Chapter - IV

DISCUSSION

PART - I

STUDIES ON EFFECTS OF SODIUM FLUORIDE (NaF) INGESTION ON SOME TISSUES OF ALBINO MALE MICE:

In the current investigations, the effects of sodium fluoride (NaF) ingestion were studied on the structure and metabolism of kidney, liver and gastrocnemius muscle as well as on blood and some serum parameters of adult male albino mice (Mus musculus) of swiss strain.

The mice were chosen for the study as their easy availability and convenient size facilitates the work. Sodium fluoride (NaF) was administered at a dose of 10mg/kg body weight/day. The dose was selected on the basis of previous work on rodents (Chinoy 1991 a, b) and LD₅₀ value of fluoride in mice which is 54.4 mgF⁻/kg body weight and 51.6 mgF⁻/kg body weight in males and females respectively (Pillai et al., 1987).

The mode of administration of NaF to mice was oral, since one of the main source of intake of fluoride is drinking water. The duration of study was 30 days,
because significant alterations in metabolism of soft tissues occurs by this time in mice (Chinoy, 1991; 1992).

The parameters studied were haematology and protein levels in liver, kidney and gastrocnemius muscle, sodium and potassium levels in blood serum. In case of haematological studies, various parameters like haemoglobin (Hb), Red Blood cell counts and white blood cell counts were done in light of our studies on endemic human population of North Gujarat. The possible effects were investigated after sacrificing the animals on 31st day of the treatment by cervical dislocation.

The treatment of NaF brought about a reduction in body weight of mice which could be attributed to less consumption of food and reduction of protein levels in several tissues (Chinoy 1991 a, b; Chinoy and Sequeira 1989 a; Chinoy et al., 1991 a, b; 1992a; 1993 a; 1994 a, b).

**EFFECTS OF FLUORIDE ON HAEMATOLOGY:**

The results revealed that NaF treatment for 30 days showed no alterations in the haemoglobin levels, red blood cell and white blood cell counts in experimental animals, which indicated the absence of anaemic conditions in treated animals in support of earlier work (Chinoy et al., 1993a). Greenberg (1982) had observed morphological abnormalities in cell structure and mitotic figure formation in immature leukocytes of mice given NaF in drinking water. Increased erythrocyte and abnormal lymphocyte counts were found in children living near aluminium plants (Macuch et al., 1963).

Recently, Rajiv Gandhi National Drinking Water Mission (1993) reported that depending upon fluoride poisoning, the erythrocyte membrane would lose the
calcium content which would lead to change in the shape of the RBCs like an amoeba with pseudopodia. The echinocytes occur in circulation in large numbers which might undergo phagocytosis and would not live the entire life span of RBC, but might be eliminated as echinocytes. This would lead to low haemoglobin levels in patients chronically ill due to fluoride toxicity. Therefore, further studies in this direction are called for.

There is a paucity of data regarding the effect of fluoride on haemoglobin level. It is not yet clear whether fluoride is responsible for the anaemic condition or it is due to malnutrition. The levels of haemoglobin in fluorotic human subjects of North Gujarat did not indicate any significant change as compared to the control population of Ahmedabad city. However, the results revealed that the values for haemoglobin were comparatively low as compared to control population from Ahmedabad city. This difference between the two mean values might due to the nutritional as well as socio-economic status of the individuals in support of earlier work (Chinoy et al., 1994f). Pillai and Mane (1985) had reported a significant decrease in the levels of haemoglobin in chicks exposed to the atmosphere near fluoride industry. On the other hand, Macuch et al., (1963) observed decrease in haemoglobin, in children living in the vicinity of a aluminium plant. In view of the controversy, further study in this direction are needed for a large fraction of endemic population.

EFFECTS ON KIDNEY, LIVER AND GASTROCNEMIUS MUSCLE:

In the course of this study, protein levels were determined in all three organs of albino male mice.

The treatment showed significant decrease in protein levels in kidney, liver and
gastrocnemius muscle which could be attributed to alteration in its metabolism due
to the impairment of polypeptide chain initiation (Vesco and Colombo, 1970;
Godchau and Atwood, 1976), or due to weak incorporation of amino acids into
proteins (Helgeland, 1976). On the contrary, Tsunoda et al. (1985) observed no
alteration in total protein in serum in goats exposed to airborne fluoride whereas,
an increase in protein content of adrenal gland was observed by Kathpalia and
Susheela (1978) due to NaF treatment to rabbits.

Protein is essential for growth and general body metabolism. Work from our
laboratory has elucidated that protein levels were significantly reduced in various
reproductive tissues, liver, muscle, and kidney of fluoride intoxicated laboratory
animals, mice, rats, rabbits and guinea pigs (Chinoy, 1991 a, b; 1992; Chinoy and
Sequeira, 1989 a; Chinoy et al., 1991 a, b; 1992 a; 1993 a; 1994 a, b). Similar findings
were obtained in stomach, duodenum and ileum of fluoride treated rabbits by Shashi
et al. (1987). It has been reported for the first time that fluoride treatment might cause
formation of some stress like proteins in testis and epididymis of rats (Chinoy et al.,
1994 b, e). So, work in protein analysis, their characterization and amino acid
sequencing are essential for further research in this direction.

**IMPACT ON ELECTROLYTE BALANCE:**

In the present study serum electrolyte concentrations were increased
significantly by fluoride treatment in corroboration with earlier work (Chinoy et al.,
1993a,b) which might be due to disturbances in kidney function, as high fluoride
intake is known to cause damage to renal tissues. The renal and serum Na⁺/K⁺ levels
were altered in rats and mice which would affect the electrolyte balance as well as
kidney function (Chinoy, 1991, a, b; 1992; Chinoy et al., 1993 a).

Similarly, the levels of serum potassium and sodium were increased significantly in fluorotic human subjects of North Gujarat (Chinoy et al., 1992 b; 1994 f). Suketa and Mikami (1977) have also reported a similar increase in the electrolyte levels. It is known that fluoride in excess in the intracellular region results in Na⁺ influx and K⁺ efflux (McIvor et al., 1985). On the contrary, a reduction in movement of Na⁺ and K⁺ ions across mitochondrial membranes has been reported by Elsair and Khelfat (1988). These contradictory results might be due to differences in the doses, animal models and the type of study undertaken. However, it is evident that the resultant changes might contribute towards weight loss due to electrolyte imbalance as well as the decrease in protein.

PART - II

STUDIES ON IMPACT OF HIGH WATERBORNE FLUORIDE IN ENDEMIC HUMAN POPULATION OF MEHSANA AND BANASKANTHA DISTRICTS OF NORTH GUJARAT:

Fluorosis is a known chronic and crippling malady prevalent in India since the last few decades. It has reached to an alarming phase by now creating severe clinical complications as well as physical manifestations among all walks of life. This disease was first detected by the farmers of Andhra Pradesh in early 1930s in our country. In those days farmers could not obtain proper production of their crops due to ploughing by afflicted bullocks. They had noticed the inability of these bullocks to walk due to painful and stiff joints. The same disease was highlighted for the first
time in our country in fluorotic human population (Shortt et al., 1937). Then fluorosis was known to be prevalent in only 4 states of India, i.e. Andhra Pradesh, Tamil Nadu, Punjab and Uttar Pradesh. However, by now, a total of 15 states have been declared endemic for fluorosis. This does not rule out the possibility that even the remaining states and Union Territories are free from fluoride poisoning in our country. Mostly these regions are not considered for epidemiological surveys or there are no published reports on the disease for these regions of our country. Gujarat is one of the most severely affected state in our country considered to be endemic to fluorosis, where about 18 out of a total of 19 districts are prone to fluorosis due to high fluoride content in drinking water. Mehsana and Banaskantha districts located in North Gujarat and near to each other are considered to be the most affected districts apart from Amreli, Sabarkantha and Baroda (Chhota Udepur). In the present study, forty villages in Mehsana district and thirteen villages in Banaskantha district were surveyed and the effects of fluoride were investigated. Parallel studies were also conducted in Ahmedabad city (non-fluoride endemic area) population which was considered as control to compare the changes occurring due to consumption of high water-borne fluoride in endemic population.

Fluoride is a geochemical contaminant and natural sources account for much of the fluoride found in surface and ground water. It is well established that the natural fluoride levels in ground water depends on factors such as geographical location, chemical and physical characteristics, porosity of the rocks present, pH, temperature, complexing action of other elements, depth of wells and consistency of the soil (WHO, 1984). It has been postulated that as the demand for drinking water
increases, the depth of wells also increase. As a consequence, the levels of fluoride are increasing due to contact with the fluoride bearing rocks. So, the people within the vicinity of these rural areas were consuming natural fluoride from drinking water either knowingly as it was the only source of water or to some extent, due to lack of awareness. As a result, the inhabitants of all age groups including children were suffering from dental and skeletal fluorosis in these villages.

Analysis of samples collected from 15 different localities in Ahmedabad city showed a low concentration of 0.56 ppm fluoride to a maximum of 0.72 ppm with a mean of 0.64 ± 0.013 in water, while the survey conducted in 53 villages revealed a wide variation in the levels of fluoride from a minimum of 1 ppm to a maximum of 6.53 ppm having a mean of 2.81 ± 0.179. The drinking water samples gathered from all the villages except one, showed fluoride levels above 1 ppm. Bore water was more contaminated due to high fluoride content than well water.

In the current investigations, fluoride levels in the serum of fluorotic human subjects varied considerably and a large number of people showed extremely high amounts, while, low fluoride levels were also obtained in serum of some children and younger people but comparatively higher than the control population of Ahmedabad city. This discrepancy may be due to variation in the level of fluoride ingested, duration of ingestion, age of the individual, level of fluoride based nutrition, meteorological factors and individual metabolic response (Shupe and Alther, 1966; Siddiqui, 1972). It has been reported that in areas with water containing less that 0.25 ppm of fluoride, the concentration of fluoride ions in blood was about 0.01 ppm (Murray et al., 1991). The fluoride in plasma is not static and the rapid rise after

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ingesting fluoride lasts only for a short period of time.

There might be a mechanism for the rapid elimination of the absorbed dose of fluoride. Krishnamachari (1986) has correlated it with the degree of renal efficiency and reported of fluoride with other factors such as binders like Mg$^{2+}$, Ca$^{2+}$, Al$^{3+}$ etc. Similarly, Murray et al. (1991) have reported that uptake by the skeleton particularly in growing children which is low in fluoride, has a greater intake capacity, while in older people, the bone fluoride is higher and it approaches equilibrium in plasma, where it rises with advancing years. All these data indicate that there might be a direct relationship between the growing age of the individual and retention of fluoride.

There is yet another mechanism for the uptake of the infused fluoride by the skeleton in the arterial blood, especially by the young bone. After stopping the infusion, arterial levels of fluoride fell and venous levels rose, in some cases exceeding the arterial values. This suggests that the skeleton takes up fluoride when the blood levels is rising and fluoride could be released from the skeleton into the venous blood when the blood levels are falling.

The rising levels of serum fluoride observed in endemic human population might affect virtually all the phase of their general body metabolism probably by altering the soft tissue functions (Chinoy and Narayana, 1992; Chinoy et al., 1992 b; 1994 f; Sheth et al., 1994).

Despite the fact that fluoride is a potent toxicant which disturbs carbohydrate metabolism, yet the precise mechanism of its action is still not clearly understood. The results in the present study revealed a significant decline in the levels of blood
glucose in fluoride afflicted human population of North Gujarat as compared to control. On the contrary, an increase in the circulating glucose levels in the mudskipper (*Boleophthalmus dussumieri*) was reported by Shaikh and Hiradhar (1985) and in fluoride intoxicated rats resulting in marked hyperglycemia (McGown and Suttie, 1977).

Several studies from our laboratory (Chinoy 1991 a, b, 1992; Chinoy, el al., 1993b; Chinoy and Sequeira, 1989 a) have reported accumulation of glycogen in liver, gastrocnemius and pectoral muscles, vas deferens and uterus of experimental mice and rats. The elevated glycogen levels in these organs due to active synthesis is ruled out, since the structure and functions of liver and muscle were found to be altered by fluoride treatment. The glycogen accumulation would indicate low carbohydrate utilization and energy turnover in respective tissues. This could be correlated with the lower levels of blood glucose. Similarly, NaF treatment brought about a decrease in phosphorylase activity in the liver, muscle and uterus which in turn would result in accumulation of glycogen in these organs and be responsible for the disturbed carbohydrate metabolism (Chinoy, 1991 a, b; 1992; Chinoy et al., 1993b; Patel et al., 1994).

Catecholamines (epinephrine and nor-epinephrine) are known to regulate the metabolism, utilization and storage of carbohydrates. In fluorotic human cases, the serum epinephrine and nor-epinephrine levels were increased significantly. This might be due to the stress on adrenal gland or else enhanced release of these hormones due to accumulation of fluoride in the body (Patel et al., 1994). This in turn affected the feedback control mechanism. The enhanced levels of catecholamines

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would probably also influence the hypothalamo-gonadal axis. Earlier workers (Cheon and Distefano, 1973) have demonstrated that fluoride significantly increased the catecholamine levels of the liver, heart and kidney. The marked hyperglycemia which accompanied acute fluoride toxicity has been reported to be mediated by epinephrine released from the adrenal medulla (McGown and Suttie, 1977). Earlier studies had clearly demonstrated that the effect of fluoride was mediated primarily by splanchnic impulses arising in the central nervous system. The release of catecholamines occurred as a result of increase in blood pressure and cardiac stimulation due to continuous exposure to fluoride (Caruso et al., 1970). Work with the adrenalectomized rats and the plasma catecholamine assays indicated that the hyperglycemic action of fluoride was mediated by enhanced catecholamines especially epinephrine (Himms-Hagen, 1967). Thus, these elevated catecholamines would alter the carbohydrate metabolism which was correlated with the glucose concentration due to fluoride toxicity in laboratory rodents (Dost et al., 1977). In the present study, fluorotic human subjects revealed a decrease in their blood glucose levels.

Although lipid metabolism is known to be affected by fluoride, current study did not indicate any significant alteration in serum cholesterol of endemic population in North Gujarat as compared to control population of Ahmedabad city. On the other hand, Saralakumari and her co-workers reported a decrease in plasma free fatty acids and total lipids in rats fed with 100 ppm fluoride in drinking water for two months. But serum cholesterol levels and phospholipids remained unaltered due to consumption of fluoride (Saralakumari et al., 1988). Moreover, Chinoy and associates
have also elucidated that the levels of cholesterol in testis and serum were within the normal range in short-term fluoride treated laboratory rodents and in endemic human population of North Gujarat (Chinoy and Sequeira, 1989 a; Chinoy, 1991 a, b; Chinoy et al., 1992 a; 1994 a). Therefore, these data suggest that there is no possibility of the occurrence of hypo/hypercholesterolemia or atherosclerosis as well, in fluorotic human population of North Gujarat.

On the contrary, recent reports from our laboratory in rats revealed that cholesterol levels, activities of 3β and 17β hydroxysteroid dehydrogenases, Leydig cell morphology of testis and circulatory testosterone levels were affected causing reduction in steroidogenesis (Narayana and Chinoy, 1994 a). Similarly, the present study indicated significant decline in serum testosterone levels of fluoride afflicted individuals of endemic population with respect to the control. This might be due to impaired steroidogenesis or else alteration in hormone receptor interaction, since it is known that phospholipids especially phosphatidylinositol (PI) which is involved in hormone receptor action was reduced in testis and epididymis. This lacunae of information requires further detailed research.

Fluoride has been implicated in impairment of protein synthesis via polypeptide chain initiation (Vesco and Colombo, 1970). Weak incorporation of different amino acids would lead to reduction in protein levels (Helgeland, 1976). In the current investigations, Serum protein levels were decreased significantly in the afflicted individuals of North Gujarat as compared to the control population of Ahmedabad city. Zhavronkov and Strochkova (1981) have also reported decline in protein levels in stomach, duodenum and ileum of fluoride treated rabbits. In

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corroboration to these results, earlier work from our laboratory has also revealed significant decline in protein levels in various reproductive and non-reproductive tissues of fluoride intoxicated laboratory animal models (Chinoy and Sequeira, 1989 a; Chinoy, 1991 a,b; 1992; Chinoy et al., 1991 a,b; 1992 a; 1993 b; 1994 a,b). However it has been reported that fluoride induces formation of some stress like proteins in testis and epididymis of rats (Chinoy et al., 1994 b,e). A reduction in protein levels would cause a decline in the overall growth and body weight of an afflicted individual as was observed during physical examinations. Susheela and Sharma (1980) reported very low levels of glycoproteins in rabbit blood plasma by low dose (i.e. 10 mg/kg body weight) of NaF while a higher dose (50 mg NaF/kg of body weight) increased their levels. Similarly, a reduction in the protein content of various tissues of rabbits administered with 50 mg/kg body wight NaF for nearly nine months period is known (Kathpalia and Susheela, 1978).

Liver is known to be severely affected by fluoride toxicity. The activities of serum transaminases (i.e. SGOT and SGPT) were increased significantly in fluorotic human subjects in endemic regions as compared to control population in Ahmedabad city. It is known that these enzymes are markers for liver function and in the event of liver cell damage, SGOT and SGPT would be released in excess. As a result, the increased activity of these enzymes would reflect on alteration in liver function. In agreement with these results, augmented liver GOT and GPT activities by fluoride exposure in fish (Chitra et al., 1983) and in goats (Tsunoda et al., 1985) were reported. A significant increase in the activities of serum transaminases (SGOT and SGPT) in animal models and endemic human population, indicating alterations in liver

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function were elucidated from our laboratory (Chinoy, 1991 a, b; 1992; Chinoy and Narayana, 1992; Chinoy et al., 1992 b; 1994 f).

The hormonal profile of thyroid gland is known to influence the metabolic rate of the body. In the current study, people residing in fluoride endemic regions did not exhibit any significant alteration in serum triiodothyronine (T₃) and thyroid stimulating hormone (TSH) levels, while serum tetraiodothyronine (T₄) levels were comparatively enhanced as compared to the population in Ahmedabad city. An increase in the level of serum thyroxin might be due to its enhanced synthesis or decline in its utilization. As a result, the basal metabolic rate (BMR) might be affected which would be responsible for altered cellular activities. However, Sonneborn and Mandelkow (1981) suggested that there is no relationship between goiter and fluoride content in drinking water, while, Chinoy and Narayana (1992) found a significant decline in T₃, T₄ and TSH levels of florotic human population of North Gujarat. Thus, data regarding thyroid hormone is quite controversial which requires further investigations in a large number of individuals.

Follicle stimulating hormone (FSH) is known to stimulate the activities of gonads (i.e. Testes in male and ovaries in female). In the present investigations, the levels of FSH were not altered significantly in the afflicted individuals of North Gujarat as compared to the control population of Ahmedabad city. These results elucidate that folliculogenesis might not be affected, and in males, spermatogenesis is likely to be maintained (Li et al., 1987). On the other hand, Tokar and Savchenko (1977) have reported that exposure to certain inorganic fluorine compounds would be responsible for the higher levels of FSH in individuals afflicted with fluorosis.
Chinoy and associates (Chinoy and Sequeira, 1989 b; Narayana and Chinoy, 1994 a, b) have elucidated that mice and rats fed with fluoride manifested the arrest of spermatogenesis due to extensive damage to the seminiferous tubules leading to denudation of cells, vacuolization in their cytoplasm and nuclear pyknosis (Chinoy and Sequeira, 1989 b; Chinoy et al., 1991 e). Hence, it is important to investigate these aspects along with the correlation of luteinizing hormone in endemic human populations.

In case of fluorotic human subjects of North Gujarat, the sodium and potassium levels in serum showed significant increase due to consumption of higher levels of fluoride in drinking water as compared to the control population of Ahmedabad city. The rise in Na\(^+\) and K\(^+\) levels in serum could be attributed to the alterations in electrolyte balance in inter or/and intracellular fluids. As a result, this might influence the movement of water inside as well as outside the cells. The overall distribution of these two cations is vital in many membrane systems where energy oriented active transport is functional. It has been reported that fluoride is known to cause potassium efflux from cells (Mclvor et al., 1985). Suketa and Terui (1980) also reported disturbances in Na\(^+\) and K\(^+\) levels in urine and serum of intoxicated rats, which they attributed to alterations in adrenal functions. Later on, Das and Susheela (1991) confirmed these results in fluorotic human population as well as in experimental animals wherein low corticosteroid levels and adrenal hypofunction was obtained. Hence, the altered electrolyte balance might be due to adrenal hypofunction and altered aldosterone action at selective resorption sites in kidney. The alterations in electrolyte levels could thus bring about a decrease in body weight due to loss of

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water along with the salts, as these individuals look very thin and weak.

Protein metabolism is known to be affected adversely due to fluoride toxicity, this fact has been discussed in details earlier in this chapter. This enhancement of protein levels in urine indicated a probable alteration in kidney structure and function.

In the current investigations, the serum calcium levels were lowered significantly in fluoride afflicted human population of North Gujarat as compared to control population of Ahmedabad city. Calcium kinetic studies carried out by Srikantia and Siddiqui (1965) revealed that administration of 800 mg calcium to fluoride endemic population as well as to the control human individuals resulted in high bone retention of calcium in the former group. This suggests either an avidity for calcium or that the patients were at a lower intake of calcium. Narasinga Rao et al. (1968) reported 53% of calcium in bones of fluorosis patients. Later experiments using radioactive calcium revealed enhanced bone mineralization and low resorption (Narasinga Rao et al., 1979).

Sriranga Reddy and Narasinga Rao (1971) showed that monkeys maintained on low protein diet along with fluoride retained less $^{45}$Ca and those monkeys on high protein had increased $^{45}$Ca retention. Similarly, a low calcium diet caused increased retention of fluoride. Hence, these studies suggest that in fluoride ingested animals, affinity for calcium increases, especially when fed low calcium. Recently, Susheela and Kharb (1990) and Kharb and Susheela (1994) reported low resorption of bone, ectopic calcification and higher content of inorganic constituents in aorta and ligament due to deposition of calcium in these tissues of NaF treated rabbits.

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In populations living in endemic fluorosis regions also showed significant decline in serum calcium levels as compared to the control population of Ahmedabad city. In view of the involvement of calcium in several metabolic processes, it is evident that various functions would be affected in fluorotic individuals.

Hence, these investigations reveal that consumption of high water-borne fluoride is harmful to the body and affects various soft tissue functions.

PART - III

STUDIES ON MASS-BALANCE OF FLUORIDE OF DEFLUORIDATION TECHNIQUE:

In the present study, a laboratory scale working model for defluoridation of water was prepared which was based on the general guidelines given by NEERI, Nagpur for Nalgonda technique of defluoridation of water.

In a prototype laboratory scale model, fluoride levels were adjusted to vary between 2.60 mg/L to 5.80 mg/L in raw water. Concentrated sodium fluoride solution (0.75%) was added at the rate of 9 ml/minute. Ferric alumina solution (0.05%) and required lime solution (i.e. 1/20th of alum dose) were added at the flow-rate of 12 ml/min and 16 ml/min respectively. Chemical doses were used as per the general guidelines of NEERI. Alum was used as a coagulant while lime was added to provide required alkalinity and proper settling of the sludge.

Ever since fluorides were known to cause different types of health hazards, numerous substances were tested for defluoridation and several methods were evolved for removing excess fluoride from drinking water. Viswanadham et al. (1974)
reported that magnesium oxide removes fluoride most efficiently in both alkaline and acidic conditions and it was comparatively economical. On the other hand, Bulusu (1985) suggested that the Nalgonda technique is the cheapest method available for defluoridation apart from its relative ease of operation and maintenance. In the present study too, ferric alumina (IS : 299-1962) was used for defluoridation of raw water.

Although some studies were carried out for the fluoride mass-balance relationship in Nalgonda technique of defluoridation of water, yet material balance in a working defluoridation unit has hitherto not been carried out. Hence, the present investigations were undertaken to work in this direction under laboratory conditions, which could help in suggesting additions/modifications in proper defluoridation technique which might help in providing safe drinking water.

In the present investigations, two types of unit process were arranged to assess the alterations in the quality and removal of fluoride in water. A total of seven runs were taken for continuous flow system and two runs were taken for the batch process. Chemical analysis of raw water was carried out using standard methods of analysis for water and waste water. The results were compared with the treated water available from outlet.

In these investigations, chemical analysis of fluoride indicated significant decline in the treated water as compared to raw water in all the sets of defluoridation unit. Similar findings were also reported in an experimental study on mass-balance relationship in Nalgonda technique of defluoridation of water (Nawlakhe, 1978). Thus, the results revealed that fluoride levels could be reduced in water using this
The level of pH were increased significantly in all the lime added sets due to release of hydroxide ions in treated water as compared to raw water in the present study. pH levels remained unaltered in the remaining sets. In general, the pH of natural water varies between the range of 4.4 to 8.5. However, pH values did not affect the quality and the taste in the present study.

Alkalinity of water is a measure of its capacity to neutralise acids. The alkalinity of natural water is due to salts of carbonate, bicarbonate, borates, silicates and phosphates. The levels of alkalinity might provide the guidance in applying proper doses of aluminium sulphate or aluminium chloride in water to be defluoridated. In the present study, the levels of alkalinity were decreased significantly in most of the sets, while in case of lime added set it had decreased slightly with respect to raw water of defluoridation unit.

Hardness of water is the traditional measure of the capacity of water to react with soap, hard water requiring a considerable amount of soap to produce a lather. Hardness of water is not a specific constituent but a variable and complex mixture of cations and anions. The major hardness causing ions are calcium and magnesium. In the present study, calcium hardness was increased in the treated water of lime added set as compared to raw water due to the increased concentration of calcium ions. As a result, total hardness was also increased in the same set as compared to raw water, while calcium hardness and total hardness remained unaltered in the remaining sets of analysis. In addition to this, magnesium hardness remained unaltered in raw water and treated water of all the sets. Depending upon the local
conditions, public acceptability of the degree of hardness might vary considerably from community to community.

Generally in potable waters, most of the matter is in dissolved form and consists of mainly inorganic salts, small amount of organic matter and dissolved gases. In the present investigations, the levels of total dissolved solids increased significantly in treated water due to addition of aluminium and calcium salts.

Chloride levels in the treated water remained unaltered in all the sets as compared to raw water in the present study. Addition of bleaching powder might slightly increase the concentration of chloride in treated water. Sulphate levels increased significantly due to addition of ferric alumina. However, these levels were within the limits of human consumption.

In the present study, an attempt was also made to establish the mass-balance between fluoride in raw water, treated water, actually collected sludge and theoretically calculated sludge. The results revealed that proper mass-balance was not achieved in theoretically calculated sludge or actually collected sludge. However, mass-balance obtained from batch process indicated better accountability than the continuous process. In addition to this, percentage of fluoride reported was better in sludge collected from batch process as compared to continuous flow system.

This data suggests that there may be an interference of aluminium in the determination of fluoride concentration in treated water from outlet. Thus, the present study reveals that establishment of material balance in such type of unit processes would be the significant contribution in existing knowledge of defluoridation which might help in modification of the defluoridation techniques.

DISCUSSION