be subjected to some form of purification before being used. It is positively dangerous to drink the water drawn from the large majority of superficial wells we see within bustees, without previously boiling and filtering it.

Water may be artificially purified by various means, of which the following are the most important, *viz.* :—*Oxidation*, *Distillation*, *Precipitation*, *Boiling* and *Filtration*. Two or more of these processes are often brought into co-operation.

Oxidation is effected by exposing water in finely-divided currents to the action of air, to oxidise organic matter. "The water is simply poured through a sieve, or a tin or wooden plate pierced with many small holes, so as to fall in finely-divided streams; or, a hand pump is inserted in a cask of water, and the water is pumped up and made to fall through perforated sheets of iron." Oxidation is aided by agitation of water exposed to air. This is one of the chief means by which the contaminated water of rivers is rendered less harmful, for in their onward course dashing over rocks, anicuts, &c., they absorb more oxygen than still water. Advantage of this physical property has been taken in several places in Russia, where the water is allowed to flow down a series of steps, passing through wire gauze as it does so. Oxidation rapidly removes sulphuretted hydrogen, offensive organic vapours, and a certain amount of the dissolved organic matter.

In connection with oxidation we may mention the use of *Condy's fluid*, which is a solution of permanganate of sodium or potassium. It is a powerful oxidising chemical salt, and is at times exceedingly useful in ridding water of the dangers associated with contained organic matter. "Pure Condy's fluid readily removes the smell of sulphuretted hydrogen, and the peculiar offensive odour of impure water that has been kept in casks and iron tanks." Its action on organic matter varies with the nature of this impurity. In some cases much of the animal and vegetable organic matter is rendered innocuous, in others the action is somewhat uncertain. The use of permanganate of potash frequently gives rise to a yellowish tint in the water, due to finely-divided peroxide of manganese in suspension. This does not interfere with the wholesomeness of the water. A little alum will carry down the suspended matter. Filtration effects the same object. There appears to be no doubt but that if the impurity of water depends upon organic matter the use of the permanganate solution considerably reduces the dangers associated with its consumption. When a little Condy's fluid is added to pure water, it gives the water a beautiful purple colour, which colour is permanent. If organic matter is present in the water, however, the purple tint is soon lost, and will not remain permanent, until all the oxidisable organic mater has been thoroughly oxidised.

"The indications for the use of permanganate are these: In the case of any foul-smelling or suspected water, add good Condy's fluid, teaspoonful by teaspoonful to three or four gallons of the water, stirring constantly. When the least permanent pink tint is perceptible, stop for five minutes; if the tint is gone, add 30 drops, and then if necessary 30 more. Now allow to stand for six hours; and then add for each gallon six grains of a solution of crystallised alum, and if the water is very soft, a little calcium chloride and sodium carbonate, and allow to stand for 12 or 18 hours." *

Distillation of water is practised on boardship from sea water, and in certain places where there is great scarcity of rainfall. By distillation water is rendered almost absolutely pure. In India this process has served no part in connection with the hygiene of water-supply, but we are of opinion that when the source of a water is impure and the impurities of an organic nature, distillation might with advantage be carried out on a small scale by means of a block tin apparatus. We have used such a vessel for some time in our analytical laboratory, and have every reason to be satisfied with the results. It might be used for drinking water only in private houses.

Various chemical agents are used in effecting the *precipitation* of impurities. The following are among the most important:—

Alum.—This agent has been used in India for

* PARKES' *Practical Hygiene*, VII. Ed., p. 80.

precipitating the impurities of water for many centuries. The aluminious salts are very serviceable in removing suspended organic matter if carbonate of lime is contained in the water. The *addition of alum* causes the formation of calcium sulphate and *aluminium hydrate, both of which fall to the bottom, carrying with them other impurities.* The *amount* of alum required is about 5 grains to the gallon. It is doubtful, however, as to whether alum has much effect on dissolved organic matter. If the water is not hard, a little carbonate of soda should be added in order that a precipitable substance may be formed. The action of alum on a turbid or muddy water is very striking; ·0001 per cent. of it renders such water clear. *Carbonate of soda* if added to water throws down calcium carbonate, especially if the water is boiled.

Finely-divided suspended organic matters are thrown drown by *perchloride of iron.* About 2½ grains to the gallon is sufficient.

The addition of *lime water* removes any considerable degree of hardness. It combines with the carbonic acid, and causes the formation of additional quantities of carbonate of lime, and this latter and all the previously contained carbonate of lime are precipitated.* It also causes the deposit of all suspended organic matter and much of the dissolved organic matter. It does not affect those salts giving rise to permanent hardness in water. It

* The following chemical equation represents the change:—

$CaCO_3 + CO_2 + CaH_2O_2 = 2\ CaCO_3 + H_2O$, or a mixed solution of carbonate of lime, carbonic acid gas and hydrate of lime, yield carbonate of lime and water.

appears to act favourably in arresting organisms. The use of lime water is carried out extensively in a few places in England to reduce hardness.

The immersion of *iron wire* is said to rid water of organic matter by decomposing the latter.

The fruit of the clearing nut, *strychnos potatorum*, is used to remove turbidity from water. It is made into a paste which is coated on the interior of the jar. It is said that 30 grains is enough for 100 gallons of water. It appears to act in the suspended matter, carrying it down, by giving to the water a delicate albuminous coagulum.

Charring the interior of casks may be mentioned here as a means of artificial purification. This practice would enhance the purity of water stored in wooden cisterns.

Of all processes of purification, that of *boiling* is by far the most certain. With regard to its effects as a safeguard against diseases produced by microbes contained in water, we quote the following from the *Sanitary Record* for April 16th, 1888 :—" In order to render our safety from micro-organisms practically absolute, it is only necessary to have our drinking water boiled. Many persons have a prejudice against boiled water in consequence of its flat and insipid taste, but these undoubted defects may be easily remedied by passing the boiled water when cool through any ordinary household filter, which will impart to the water its original freshness and palatability. In fact nearly all the terror which micro-organisms are justly capable of inspiring melts away when we remember that we can effectually combat them by heat. Thus milk and water, each of which is infected with hurtful microbes, is capable of doing so much mischief to mankind, can be rendered practically safe by merely submitting them to the process of boiling. Indeed, it cannot be widely enough known, that perhaps the two most effective private measures which can be taken in avoiding zymotic disease, consist in boiling all our milk and all our drinking water. By insisting upon these simple operations being systematically carried out, every family can render itself independent of the purity of our public milk and water supplies, the safety and wholesomeness of which it is altogether beyond the power of private individuals to control."* It may be interesting to know that the insipid taste given to water by boiling is remedied by the addition of a little limejuice or sugar, or both.

Water containing much organic matter should *never be used for drinking purposes without previous boiling*; especially is this the case when there is an epidemic of cholera or enteric fever in the town or district. By boiling the water, we reduce to a minimun the possibility of the disease attacking ourselves. It not only destroys the organic impurities, but also causes at precipitation of much of the dissolved mineral matter.

If brightness and sparkle be not an indication of purity of water, nor want of clearness a ground for the condemnation of a drinking water, how are we to protect ourselves from the possible dangers arising from the consumption of water with the quality of which we are unacquainted? We feel

* *The Beneficent and Malignant Functions of Micro-Organisms.* By Percy Frankland, Ph.D., B.Sc.

convinced that the greatest safeguard lies in *boiling all drinking water*, and in epidemic seasons this is the best possible prophylactic measure we can adopt.

PURIFICATION BY FILTRATION.

Filtration may be carried out either on a large or on a small scale. On a large scale it is conducted in the filter beds of public water works, in which case *sand* is the chief filtering medium; and on a small scale it is carried on in domestic filters, in which the filtering material varies.

The *filter beds* of public water works usually consist of a shallow tank, with stone or brick walls, lined with cement or concrete. The floor, lined in the same way, is grooved with small channels, leading to a main exit channel. Clean gravel, coarse below and fine above, is laid to the depth of three feet, and over this fine clean sand to a depth of three feet. The water that is to be filtered is allowed to flow over this to a depth that should not exceed two feet. Two filters are usually constructed alongside one another, so that one may work when the other is being cleaned. The filtered water is stored in a covered, cement-lined, tank. From this latter reservoir the water is distributed to streets and houses in iron pipes. Iron pipes are used because they are less expensive, and more convenient than stone ones, and can be carried over undulating ground. A further advantage is that they can bear greater pressure. The iron pipes should be bedded on a firm foundation to prevent *leakage at joints, and valves or taps must be provided* at the summit of upward and at the bottom *of downward curves to allow of the removal of air or* of salt. Water-pipes, especially in a descent, are likely to admit gaseous liquid or even solid impurities through leaky joints. Such pipes should have a solid foundation, and should not be laid in polluted soil or near drains; otherwise concrete beds are necessary for them. If the water is muddy, it should be permitted to stand for some time in a *settling-tank*, so that the mud may subside before the water reaches the filter. Open distributing channels are always objectionable, as the water they convey can never be preserved from pollution.

Sand is the principal filtering medium of nearly all modern water works—whether the supply be from gathering grounds, rivers, reservoirs, lakes or tanks. Sand forms a very satisfactory barrier to our infection by disease-producing microbes conveyed by water, and the experiments performed by Dr. Percy Frankland indicate this. In the analytical report given in the Appendix, the water from the hydrants showed an absence of any harmful impurities, except a few micrococci, notwithstanding that the water in its raw condition from the Hoosain Saugor Tank contained much ammonia (both saline and albuminoid) and crowds of bacterioid organisms.

The fact that deep well water contains but few micro-organisms is another indication of the filtering power of the soil.

With regard to *domestic filtration* much may be said, but we shall endeavour to condense our remarks. The media used vary considerably. Professor PARKES* states : " The filters in the market are very numerous, but the most important are the following :—

1. Those containing animal charcoal in granules or powder.

2. Animal charcoal compressed into blocks by admixture with silica and other substances.

3. Spongy iron filters.

4. Magnetic iron filters.

5. Those containing other substances of a nature chiefly mineral.

Before remarking on particular forms of filters and the value of the various kinds of filtering media, we shall make another quotation from Dr. Parkes' book regarding the requirements of a good filter. He says : " A good filter should fulfil the following conditions :—

" 1. Every part of it should be easily got at for the purpose of cleaning, or of renewing the filtering medium.

" 2. The filtering medium should have a sufficient purifying power, both as to chemical action on organic matter in solution, or arrest of organisms or their spores in suspension, and be present in sufficient quantity.

" 3. The medium should yield nothing to the water that may favor the growth of low forms of life.

" 4. Its purifying power should be reasonably lasting.

" 5. There should be no material used in the construction of the filter itself that is capable of undergoing putrefaction, or of yielding metallic

* Practical Hygiene, *opus cit.*, p. 85.

impurities to the water. The filtering medium should not be liable to clog; and lastly the delivery of the water should be reasonably lasting.

"The *first* of these conditions obviously sets aside all filters of the older, and what used to be the usual, pattern, where only a small layer of filtering material was present, which was cemented up, so as not to be reached without breaking open the apparatus.

"The *second* condition is fulfilled, so far as filtering power is concerned, by a number of media, chiefly spongy iron, magnetic oxide, or carbide of iron, and charcoal for a short time. Coke, sand, and some other substances arrest organisms for some time, but do not affect the organic constituents chemically. With regard to bulk of material, this is fairly well attended to in the filters where loose material is used; but where solid blocks are employed, the size is often quite incommensurate with the work they are called upon to do.

"The *third* condition is complied with by spongy iron, magnetic oxide, or carbide, and some other materials; but (as before mentioned) not by animal charcoal in the loose condition. As solid blocks, it seems to yield less to water than in the granular condition.

"The *fourth* condition depends a good deal upon the relative degree of impurity of the water. The spongy iron, and the magnetic oxide or carbide on the whole, last the longest.

"The *fifth* condition demands that nothing organic shall be used in the construction of the filter, or in the packing of the interior. Iron or other material must be protected from the action of the water.

" The *sixth* condition is generally fulfilled when the material is loose, and when the water is not too full of suspended matter. Sometimes sponge is used to arrest suspended matter, but it is so apt to get foul that its use had better be avoided. The block filters are very apt to clog, a slimy substance forming on their surface. This is partly obviated now by the use of asbestos strainers (as in the silicated carbon filter). Spongy iron is apt to cake, unless kept constantly covered with water, but this is arranged for in the new forms of filter."

As regards rapidity of delivery, animal charcoal has the advantage over spongy iron and block filters in the following ratio:—

1. Animal charcoal { Water runs through fairly well purified in $2\frac{1}{2}$ to 4 minutes.
2. Silicated carbon, average exposure, 15 minutes.
3. Spongy iron „ „ 22 „

Domestic Filtration can be readily carried out in all households. A simple form of filter is made by suspending three earthenware chatties, one above the other, in a triangular wooden frame. The top chatty is kept half full of clean charcoal, the middle one half full of sand. Into the lowest one, the filtered water drops and is collected. A small hole is to be made in the bottom of the two upper *gurrahs*. The lower two should be covered with perforated earthenware plates, and the uppermost one with an unperforated cover. These exclude dust, and prevent birds, squirrels, mosquitoes and other insects finding access to the water. An arrangement of this kind keeps the water cool and pleasant, and permits of free admixture with air, thus removing the unpleasant and insipid flavor given by boiling if this has been previously carried out. Every two months the charcoal should be thoroughly washed, brushed and dried in the sun; or fresh charcoal should be used. The use of an oven for this drying process is convenient and very effective. As the active part of the sand in filtration is the upper half inch or so, this should be removed every four weeks, thoroughly cleaned and relaid, and every three months the entire quantity changed. There are many points in favor of this form of filtration if properly carried out. It is simple, inexpensive, easily constructed, and reliable, the filtering media can be easily got at, cleaned, or renewed. The materials for its construction can be obtained in any village. To be efficient, however, it must be carefully attended to. The covers must be kept on to exclude dust, bird droppings, mosquitoes, insects, &c. A clean vessel must be used in removing the water for use, and water should be removed from the lowest *gurrah* only. The *bheestie* if not watched may empty his *mussack* into the lowest or middle chatty, to obviate the trouble of reaching the uppermost one. We may here mention with regard to the domestic supply of water by hand that when bheesties' mussacks or *pakals* are in use, they add their quota of impurity. It is not easy to keep these bags clean and free from the possibility of polluting water. We have frequently seen mussacks ripped up, or cut into with the object of examining the interior, and almost invariably we found them lined with a thick layer of slimy organic matter. Besides the bheestie is not always particular as to whence he fills his bag.

It would take very many pages to describe a tithe of domestic filters in use: we shall, therefore, confine our remarks to a few of those that have met with universal approval.

1. **The Spongy Iron Filter.**—(Bischoff's patent). The spongy iron which forms the filtering medium is a hæmatite ore, reduced at a low temperature by means of carbon, and thus rendered vesicular or spongy. It is exceedingly successful in oxidising organic impurities. It has the power of destroying microscopic vegetable organisms. It has been proved experimentally by Frankland that living bacteria or their spores in water are destroyed by contact with spongy iron. This is certainly true with regard to the bacteria of putrefaction, but whether it is so with regard to the specific germs of disease has not yet been proved. Spongy iron is the only substance known that destroys the bacterial forms of life. It also removes the organic matter in solution, and in this respect is about equal to charcoal. But unfortunately animal charcoal has exactly the opposite quality with regard to bacterial life to that possessed by spongy iron. It removes lead in solution, and reduces the hardness of the water. After the experience of four or five years, its purifying action was still unaffected; but it is recommended that the filtering medium should be renewed about once a year. One condition of its use is, that it should be always covered with water to prevent atmospheric oxidation.

All the filters we shall describe act both mechanically and chemically, separating and oxidising the impurities, but the chemical activity of the spongy iron filter is far greater than in the others, for it decomposes a part of the water itself, setting free the oxygen. The water that has filtered through it is almost chemically pure.

2. The "*Filtre Rapid*" (Maignen's patent), otherwise called the "carbo-calcis filter." In this the active filtering agent is purified animal charcoal intimately combined with pure insoluble calx. It is rapid and efficient in its action, and at the same time very convenient to use in purifying water from organic matter, ammonia, lime, sulphuretted hydrogen, iron, lead, and most of the mineral poisons. It is said to have some influence in removing bacteria. It reduces the hardness of water. The filtering material should be renewed every three months or oftener, especially if the water is of suspicious quality, or drawn from shallow wells. All parts of the filter are accessible, and the asbestos cloth, upon which the filtering medium rests, may be heated to redness and so efficiently purified when foul.

3. The "*Silicated Carbon Filter*" consists of compressed blocks composed of carbon, silica, aluminia, and iron. They remove organic impurities, coloring matters and especially lead from water. At the same time the water is softened. New blocks are easily fixed to replace the old ones. The period of their activity is about three years.*

* Carbon and silicated carbon block filters are cleansed by thoroughly brushing the surface. After this they should be replaced and two pints of diluted Candy's fluid (1—4 parts of water) allowed to pass through the filter. Then about 2 or 3 gallons of boiled and filtered water containing an ounce of muriatic acid should be passed through the filter. Finally pure water should again be used to wash away the taste of the drugs used. The filter is then once more fit for use.

4. The "*Improved Granular Charcoal Filter*" is an excellent form of filter. Its construction is simple, and its action efficient. The filtering medium is granular charcoal, one of the best filtering agents known.

Almost all the different kinds of charcoal filters act efficiently, and indeed the same may be said of nearly all domestic filter media, when properly attended to.

5. **Carfarel** has been used as a filtering medium. It consists of a mixture of iron, clay and charcoal. Some experiments carried out at Netley showed that it acted well for a time and then became inefficient.

6. The "*Magnetic Filter.*" In this the filtering medium is magnetic, spongy, protoxide of iron, combined with a small proportion of carbon, forming what is known as magnetic probocarbide of iron. Its chemical activity has not been found to have diminished after more than twenty years' use. It does not easily become clogged.

Sponge occasionally forms part of the filtering material. They should be placed in boiling water for a few minutes every two days.

With regard to the use of domestic filters, we should remember that nothing short of intelligent personal. supervision will keep them working properly. Servants are too apathetic in such matters to attend to the required details.

All filters are repositories for the impurities of water—a form of dust-bin. They take up and retain the foreign matter they have separated from the water. It should be remembered that a filter may become the breeding ground of germs, and may thus, if not kept clean, give rise to the injurious effects it is intended to prevent. They all require regular and thorough cleaning. A foul filter is most dangerous, for in this state it gives to the water the impurities it had previously removed. A foul filter is worse than no filter at all; it is a water polluter, instead of a water purifier. Any form of filter that does not permit of free access to the filtering medium is defective. However bright and apparently pure a water may be, except it be from some primary spring remote from habitations, and on elevated ground, it should always be subjected to filtration, for a water may appear unimpeachable as to its wholesomeness, and yet contain the germs of disease, which good filters are capable of removing.

It should be remembered that filtration, and still more filtration with boiling, lessens the keeping power of water, so that these processes should only be carried out a short time before the water is to be used.

When travelling, particularly in jungle districts, the small "pocket silicon carbon filter," "portable carbon filter," or the "stone bottle filter" is very useful. With regard to the latter, when in use it is placed in a large-mouthed vessel containing the water to be filtered. The water should be allowed to stand for a while before immersing the filter. The water filters through the porous walls of the bottle into the interior chamber. The filtered water thus provided is usually potable.

CONCLUSION.

In the matter of Public Health, the part played by WATER is of overwhelming importance, and without wishing to attach undue weight to it, we feel convinced that in the absence of a proper water-supply to a community, the very rudiments of sanitary matters cannot be properly attended to. We do not pretend to have presented any original observations to our readers. The main points alluded to are only too familiar to sanitary and inspecting officers of Indian towns and districts. What we have aimed at is an attempt to popularise a recognition of the evils associated with habits that produce a deterioration of our water-supplies, and the means of counteracting these evil practices. Some general information on this subject is indispensable if we wish to maintain the purity of our water-supplies. The inhabitants of India, as we have seen, are exceedingly thoughtless as to the extent of contamination to which they subject their water-supplies, and if to the slightest degree the perusal of this small volume effects the ends aimed at, we shall consider that our task has not been undertaken altogether in vain.

APPENDIX.

USEFUL MEMORANDA IN CONNECTION WITH WATER-SUPPLY.

1 Gallon = 10lbs. = ·1605 Cubic feet = 70000 grains.
=4·5434 litres = 277·273 c cubic inches.

224 Gallons = 1 ton = 35·942 c. feet = 1·331 c. yards.

1 Pint = 34·6592 cubic inches = 1·25 lbs. = 0·206 c. feet
= ·5679 litre = 8750 grains.

1 fluid ounce = 1·72 cubic inches = 437·4976 grains.

1 dram = 27·3436 grains.

1 cubic inch = 252·5 grains.

1 gallon = ·1604 cubic feet.

35·943 c. ft. = 1 ton.

1 cubic yard = 168·2694 gallons.

1 cubic foot = 997 ounces.

The following simple formula gives the capacity of a storage reservoir :—

$$D. — \sqrt{F.}$$

When D = number of days supply to be stored and F = *mean rainfall in inches for three consecutive years.*

Maximum density under barometric pressure of 30″ of Mercury occurs at 39·2° F. or 4 C and is taken as 1. We usually take it at 60° F.

Density of ice at 32° F. = ·916.

1 cubic inch at 62° F. (barometric pressure being 30″) = 252·458 gallons.

The average rainfall in the three Presidencies is

Madras Bengal Bombay	Mean average.

A fall of 1″ rain per acre = 100 tons = 22624 gallons = 64,640 tons per square mile.

The average proportion of rainfall sinking below the surface is between 40 and 50°/$_o$.

The evaporation of one grain of water causes as much heat to be absorbed as would raise 260 grains 1° F.

Analytical Results.

To convert parts per million (which is the same as milligram per litre) into grains per gallon multiply by ·07.

To convert parts per 100,000 into pints per million multiply by 10.

To convert grains per gallon into parts per million multiply by 14·3.

In finding the capacity of wells and tanks, the following table may be found useful :—

1. Area of Superfices.

Area of circle { D^2 (square of diameter) × ·7854.
{ C^2 (square of circumference) × ·0796.

Circumference of circle = D × 3·14159.
Diameter of ,, = C ÷ 3·14159.
Area of rectangle = length × breadth.
,, ,, = base × ½′ height or height × ½ base.

Cubic Capacity.

Cubic capacity of a tube = length × breadth × height.
Cone or pyramid = area of base × ⅓ height.
Cylinder = area of base × height.

Cubic space occupied by a man = ¼ his weight in stones.

1 Acre = 4840 square yards.

1 Square mile = 640 acres.

To calculate the Time employed in filling and emptying a Reservoir when the supply and consumption are going on simultaneously :—

Q = Supply of water to reservoir in cubic feet per minute.

q = Consumption of water from reservoir in cubic feet per minute.

C = Contents of reservoir in cubic feet.

T = Time required for filling reservoir in minutes.

t = Time required for emptying reservoir in minutes.

$$T = \frac{c}{Q-q} \qquad t = \frac{c}{q-Q}$$

1. The quantities of a fluid discharged in equal times by the same apertures, from the same head, are nearly as the areas of the apertures.

2. The quantities of a fluid discharged in equal times by the same apertures under different heads are nearly the square roots of the corresponding heights of the fluid above the surface of the apertures.

3. The discharge of fluid through a cylindrical horizontal tube, the diameter and length of which are equal to one another, is the same as through a simple aperture.

4. If the horizontal tube is of greater length than the diameter, the discharge of fluid is much increased, and may be increased with advantage up to a length of tube four times the diameter of the aperture.

To find the pressure of fluid on the bottom of its containing vessel.—Multiply area of base by height of fluid in feet and the product by the weight of a cubic foot of the fluid.

To compute the pressure of a fluid upon a vertical inclined curved or any surface.—Multiply the area of the surface by the height of the centre of gravity of the fluid in feet and the product by the weight of a cubic foot of the fluid.

Give the pressure on a sloping side of a pond of fresh water 100 feet square, the depth being 8 feet.

Centre of gravity $8 \div 2 = 4$.

Then $10^2 \times 4 = 400 \times 62{\cdot}5 = 25{,}000$ lbs.

Required the direction and magnitude of the pressure against a flat circular valve inclined to the horizon at an angle of 45°, and employed to retain fresh water in a reservoir; the centre of the valve is sixteen feet below the surface of the water, and the diameter of the valve one foot.

The direction of the pressure is at right angles to the valve.

The area of valve = 12 × 12 = 144 × ·7854 = 113·09.

Pressure of water per sq. inch at 16 feet is ·4332 × 16 = 6·9312lb.

Therefore the pressure on the valve is 6·9312 × 113·09 = 783·849 lb. the total pressure on the valve.

One cubic inch of water = ·0361lb.∴·0361 × 12 = ·4332lb.
Area of valve = D × ·7854. D = diameter.

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