

**Status of Fluoride in Underground Irrigation
Water of Ladnu Tehsil (Nagaur district) and its
Effect on Wheat and Mustard**

**यकमु रगलहय ¼ukxkj ftyk½ d Hkfexr
flpkb ty e ½yjkbm dk Lrj vkj mldk
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Rajendra Kumar Jakhar

Thesis

Doctor of Philosophy in Agriculture



उत्तमा वृत्तिस्तु कृषिकर्मेव

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**DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL
CHEMISTRY
COLLEGE OF AGRICULTURE
SWAMI KESHWANAND
RAJASTHAN AGRICULTURAL UNIVERSITY, BIKANER**

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f l pkb t y e f y k j k b M dk L r j v k j m l d k
x g , o l j l k i j i H k k o**

Thesis

**Submitted to the
Swami Keshwanand
Rajasthan Agricultural University, Bikaner
in partial fulfillment of the requirement for
the degree of**

**Doctor of Philosophy in the
Faculty of Agriculture
Soil Science and Agricultural Chemistry**

BY

Rajendra Kumar Jakhar

2014

**Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner**

CERTIFICATE – I

Date: _____

This is to certify that **Mr. Rajendra Kumar Jakhar** has successfully completed the preliminary examination held on as required under the regulation for Ph.D. degree.

(I.J.Gulati)
Head

Department of Soil Science and
Agricultural Chemistry
College of Agriculture,
SKRAU, Bikaner

**Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner**

CERTIFICATE – II

Date : _____

This is to certify that the thesis entitled “Status of Fluoride in Underground Irrigation Water of Ladnu Tehsil (Nagaur District) and its Effect on Wheat and Mustard” submitted for the degree of Doctor of Philosophy in the subject of Soil Science and Agricultural Chemistry embodies bonafide research work carried out by Mr. Rajendra Kumar Jakhar under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on _____.

**(I.J.Gulati)
HEAD**

Department of Soil Science and
Agricultural Chemistry

**(I.J.Gulati)
Major Advisor**

**(I.J.Gulati)
DEAN**

College of Agriculture
SKRAU, Bikaner

**Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner**

CERTIFICATE – III

Date : _____

This is to certify that the thesis entitled “**Status of Fluoride in Underground Irrigation Water of Ladnu Tehsil (Nagaur District) and its Effect on Wheat and Mustard**” submitted by **Mr. Rajendra Kumar Jakhar** to the Swami Keshwanand Rajasthan Agricultural University, Bikaner in partial fulfillment of the requirement for the degree of **Doctor of Philosophy** in the subject of **Soil Science and Agricultural Chemistry**, after recommendation by the external examiner, was defended by the candidate before the following members of the advisory committee. The performance of the candidate in the oral examination on her thesis has been found satisfactory. We therefore, recommend that the thesis be approved.

(I.J. Gulati)
Major Advisor

(B.L. Kumawat)
(Advisor)

(Yogesh Sharma)
(Advisor)

(R.S. Yadav)
(Advisor)

(Y. Sudarshan)
(Dean PGS Nominee)

External Examiner

(I.J. Gulati)
HEAD
Department of Soil Science and
Agricultural Chemistry

(I.J. Gulati)
DEAN
College of Agriculture
SKRAU, Bikaner

Approved

DEAN
POST GRADUATE STUDIES

**Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner**

CERTIFICATE – IV

Date : _____

This is to certify that **Mr. Rajendra Kumar Jakhar** of the **Department of Soil Science and Agricultural Chemistry, College of Agriculture, Bikaner** has made all corrections/modifications in the thesis entitled **“Status of Fluoride in Underground Irrigation Water of Ladnu Tehsil (Nagaur District) and its Effect on Wheat and Mustard”** which were suggested by the external examiner and the advisory committee in the oral examination held on ____/____/2014. The final copies of the thesis duly bound and corrected were submitted on ____/____/2014 are enclosed herewith for approval.

(I.J.Gulati)
Major Advisor

(I.J. Gulati)
HEAD
Department of Soil Science and
Agricultural Chemistry

(I.J. Gulati)
DEAN
College of Agriculture
SKRAU, Bikaner

Approved

DEAN, PGS
SKRAU, Bikaner

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Place: Bikaner

(Rajendra Kumar Jakhar)

Dated: ... / ... / 2014.

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1. INTRODUCTION

Water is an essential natural resource for sustaining life and environment, however, chemical composition of surface or subsurface water is one of the prime factors on which the suitability of water for domestic, industrial and agricultural purpose depends. Fresh water occurs as surface water and groundwater, though groundwater contributes only 0.6 per cent of the total water resources on earth but it is a major source of irrigation besides domestic needs, particularly in semi-arid and arid areas due to an erratic rainfall and scarcity of surface water. The demand for water has increased over the years and this has led to water scarcity in many parts of the country. At present about 85 per cent of India's fresh water resources are being utilized in agriculture and remaining 15 per cent in industrial and domestic sector. High fluoride concentration in groundwater and surface water in many parts of the country is a cause of great concern. The main source of fluoride in groundwater is fluoride bearing rocks such as fluorspar, fluorite, cryolite, fluorapatite and hydroxylapatite. In India about 25 million people in nineteen states and union territories are affected with the problem of excessive fluoride content and another 66 million are at risk.

Rajasthan, being largest state of India having 10.41 per cent nation's area and 5.5 per cent of country's human population but has low water resources *i.e.* 1 per cent of country's resources. The state has extreme climatic and geographical condition. Rajasthan suffers with both the problems of quantity and quality of water. In most parts of the state, groundwater is either saline or having high nitrate and fluoride content. In Rajasthan, due to excessive fluoride concentration in groundwater, cases of both dental and skeletal fluorosis are quite prevalent. The state ranks second amongst the most endemic areas of country and shares approximately 10 per cent of the world fluorosis problem. Most severely

affected areas are of Nagaur, Barmer, Jaisalmer, Tonk, Dausa, Karauli, Sawai Madhopur, Sirohi, Udaipur and Dungarpur districts.

Fluoride related health hazard is a major environmental problem in many regions of the world. Fluoride ion exhibits unique properties as its concentration in optimum dose in drinking water is advantageous to health and if the concentration exceeds the limit, this affects the health problem. Fluoride is considered to be beneficial for human health if taken in controlled quantity ($1.0 - 1.5 \text{ mg L}^{-1}$) preventing dental cavities, but it is also known to cause dental and skeletal fluorosis when its concentration is higher than 3.0 mg L^{-1} in water (WHO, 1984). The problem of high fluoride concentration in groundwater resource has become an important health related geoenvironmental issue in 23 districts of Rajasthan (Agrwal *et al.*, 1997; Maithani *et al.*, 1998; Datta *et al.*, 1999).

Fluoride content in water depends not only on the geochemical background and climate-biological factors such as hydrological condition, land form, rainfall and evaporation, but also on the adsorption and leaching of fluoride in soil. The fluoride concentration in equilibrium solution is governed by a number of factors such as pH, organic carbon, ESP, calcium carbonate, texture, parent material, quality of irrigation water, fertility status and addition of fluoride bearing compounds. Phosphatic fertilizers especially the super phosphates are most important source of fluoride in agricultural lands. Intake of fluoride ion into roots is largely dependent on the concentration of fluoride ion in soil and on the type of soil.

The role of fluoride in plant nutrition is not yet well established, only its stimulating effect on growth of some plant species have been reported. On the other hand, high fluoride levels inhibit germination, causes ultrastructural and malformations, reduces photosynthetic capacities, alter membrane permeability, reduces productivity and biomass and inflict other physiological and biological disorders in plants. Fluoride usually

occurs in plant material in the range of 2-20 mg kg⁻¹ (dry weight basis) in dry matter, although some plants are able to absorb much higher amounts. The accumulation of fluoride in plant tissues is important due to their use as feeds and fodders, and potential health hazards associated with it, regardless of its role in plant growth.

Since last one decade there is growing tendency in the farmers of Rajasthan to dug tube wells and irrigate their crops by sprinkler irrigation. Thus, there is need to generate information regarding concentration of fluoride in irrigation water and to evaluate the fluoride build up in soil and plant. Therefore, keeping above mentioned facts study entitled "Status of fluoride in underground irrigation water of Ladnu tehsil (Nagaur district) and its effect on wheat and mustard" had been undertaken with the following objectives:

1. To find out the fluoride concentration in underground irrigation water of Ladnu tehsil.
2. To study the relationship between fluoride content of soil with different soil and water parameters.
3. To evaluate fluoride buildup in soil.
4. To study the effect of fluoride contents of waters on yield and quality of wheat and mustard.

2. REVIEW OF LITERATURE

The relevant literature pertaining to the "Status of fluoride in underground irrigation water of Ladnu tehsil (Nagaur district) and its effect on wheat and mustard" has been reviewed in this chapter. The available literature as per the requirement of the present study has been reviewed under the following heads:

2.1 Sources of fluoride in soil

2.1.1 Water

2.1.2 Atmosphere

2.1.3 Earth crust

2.1.4 Minerals

2.1.5 Fertilizer

2.1.6 Industrial waste

2.2 Distribution of fluoride

2.2.1 Water

2.2.2 Soils

2.2.3 Plants

2.3 Effect of fluoride on plant growth

2.1 Sources of fluoride in soil

Fluoride is an element of halogen group having atomic No. 9 and molecular weight 19. It is the most electronegative of all the elements known to the world and exists as a diatomic molecule with remarkably low deionosation energy. As a result, it is highly reactive and has strong affinity to combine with other elements to produce compounds known as fluorides.

2.1.1 Water

Rain water will contain traces of fluorine unless, it falls through a polluted atmosphere. MacIntire (1942) reported that about 0.15 kg of fluorine per hectare was added annually through rain waters in the areas of coal mines. Sea water contains appreciable amounts of fluorine ranging from 0.08 to 1.40 mg L⁻¹ (Wattenberg, 1943, Kappana *et al.*, 1962). Occurrence of fluorine in well water in Andhra Pradesh, Punjab, Haryana and Rajasthan was reported by Rao and Bhaskaran (1964), Singh *et al.* (1962), Kanwar and Mehta (1968) and Paliwal *et al.* (1969), respectively.

2.1.2 Atmosphere

Fluorine is invariably present in atmosphere originating from the dusts of fluorine containing soils (Williamson, 1953), gaseous industrial wastes (MacIntire *et al.*, 1952) and from burning of coal fires in polluted area (Cholak, 1959). The fluorine content of air is governed by these factors and has been reported to be less than 0.01 µg m⁻³ (Bowen, 1966)

Russel and Thomson (1983) reported mechanism leading to enrichment of the atmospheric fluorocarbons in groundwater. Sorption and desorption of fluorocarbons from soil surface in response to change in soil moisture may be responsible for enrichment of fluorine in well water.

2.1.3 Earth crust

Clarke and Washington (1924) reported an average value of 290 mg kg⁻¹ in 10 mile deep crust of igneous and sedimentary rocks. Goldschmidt (1937) estimated that the earth crust contained 270 g of fluorine and 786 g of phosphorus per ton of rock material. Fleischer (1953) reported that fluoride constitutes about 0.032 per cent of earth's crust.

2.1.4 Minerals

The fluoride content of some common mineral was reported by Dana (1914) in percentage as follows: biotite (traces to 4.23), tourmaline (0.06 to 1.19), muscovite (0.12 to 1.26), apatite (0.12 to 1.26) and fluorspars (0.12 to 0.26).

Steninkoeing (1919) reported original source of fluorine in soils as micas, apatite, and tourmaline in the parent materials. He also observed that fluorine was widely distributed in soils, particularly in association with phosphorus as fluorapatite and with calcium as fluoride (fluorspar).

Clarke and Washington (1924) reported fluorine as the essential element of the mineral apatite, cryolite, topaz, phlogophite and lepidorite. Minerals biotite and muscovite contain as much as 4 and 2 per cent fluoride, respectively.

Turekian and Waderphol (1961) observed the distribution of fluorine as 740, 370 and 330 mg kg⁻¹ in shales, sand stones and carbonates, respectively.

Wodeyar and Sreenivasan (1996) reported that the source of fluoride were apatite, hornblend and biotite from the gneisses granites and hornblend schists of peddavankahall basin, India.

2.1.5 Fertilizer

Fertilizer contributes a major amount of fluorine in the soils, particularly phosphate rocks containing phosphorus and fluorine in apatite mineral structures.

Robinson and Edgington (1946) estimated that application of 1000 kg ha⁻¹ superphosphate increased the fluorine content of plough depth soil to about 7.5 mg kg⁻¹.

Swain (1962) reported that the fluorine content of monocalcium phosphate, dicalcium phosphate, tricalcium phosphate, super phosphate

and bonemeal as 200, 1.30, 0 to 140, 149, and 270 to 450 mg kg⁻¹, respectively.

Oelschlager (1968) observed that superphosphate alone applied 8 to 20 kg ha⁻¹ fluorine annually to cultivated soils.

The by- product of gypsum also contains varying amount of F. The phospho - gypsum obtained from M/S Hindustan Ltd. contains 0.43 per cent fluorine (Singh, 1978). Continuous use of such fertilizers and amendments may lead to accumulate fluorine in soils.

Omueit and Jones (1977) reported that between 1904 and 1971 fluorine content in marrow plots soils varied from 275 to 381 mg kg⁻¹. The cause of variation in fluorine content was related to phosphorus fertilization practices.

Okarov *et al.* (1994) reported that application of fertilizers and phosphogypsum to solonetzic meadow chernozem increased the content of mobile forms of fluorine in 0-50 cm layer, but had little effect on naturally high content in lower layers on southern chernozem under high rates of phosphatic fertilizers, high rates of mobile fluorine in 50-100 cm layer.

Karblane (1995) reported that fluorine in soil increased with the use of phosphatic fertilizers.

2.1.6 Industrial waste

Wenzel and Blum (1992) reported that deposition of air borne fluorine from aluminum smelter over 50 years caused accumulation of fluorine in soils up to 170 g m⁻², corresponding to annual deposition of 3.79 g m⁻².

Arnesen (1997) noticed that fluorides are emitted to the atmosphere as hydrogen fluoride (HF) gas and in particle forms from the production of aluminum (Al). Dust particle deposited to a great extent solublize and react with soil. The reaction of F in soil depends on soil type,

with little sorption in organic soil and strong sorption in mineral horizons with Al- oxides/ hydroxides.

2.2 Distribution of fluoride

2.2.1 Water

Fluoride has been reported to be widely distributed in drinking water throughout the world. There are areas, often with a recent volcanic geology, where both surface and shallow groundwater that are either potential or actual source for irrigation, contains higher levels of fluoride.

According to Nicholas (1939) only few waters could be found in U.S.A. that would not contain 0.5 mg L^{-1} of fluorine. The concentration up to 14 mg L^{-1} was also reported.

White (1951) reported that many waters contain fluorine in toxic amounts or might become toxic through evaporation. Thermal waters rich in bicarbonate were generally high in fluorine. The highest content was reported 50 mg L^{-1} in Queensland.

Singh *et al.* (1962) observed that an average fluorine content of 60 water samples from village Bajekhana of district Bhatinda (Punjab) ranged from 2.4 to 16.2 mg L^{-1} with a mean of 8.4 mg L^{-1} .

Anand *et al.* (1963) found that fluorine content of well waters in Bindapur village near Delhi ranged from 0.4 to 4.0 mg L^{-1} . Rao and Bhaskaran (1964) reported that in well waters collected from Kurnool district of Andhra Pradesh, the fluorine content ranged from 0.16 to 6.0 mg L^{-1} .

Kanwar and Mehta (1968) reported toxic concentration of fluorine content in irrigation water of Haryana and Punjab. About 91 (Punjab) to 100 per cent (Haryana) samples showed the fluorine content of irrigation water more than 1 mg L^{-1} . Kope *et al.* (1968) reported that well waters from lime stone areas and areas free from lime contained 0.128 and 0.08 mg L^{-1} fluorine, respectively.

Paliwal *et al.* (1969) reported that in Bhilwara district of Rajasthan, 118 well water used for crop irrigation contained a mean (weighted) levels of 5.8 with a range of 2.1 to 24.0 mg L⁻¹.

Somani *et al.* (1972) reported that well water from Nagaur and Jaipur districts of Rajasthan contained 4.5 to 28.1 mg L⁻¹ fluorine with a mean of 4.5 mg L⁻¹ and 1.5 to 13.3 mg L⁻¹ fluorine with a mean of 4.5 mg L⁻¹, respectively.

Somani (1974) examined 166 well water samples in the Udaipur district of Rajasthan and found a medium value of 4.5 with a range of 0.15 to 21.6 mg L⁻¹ fluorine. He noted that fluoride content of well water increased with the depth of well in this region.

Singh and Sinsinwar (1975) observed positive correlation of fluorine with a depth of water table, EC, and sodium content of water.

Sinsinwar *et al.* (1981) reported that fluoride content in well waters of Sriganganagar district ranged from 0.10 to 28.2 mg L⁻¹.

Gupta (1986) observed more than 40 percent groundwater in Pali and Jalore district contains fluoride concentration above the permissible limits of 2.0 mg L⁻¹. The groundwater in the region is saturated with respect to calcite and about 27 per cent of them have fluoride concentration above the solubility product for fluoride.

Singh *et al.* (1987) reported that fluoride content of 356 well waters of Hisar and Sirsa district of Haryana ranged from 0.83 to 18.70 mg L⁻¹. Out of these, only 15 per cent water sample were having safe limit for drinking purpose (1 mg L⁻¹).

Singh and Anand (1991) reported that groundwater of Jhunjhunu district is suitable for drinking purpose but at some locations fluoride content exceeds 30 mg L⁻¹.

Ozha and Sharma (1993) while making investigation of 1870 water samples from Nagaur, Barmer and Jalore districts of western Rajasthan

found that more than 50 per cent water samples had fluoride concentration $> 1.5 \text{ mg L}^{-1}$ and the problem was more acute in Nagaur district.

Datta *et al.* (1996) studied stable isotope ^{18}O fluoride signatures in groundwater to characterize the sources and controlling process of fluoride contamination in the Delhi area of India. The study indicated that almost 50 per cent of the area affected by fluoride is contaminated beyond the maximum permissible limit.

The fluoride occurs in groundwater in almost all districts of Rajasthan irrespective of salinity. The percentage of water having fluoride higher than 10 mg L^{-1} is very small (<5) and highest concentration is 30 mg L^{-1} except Nagaur district where it occurs up to 90 mg L^{-1} (Anonymous, 2000).

Bagoria (2002) reported that fluoride content of Nagaur tehsils ranged between 0.10 to 11.0 mg L^{-1} and about 20.0 per cent water samples were found to have fluoride content within permissible limit as per W.H.O.

Yadav (2002) observed that fluoride content of Jayal tehsil of Nagaur district ranged between 0.20 to 12.0 mg L^{-1} and about 12.7 per cent water samples were found to have fluoride content within permissible limit as per W.H.O.

Ojha and Golani (2005) reported that in nine districts of Rajasthan $> 50 \%$ villages are affected by fluoride toxicity.

In Nagaur district fluoride content in irrigation waters varied between traces to 25 mg L^{-1} about 80.1, 13.4 and 6.5 per cent water samples contained fluoride content < 5 , 5-10 and $> 10 \text{ mg L}^{-1}$, respectively (Anonymous, 2006).

Gupta *et al.* (2006) reported that most of the F levels were within permissible limits, whereas a significantly higher concentration of 1.95 mg L^{-1} was found in artesian well samples of Nasipur village. The F in

groundwater appears to be controlled by the distribution of Ca^{2+} and to some extent SO_4^{2-} , ionic strength and the presence of complex ions. From correlation coefficient analysis, F was found to be inversely related to Ca^{2+} and positively related to Na^+ .

Sabal and Khan (2008) analyzed 200 groundwater sample from 40 village of Phulera tehsil. The result reveals that fluoride concentration in groundwater samples of twenty-four villages varies from 1.5- 5.0 mg L^{-1} . In thirteen villages, fluoride concentration ranged from 5.0-10.0 mg L^{-1} followed by more than 10.0 mg L^{-1} in three villages. Fluoride concentration in three villages is very alarming. The maximum concentration of fluoride was recorded in Macharkhani ($16.0 \pm 0.13 \text{ mg L}^{-1}$), Phulera ($18.0 \pm 0.09 \text{ mg L}^{-1}$) and Shyosinghpura ($11.0 \pm 0.16 \text{ mg L}^{-1}$).

Yadav *et al.* (2009) reported that the fluoride content in soil was 1.5-3.0, 3-6, 6-8, 8-10 and more than 10 ppm in 44.93, 40.63, 7.55, 3.63 and 3.25 per cent area of Tonk district, respectively.

Nayak *et al.* (2009a) revealed that the total water soluble fluoride were positively correlated with total fluoride concentration ($r=0.76$, $P<0.05$) and exchangeable sodium percentage of soil ($r=0.75$, $P<0.05$).

Bhargava and Bhardwaj (2009) reported that fluoride concentrations in groundwater samples of 10 endemic villages of Northern-Eastern Rajasthan varied from 1.50 to 11.82 mg L^{-1} , which was much beyond the WHO permissible limit of 1.5 mg L^{-1} .

Gautam *et al.* (2010) reported that fluoride content in well water of Nawa tehsil of Nagaur district was found in the range between 7.36 ppm to 13.83 ppm.

Dave *et al.* (2010) analysed the groundwater samples for fluoride concentration from several villages of Modasa taluka, Dist-Sabarkantha (N.G.). Out of 88 sources of 23 villages, 34 sources were found to have fluoride concentration 1.0 mg L^{-1} , 52 sources were found to have fluoride concentration 1.0 to 1.5 mg L^{-1} , which is maximum desirable limit of

drinking water standards and 2 sources were found to have fluoride concentration between 1.5 to 3.0 mg L⁻¹.

Gautam *et al.* (2011) observed that the fluoride concentration in the three different zones ranged from 0.64 to 14.62 mg L⁻¹ where 13.04 per cent samples were found within permissible limit while 86.96 per cent had fluoride beyond permissible limit (> 1.5 mg L⁻¹). It was found that among the three different zones south-eastern zone was under serious fluoride contamination where fluoride concentration ranged between 1.10 to 14.62 mg L⁻¹. In the eastern zone fluoride concentration was recorded from 1.52 to 5.13 mg L⁻¹ whereas, in the southern zone it was found between 0.64 to 3.63 mg L⁻¹.

Arveti *et al.* (2011) reported that the alkaline pH and high bicarbonate are responsible for release of fluoride-bearing minerals into groundwater.

Ambade and Rao (2012) assessed the groundwater quality in Rajnandgaon District of Chhattisgarh State and the result reveal that the fluoride concentrations in the existing GW ranging between >0.50 to <5.07 ppm. Most of the places in the study area are affected by high fluoride concentrations, and is evident from the fact that 23 per cent of total samples collected showing >1.5 ppm of fluoride concentration.

Khan and Ravi Kumar (2013) reported that the alkalinity values were found to be more than the permissible limit. It plays an important role for the release of fluoride ion from its ore to the groundwater. It was observed that an increase in the alkalinity value made a similar increase in the amount of fluoride. In alkaline environment, the fluoride ion can be easily liberated from their ore because OH⁻ and F⁻ ions have similar radii. Hence they easily exchange with each other.

2.2.2 Soils

Steinkoeing (1919) reported that fluorine in 15 samples from some locations in Eastern United States varied from traces to 1500 mg kg⁻¹.

McHargue and Hodgkiss (1939) reported that a red clay soil contained 45 mg kg⁻¹ and two lysimeter soils from Tennessee agricultural experiment station contained 83 to 411 mg kg⁻¹ of fluorine. Macintire *et al.* (1942) reported 93 mg kg⁻¹ of fluorine for fine sandy loam and from 80 to 338 mg kg⁻¹ for various samples of silt loam.

Robinson and Edgington (1946) found that the fluorine content of 137 samples from 30 profiles varied from traces to 7.5 mg kg⁻¹, with an average value of 292 mg kg⁻¹. The highest fluorine concentration was found in Tennessee soils which also contained high amounts of phosphorus. They also reported that fluorine content of unfertilized soils increased with the depth in cultivated soils. Silt and clay loams showed higher concentration of fluorine than sandy soils.

Cemmel (1946) reported that fluorine content of New Zealand soils varied from 68 mg kg⁻¹ in coarse sand to 540 mg kg⁻¹ in clay soil with an average of 200 mg kg⁻¹.

Zemlyanitskaya (1957) found that soils of Volzhskii, Oshram and Sernur Rayons of Mordovskaya ASSR contained 220 to 1000 mg kg⁻¹ fluorine and those of S. Viyazhsk, Stolbishchon and E. Uslon rayons of tatarskaya ASSR contained 9 to 1000 mg kg⁻¹ fluorine.

Singh *et al.* (1962) reported that fluorine content of Bhatinda soils varied from 2.5 to 85 mg kg⁻¹. The water soluble fluorine content of Hissar (Haryana) and Sangrur (Punjab) soils ranged from 0.45 to 14.00 mg kg⁻¹. Hot water soluble and total fluorine content of sierozem soils of Hissar varied from 0.13 to 18.5 mg kg⁻¹ with a mean of 0.93 mg kg⁻¹ and 6.0 to 61.5 mg kg⁻¹ with a mean of 30.3 mg kg⁻¹, respectively.

Paliwal *et al.* (1969) reported that fluorine content found to be significantly correlated with the electrical conductivity, Sodium adsorption ratio and boron content of wells water. Recommended maximum concentration of fluoride in irrigation water to be used continuously on all

soils is 1.0 mg L^{-1} whereas for use upto 20 years on fine textured soils of pH 6.0 - 8.5, is 15 mg L^{-1} (NAS and NAE, 1972).

Eysinga and Roordavan (1974) observed a very close positive correlation between total soil fluorine and the proportion of clay in the soils of Netherland.

Singh and Randhawa (1978) studied fifteen soil profiles in the Malerkotla block of the Punjab state for ascertaining the distribution of water soluble fluoride in surface and sub-surface layers. Seventeen undergroundwater samples from these soil series were examined for fluoride content. The mean value of water soluble fluoride for saline, sodic and normal soils were 2.81, 1.67 and 1.30 mg Kg^{-1} . Water soluble fluorides were positively and significantly correlated with pH, ECe, CaCO_3 and silt+ clay but they were negatively correlated with sand.

Chhabra *et al.* (1980) observed that water extractable F increases with increase in soil ESP and pH.

Sinsinwar *et al.* (1981) reported that soils of Sriganganagar district had fluoride content between 2.02 to 4.48 mg kg^{-1} .

Flizhler *et al.* (1985) studied the leaching of fluoride in a heavily F contaminated soil 800 m away from an Al smelter. The flow dependent soluble exchange did not affect decontamination by F leaching and leachate F contents.

Pickering (1985) observed that the mobility of fluorine tended to be a function of soil type, system pH and F levels with retention being favoured in acidic sediment containing clays and poorly ordered hydrous oxides of Al.

Malik *et al.* (1987) noted that adsorption of F in CaCO_3 saturated sand increased with increasing level of CaCO_3 at all equilibrium F concentration. They further reported that adsorption of fluorine in sandy

loam and clay loam soils could be described by Langmuir and Freundlich adsorption isotherms up to an equilibrium fluorine concentration of 575 $\mu\text{mole L}^{-1}$. They observed that the adsorption was more in clay loam soil than sandy loam soil the fluorine adsorption decreased with increasing ESP of soil.

Breimer *et al.* (1989) reported that in calcareous soils, F concentration was restricted to the upper 40-50 cm due to CaF_2 formation.

Grewal and Dhaiya (1992) collected data on water-soluble fluorine (F) content of 470 soil samples (collected at a grid of 10×10 km) of the different agro climatic zones of Haryana and reported that the mean values of water soluble F were 4.42, 4.60, 4.23, 2.47 and 2.12 mg kg^{-1} for the hot and arid, hot and dry, hot and semi dry, hot and sub humid and hot and humid zones, respectively with a mean value of 4.19 mg kg^{-1} for the entire state.

Karblane (1995) reported that fluorine in the soil increased with the use of phosphatic fertilizers.

Fluoride in soils of Nagaur Tehsil varied from 0.43-3.7 mg kg^{-1} . About 40.0, 36.4, 16.4 and 7.2 per cent soil samples had F content < 1.0, 1.0 - 2.0, 2.0 - 3.0 and > 3.0 mg kg^{-1} (Bagoria, 2002).

Madhavan and Subramanian (2002) study in soils of Ajmer district and concluded that the clay contained a high amount of fluoride, whereas sand and silts are enriched with much less fluoride.

Dutta *et al.* (2006) reported that the fluoride contents, as a whole, have poor positive correlation with Na^+ , K^+ , pH and depth of source, and poor negative correlation with Mg^{2+} , Ca^{2+} and total hardness with cumulative data spread over entire area of study.

Romer *et al.* (2009) reported that addition of fluoride to soils resulted in increases in pH and concentrations of Fe, Al, and organic

matter in the equilibrium solutions and decreases in concentrations of Ca, Mg, and K.

Okibe *et al.* (2010) found that the mean soil leachable fluoride for all the soils was in the range of 0.075-0.200 mg Kg⁻¹ range. At 95% confidence limit ($p=0.05$), the mean concentration of soil leachable fluoride for soils from the farms A, B, and C investigated were 0.139+ or - 0.030, 0.115+ or -0.041, and 0.080+ or -0.005 mg Kg⁻¹, respectively.

Paul *et al.* (2011) estimated fluoride levels of water, soil and vegetables from four irrigation farms at the bank of Basawa River, Zaria, Nigeria by using Alizarin red spectrometric method and reported that soil samples from the four farms had a mean soil leachable fluoride in the range of 0.091 mg kg⁻¹ to 0.135 mg kg⁻¹, while the river water had mean fluoride levels in the range 0.081 to 0.191 mg kg⁻¹.

Saxena and Rani (2012) reported that in alkaline soils, fluoride leaching will increase with increase in added NaF salts. An increase in Ca²⁺ levels of extractant has decreased $[F^-]_i$ and LR_{obs}. An increase in Na⁺ level of extractant, some of the unleachable fluoride converts into leachable form as $[F^-]_{extra}$.

2.2.3 Plants

The role of fluoride in plant nutrition is not yet well established; through it adversely affects the quality of fodder crops beyond certain limits. Earlier investigations indicated increase F in plant parts where metabolism is higher. Higher metabolic activity can be associated with higher intake of water.

Robinson and Edington (1946) noticed 3.40 mg kg⁻¹ F in cabbage (edible), 8.40 mg kg⁻¹ in carrot (roots), 11.34 mg kg⁻¹ in potato and 28.30 mg kg⁻¹ in the leaves of spinach. Zimmerman *et al.* (1957) reported 790 to 3060 mg kg⁻¹ in ornamental camalies and 1530 mg kg⁻¹ in green leaves of tea.

Prince *et al.* (1949) reported that the amount of fluoride content in which was taken up from soil by tomato and buck- wheat was usually not related to its content in the soil. They generally used springing soluble salt like CaF_2 in their studies. They also reported that at lower pH values fluorine toxicity was much pronounced but increased addition of P_2O_5 proved most effective in preventing fluorine toxicity. They further observed that the injurious effects from comparable fluorine treatments were of much greater severity on sandy loam soil than on loam soil.

Danies *et al.* (1952) observed that the fluorine content was found to be 76.0 mg kg^{-1} in tomato and 196.0 mg kg^{-1} in buckwheat.

Hansen *et al.* (1958) reported that alfalfa plant contains 15 to 18 mg kg^{-1} fluorine. Addition of fluorine up to 800 mg kg^{-1} as its sodium salt resulted in only slight increase of fluorine in plants grown on the calcareous soils.

Cholak (1959) observed that the tissues of most of the plants were found to contain 0.01 to 1.0 mg kg^{-1} fluorine on dry weight basis. Some African and Australian species were known to contain organic compounds of fluorine.

The fluorine accumulation in plants is governed by its concentration in the soil solution. Kanwar and Mehta (1968) reported that the berseem (green fodder) irrigated with fluorine rich tube well water was found to contain 18 to 52.7 mg kg^{-1} fluorine. The fluorine accumulation in plants was positively correlated with fluorine contents of tube well water.

Eysinga and Roordhavan (1972) has tabulated fluorine values for different parts of plants grown under variety of condition without specific treatment of fluorine. His data refers nine vegetable species, maize (*Zea mays*) and *Gladiolus spp.*

Maclean *et al.* (1976) conducted in a sand culture experiment with a low and high magnesium concentration for seven days and fumigated the tomato plants with hydrogen fluoride. They reported that the severity

of hydrogen fluoride induced chlorosis on apical leaves was enhanced in magnesium deficient plants and suppressed in plant grown at highest level of magnesium (6 mg L^{-1}).

Singh (1978) observed that the F content in straw of rice ranges from 18.2 to 58 mg kg^{-1} and 20.1 to 68.4 mg kg^{-1} in the straw of wheat.

Singh *et al.* (1979a) observed that fluorine content in the rice straw increased linearly with its increasing concentration in the growth medium. They also reported that higher concentration of fluorine in the plants decreased the Ca, Mg, K and P and increased the Na concentration in the plant tissue. The dry matter yield of rice decreased significantly with increasing levels of F in the soil and the decrease was more marked in soil of high ESP.

Singh *et al.* (1979b) reported that the concentration of F in wheat straw increased with its increasing level in soil. The wheat accumulated more F than rice.

Yadav (1985) observed that fluorine concentration and uptake by rice increased with increasing levels of F and ESP. The fluorine concentration increased from 8.89 to 15.95 mg kg^{-1} when the fluorine level was raised from 0 to 200 mg kg^{-1} . Similarly, fluorine concentration in the plants was 10.01 , 11.45 , 12.02 and 15.24 mg kg^{-1} at 0.4 , 15 , 27 and 47 ESP levels, respectively.

Parmar (1988) observed a significant reduction in grain and straw yield of wheat at 80 mg L^{-1} F level which in turn resulted in F concentration of 35.6 and 1.52 mg kg^{-1} straw and grain samples, respectively.

Gritsan (1992) noticed that fluoride accumulation in straw of wheat crop grown at 0.3 , 2 , 4 , 5 and 60 km distance averaged 439.0 , 49.1 , 28.5 , 19.6 , 18.1 and 2.4 mg Kg^{-1} dry weight, respectively.

The fluoride content in wheat grain grown in Nagaur tehsil ranged between 0.17 to 0.54 mg kg^{-1} with an average value of 0.28 to 25.4 mg kg^{-1} . About 25.5 , 60.0 and 14.5 per cent plant samples showed fluoride

content in the range 0-10, 10-20 and 20-30 mg kg⁻¹, respectively fluoride content in wheat grain ranged between 0.17 to 0.54 mg kg⁻¹. Plant samples having higher content of fluoride had lower content of P and K. (Bagoria, 2002).

Kotova *et al.* (2002) recorded the data on spring wheat productivity, fluorine content in roots and aboveground part of the plants, NPK content of the plants, overall nitrogen balance and nitrogen content of the aboveground part of the plants are tabulated. Adverse effect of fluorides on mineral nutrition and productivity of the plants was detected at contamination level of 6 ppm maximum a permissible concentration (MPC), which corresponds to 60 mg water soluble F/kg of soil.

Chaudhary *et al.* (2004) reported that application of 150 ppm NaF noted decrease in fresh weight and dry weight of plants to the extent of 65.2 and 69.0 per cent, respectively. Growth and yield were markedly depressed, and fluoride-induced growth reduction was also associated with the reduction of quality and quantity of crops.

Patel (2007) studied the effect of fluoride at different concentrations (100, 200, 300, 400 and 500 ppm) on fenugreek growth. The result has shown that the overall-growth of the fenugreek was affected. The effect on vegetative and reproductive growth was correlated with concentration and the inhibitory effect was visible even in 15 days old plant. Flowering did not occur in the plants grown on 400 ppm and higher concentration of NaF contaminated soil.

A pot experiment was carried out under controlled condition to investigate the accumulation, uptake and toxicity effects of fluoride (F) in onion (*Allium cepa* L.) grown on the soil contaminated by inorganic fluoride (NaF). The result indicates that F concentration in shoot, bulb and root varied between 16.3 and 109.1 mg F kg⁻¹, 15.8 and 54.3 mg F kg⁻¹ and 18.6 and 151.6 mg F kg⁻¹ respectively. (Jha *et al.*, 2009).

Nayak *et al.* (2009b) revealed that fluoride concentration in grain of rice and wheat was higher in phosphogypsum treated field. It was 13.5 and 14.3 mg/kg in rice and wheat grain, respectively.

Bhargava and Bhardwaj (2009) reported that fluoride content of 10 endemic villages of Northern-Eastern Rajasthan in vegetables and cereals varied between 3.91 to 29.15 $\mu\text{g g}^{-1}$ and 0.45 to 5.98 $\mu\text{g g}^{-1}$, respectively.

Gautam *et al.* (2010) revealed that fluoride concentration in crops varied between 1.88 $\mu\text{g g}^{-1}$ (Bajra from Chitawa village) to 15.88 $\mu\text{g/g}$ (Chana from Chosla). Leafy vegetables grown in fluoride endemic area contain high fluoride content. In the present study, maximum concentration (25.7 $\mu\text{g g}^{-1}$) was reported in spinach (*Spinacea oleoracea*) and 24.86 $\mu\text{g g}^{-1}$ in Sarso leaves (*Brassica campestris*).

Okibe *et al.* (2010) found that the mean fluoride content in vegetable at the same confidence limit was Cabbage 0.054+or-0.0093 mg kg^{-1} , Carrot 0.035+or-0.01 mg kg^{-1} and Lettuce 0.096+or-0.0199 mg kg^{-1} .

Gupta and Banerjee (2011) reported that the F translocation in edible parts was much lower ($\text{TF}<1$) for the grain-yielding crop plant (mustard), fruiting vegetables (tomato, brinjal), and tubers (potato), with an exception of beans ($\text{TF}>1$), while higher Translocations was observed for leafy vegetables (spinach, coriander leaves, and marcellia).

Yadav *et al.* (2012) assessed the accumulation of fluoride in vegetables and cereal crop grown in potentially fluoridated area in Dausa district of Rajasthan and reported that maximum fluoride concentration was found in wheat i.e. 14.3 $\mu\text{g g}^{-1}$ where fluoride concentration in water samples was found 6.2 ppm.

2.3 Effect of fluoride on plant growth

Fluorine is essential for normal plant development and its small amount of it stimulated the plant growth (Salm- Harstmar, 1861).

Maze (1915) reported that fluorine is essential for normal plant development as small amount of it stimulate the plant growth. Gautier (1915) observed remarkable stimulation in growth of mustard and other species in presence of fluoride salts. However, Mitchell and Edman (1945) reported that the element is not essential for plants.

Leone *et al.* (1948) reported that first symptoms of fluorine toxicity in buck wheat and tomato appeared on the tips of younger leaves and the chlorotic area may become necrotic with symptoms progressing from the tip to down-ward along with the margins and increased towards the midrib. At relatively higher fluorine concentration the necrosis was followed by general wilting of plants probably as a result of root injury.

Better tomato growth at 1.25 mg L^{-1} fluorine level was observed by Baumeister and Burghardt (1957). Hansen *et al.* (1958) observed that addition of 160 mg kg^{-1} fluorine resulted in a marked decrease in plant yield of alfalfa.

Brewer *et al.* (1969) reported that the growth rate and yield of 4 year old seedlings of Naval orange trees were markedly reduced by application of 25 mg L^{-1} fluorine when applied as hydrogen fluoride.

Applegate *et al.* (1959) and Newman (1961) found that higher fluoride concentration inhibited oxygen uptake by the plants, whereas the lower concentration increased it. Newman (1961) also reported that fluorine reduced the chlorophyll, carotenoids and soluble Mg components and increased the amounts of free amino acids.

Chang and Thompson (1966) observed that the chlorophyll may be the site of most of fluorine accumulation in leaves. Although, leaf is the major organ of fluorine accumulation in plants, other parts also contains measurable amounts.

Holub (1975) reported that F caused a rapid lowering of leaf water content in wheat seedling leading to apical desiccation but decreased chlorophyll degradation and ultra structural injury appeared to be confined to the members of organelles, especially chloroplasts.

Somani (1977) reported that there was no significant effect of fluorine on the growth of wheat at concentration upto 10.0 mg L^{-1} .

Singh *et al.* (1979a) reported that the dry matter yield of rice decreased significantly with increasing levels of fluorine in the soil and decrease was more in high ESP soils.

Verma (1979) observed that the straw and grain yield of barley, wheat and raya decreased with 75 mg kg^{-1} applied fluorine in soil as compared to 2.5 mg kg^{-1} fluoride.

Pushnik and Miller (1983) noticed that plants exposed to hydrogen fluoride initially exhibited changes in respiratory pattern and eventually displayed foliar damage depending on several factors such as species, age of the plants, duration of exposure and fluoride concentration.

Gupta (1984) conducted a pot experiment for four year to evaluate the effect of F on the growth of wheat. The irrigation water having EC of 5 dS m^{-1} containing different amount of F was used for irrigation on sandy loam calcareous normal soil. In general, neither the grain nor the straw yields of wheat were affected significantly.

Lopez-Belmonte *et al.* (1984) found that the most marked effects of fluorine were on plant height and leaf area, but even the higher rates (100 and $150 \text{ mg kg}^{-1} \text{ F}$) did not delay development.

Doley (1986) studied the effects of hydrogen fluoride on grapevine during four successive seasons. No significant effect of fluorine was observed on the number of leaves and leaf size in the early stage but the leaf size at the maturity was significantly reduced.

Rathore (1987) reported that maximum leaf chlorophyll content occurred at the highest NPK without fluoride treatment and minimum leaf chlorophyll content at the highest fluoride concentration when no NPK

fertilizer was applied in onion. Foliar symptoms of fluoride toxicity increased with increasing fluoride concentration but were modified by increasing NPK rates.

Parmar (1988) observed that increasing levels of above 80 mg L⁻¹ decreased wheat grain and straw yield. The decrease in wheat grain and straw yield was more marked in loamy sand than in clay loam soil.

Wang *et al.* (1995) and Nagoor (1997) reported that inhibition of root, shoot and leaf elongation occurs by sodium fluoride treatment.

Elrashidi *et al.* (1998) from an experiment on the effect of F and P addition on mineral composition of barley, reported that addition of P depressed the F uptake by plants. F addition had a negative effect on dry matter yield of barley grown on the acid and neutral soil while no effect was observed for the alkaline soil. On the other hand, increasing F addition depressed P uptake for the acid soil and no clear trend was observed for the neutral and alkaline soil.

McLaughlin *et al.* (2001) in a long term experiment reported that long term application of super phosphate was leads to increase in concentrations of the more soluble fraction of F in the soil. The more soluble F fraction in the soil surface lead to increased F concentrations in herbage (11 to 22 mg F kg⁻¹) were not high enough to be toxic to plants or grazing animals. Fluoride applied as an impurity in phosphatic fertilizer was generally found to accumulate in the upper soil profile (0 – 6 cm depth). Such increase could also increase F ingestion by ruminants through incidental soil ingestion while grazing.

Singh *et al.* (2001) observed that different concentration of sodium fluoride inhibited germination, plant height, leaf sizes, number of effective tillers/plants, 100 grain weight, and total yield plant⁻¹ of wheat. Leaves at higher concentration of NaF exhibited chlorosis and necrosis.

Bhardwaj (2006) reported that the grain yield of wheat decreased with increasing level of F in the soil and extent of decrease was from 12.53 to 10.83 g/ pot with increasing F levels from 0 to 200 mg kg⁻¹ at ESP 5.8 and from 7.11 to 5.59 g pot⁻¹ at ESP 56.6 at same F levels.

3. MATERIAL AND METHODS

The investigation reported herein "Status of Fluoride in under ground irrigation water of Ladnu tehsil (Nagaur district) and its effect on wheat and mustard" was undertaken in two parts for two consecutive years during 2007-08, 2008-09. The details of techniques and methodology followed during the course of investigation are presented as under :

3.1 General description of survey area

3.1.1 Study area and its location

Ladnu tehsil of Nagaur district is a part of Agro-climatic zone-II (a) *i.e.* transitional plain of inland drainage of Rajasthan. In the north, it is surrounded by Sujangarh tehsil of Churu district, in the east Dhod tehsil of Sikar district, in the west Jayal tehsil of Nagaur district and in the south Didwana tehsil of Nagaur district.

3.1.2 Climate

The climate of Ladnu tehsil is semi-arid with a cool winter from November to March. During this period north-eastern winds prevail and there is occasional rains. Summer is hot and dry from April to June. In this hot period, strong south-western winds blow causing frequent dust storms. Scattered rains occur during July to September with an average rainfall of 263.3 mm per annum. The rainfall is extremely scattered and variable with severe drought, which is of common occurrence. The temperature ranges from 3 °C to 46 °C and some times minimum and maximum temperature goes even up to 0 °C to 50 °C, respectively.

3.1.3 Land use pattern

The main crops grown are pearl millet, clusterbean, groundnut, green gram, mothbean and sesame in *Kharif* and wheat, barely, mustard, chickpea and fenugreek in *Rabi* season.

3.1.4 Vegetation

Vilayati babool (*Prosopis Juliflora*), Babool (*Acacia arabica*), Neem (*Azadirachta indica*), Aak (*Calotropis procera*), Ber (*Ziziphus mauritiana*), Sisam (*Dulbergia sisso*), Dhamasa (*Tephrosia purpurea*), Ker (*Capparis decidua*), Bhurt (*Cenchrus biflorus*), Lapla (*Aristiza depressa*) and Kard (*Dicanthium annulatum*) etc. are the common trees, shrubs and grasses found in the region.

3.1.5 Soils

The texture of soils of the area under study varies from sand to sandy loam showing dominance of sand. The prominent soil series of the study area are as under:

- Molasar Series: mixed, hyperthermic typic, torripsamments (pH 7.9)
- Gajsinghpura series: Fine loamy mixed hyperthermic typic camborthides (pH 8.4)
- Parbatsar series: Dominant soil series of part, coarse loamy mixed hyperthermic, typic camborthits (pH 7.9)
- Asop and Panchroli soils: It is criss crossed with Panchroli and Parbatsar series and is prominent mostly in southern part-coarse loamy, mixed, typic calciorthits, hyperthermic (pH 8.4).

3.2 Plan of work

The study was carried out in two phases.

3.2.1. Phase-I Inventory Survey

An inventory survey of the area had been done, wherein 100 groundwater samples were collected from 31 fluoride affected villages of Ladnu tehsil during 2007. The sites of samples collected are depicted in Map 3.1. Details of all the 100 water sampling sites, viz. name of village, name of farmer, depth of water table and year of start of well/ tube well are presented in table 3.1.

The water samples were collected in pre cleaned polythene bottles of one litre capacity, with necessary precautions (Brown *et al*, 1974). The bottles were carefully corked, properly labeled and brought to the laboratory for further analysis.

Along with each water sample, composite soil sample from 0 - 30 cm depth was also collected from the field which is being irrigated by the tube well. Soil samples were taken with the help of a spade and 'khurpi' and were collected in polythene bags. Each soil sample (approximately 2kg) was carefully labeled carrying all the relevant details and was brought to the laboratory for analysis.

3.2.2 Phase-II Monitoring and assessment of changes in groundwater, soil and crops due to fluoride water irrigation

Based on the fluoride content of 100 water samples collected during inventory survey five categories of water were framed, viz. F_1 : < 2.0 mg L⁻¹ fluoride, F_2 : 2.1 – 4.0 mg L⁻¹ fluoride, F_3 : 4.1 – 6.0 mg L⁻¹ fluoride, F_4 : 6.1 – 8.0 mg L⁻¹ fluoride and F_5 : > 8.0 mg L⁻¹ fluoride. Thereafter, for each category of fluoride water four sites were selected for monitoring the changes in the soil and crops *i.e.* mustard and wheat and also in the quality of groundwater, as a result of use of fluoride waters. The details of twenty sites selected for monitoring work are presented in table 3.2. In all the twenty sites selected in different villages of Ladnu tehsil, mustard (Pusa bold) and Wheat (Raj 3077) crops were grown in rabi season during 2007-08 and 2008-09 as per package and practices for the agro-climatic zone-II (a). Soil and water samples were collected at the time of sowing and harvesting of both the crops during both the years. Yields of both the crops were also recorded. The plant samples of mustard and wheat were collected at 30 DAS and harvest for detailed analysis.

Table 3.1 Details of sampling sites

Sample No.	Name of villages	Name of farmers	Water table depth (m)	Year of start
1	Khamiyad	Kana Ram S/o Chimana Ram	153.3	1998
2	Dhudia	Mohan Lal S/o Kishana Ram	156.7	2000
3	Ratau (a)	Tulsi Ram S/o Bhairamal	66.7	1997
4	Ratau (b)	Shyam Singh S/o Bhanwar Singh	70	2000
5	Ratau (c)	Pema Ram S/o Gobind Ram	70	2000
6	Ratau (d)	Rupa Ram S/o Gobind Ram	80	1995
7	Ratau (e)	Bhola Ram S/o Ramdhan	80	2001
8	Ratau (f)	Shukha Ram S/o Pratap Ram	86.7	2005
9	Sikarali	Pema Ram S/o Hemmant Ram	193.3	1998
10	Malgoan (a)	Moola Ram S/o Phoosa Ram	163.3	2003
11	Malgoan (b)	Surja Ram S/o Khinya Ram	200.3	1998
12	Malgoan (c)	Lichha Ram S/o Shaiya Ram	120	2001
13	Sandas (a)	Bhawara Ram S/o Ganesh Ram	86.7	2000
14	Sandas (b)	Shimbhu Puri S/o Bhairu Puri	80	2005
15	Sandas (c)	Ram Kishan S/o Rewant Ram	166.7	2004
16	Sandas (d)	Keshav Puri S/o Hardeen Puri	66.7	2005
17	Bhakaran ki Dhani (a)	Jora Ram S/o Khumbha Ram	100	1997
18	Bhakaran ki Dhani (b)	Choona Ram S/o Purana Ram	100	2000
19	Bhakaran ki Dhani (c)	Mohan Lal S/o Phoosa Lal	75	2001
20	Lokat	Johar Singh S/o Kalyan Singh	133.3	2003
21	Genana (a)	Rameshwar S/o Bhoora Ram	70	1996
22	Genana (b)	Jhoomar Mal S/o Inder Chand	70	1997
23	Baladoo (a)	Sona Ram S/o Narayan Ram	100	1994
24	Baladoo (b)	Balu Ram S/o Labhu Ram	120	1993
25	Baladoo (c)	Bhagirath S/o Bhiwa Ram	66.7	2004
26	Baladoo (d)	Rameshwar S/o Inder Chand	106.7	1994
27	Baladoo (e)	Dalam Chand S/o Mansa Ram	116.7	1996
28	Khokhari (a)	Shankar S/o Dharma Ram	116.7	2005
29	Khokhari (b)	Moti Ram S/o Tilok Ram	93.3	2003
30	Nimbi Jhodha (a)	Narayan Ram S/o Kana Ram	113.3	1998
31	Nimbi Jhodha (b)	Rashraj Singh S/o Umed Singh	116.7	2003
32	Beron ki Dhani (a)	Purakha Ram S/o Asha Ram	110	1997
33	Beron ki Dhani (b)	Ashu Ram S/o Kana Ram	100	1993

Sample No.	Name of villages	Name of farmers	Water table depth (m)	Year of start
34	Beron ki Dhani (c)	Amara Ram S/o Kripa Ram	110.7	2000
35	Jhardia (a)	Ramsukh S/o Mangi Lal	120	1998
36	Jhardia (b)	Hari Ram S/o Chhoga Ram	120	1999
37	Jhardia (c)	Indra Ram S/o Surata Ram	113.3	1996
38	Jhardia (d)	Ram Rakha S/o Choona Ram	120	1997
39	Jhardia (e)	Budha Ram S/o Deepa Ram	143	2000
40	Bharnawa (a)	Banna Ram S/o Harkha Ram	152	2001
41	Bharnawa (b)	Raju Ram S/o Umara Ram	156	2000
42	Hudas (a)	Karni Singh S/o Ram Singh	66.7	2000
43	Hudas (b)	Jai Singh S/o Pratap Singh	66.6	1996
44	Hudas (c)	Karni Singh S/o Kishan Singh	70	1998
45	Bharnawa (c)	Harji Ram S/o Loona Ram	135	2000
46	Bharnawa (d)	Ramsukh S/o Ganesh Ram	80	2005
47	Bharnawa (e)	Jeewaraj Singh S/o Roop Singh	141	2007
48	Manoo	Bhima Ram S/o Khushi Ram	200	2006
49	Chandai (a)	Kana Ram S/o Sobha Ram	150	2001
50	Chandai (b)	Bhanwara Ram S/o Chhoga Ram	150	2003
51	Lukas (a)	Chhoga Ram S/o Bhinwa Ram	166.7	2003
52	Lukas (b)	Anna Ram S/o Dhudha Ram	183.3	1998
53	Lukas (c)	Sona Ram S/o Bhinwa Ram	150	2000
54	Lukas (d)	Adu Ram S/o Ladu Ram	150	1998
55	Lukas (e)	Sanwat Ram S/o Kana Ram	125	2002
56	Lukas (f)	Ramu Ram S/o Bala Ram	125	2001
57	Audint (a)	Pralad Singh S/o Narayan Singh	126.7	1994
58	Audint (b)	Omprakash S/o Sona Ram	133.3	1998
59	Audint (c)	Maloo Ram S/o Sona Ram	71	1988
60	Audint (d)	Rameshwar Lal S/o Asha Ram	133.3	1994
61	Audint (e)	Sanwat Ram S/o Lalu Ram	133.3	1994
62	Audint (f)	Chhotu Ram S/o Ratana Ram	133.3	2001
63	Heerawati (a)	Bhoora Ram S/o Chhokha Ram	150	1995
64	Heerawati (b)	Bega Ram S/o Bala Ram	150	2006
65	Heerawati (c)	Himmat Singh S/o Sukan Singh	150	2000
66	Sonari (a)	Likhma Ram S/o Bhagana Ram	166.7	2001
67	Sonari (b)	Binwa Ram S/o Bhagana Ram	133.3	2005
68	Sonari (c)	Laxaman Singh S/o Prithavi Singh	126.7	2003
69	Sonari (d)	Ghasi Ram S/o Magha Ram	146.7	1991
70	Sonari (e)	Teja Ram S/o Girdhari Lal	150	1997
71	Ladnu	Ramniwas S/o Deva Ram	100	1993
72	Mangalpura	Dula Ram S/o Sohan Lal	240	1998
73	Natas (a)	Girdhari Lal S/o Dala Ram	121.7	1998
74	Natas (b)	Tola Ram S/o Bhaira Ram	120	2002

Sample No.	Name of villages	Name of farmers	Water table depth (m)	Year of start
75	Dujar (a)	Kanhaiya Lal S/o Shyam Lal	123.3	2001
76	Dujar (b)	Hira Lal S/o Budha Ram	213	2001
77	Dujar (c)	Hardayal S/o Girdhari Lal	166.7	1990
78	Bakolia (a)	Likhma Ram S/o Banna Ram	150	2000
79	Bakolia (b)	Hardayal S/o Pema Ram	150	1990
80	Bakolia (c)	Kishana Ram S/o Ganpat Ram	106.7	2004
81	Bakolia (d)	Narayan Singh S/o Suraj Singh	106.7	2003
82	Bakolia (e)	Mala Ram S/o Ganga Ram	133.3	1995
83	Baded (a)	Kalu Ram S/o Hukhama Ram	100	1993
84	Baded (b)	Ramu Ram S/o Arjun Lal	150	1995
85	Baded (c)	Prabhu Ram S/o Phusa Ram	133.3	2001
86	Baded (d)	Pema Ram S/o Kumbha Ram	133.3	2001
87	Bheid (a)	Moola Ram S/o Ghasi Ram	150	1995
88	Bheid (b)	Magna Ram S/o Teja Ram	216.3	2003
89	Bheid (c)	Prabhu Ram S/o Bhena Ram	108.3	1999
90	Bheid (d)	Karna Ram S/o Purkha Ram	200	2003
91	Bheid (e)	Prabhu Ram S/o Bagha Ram	108.3	2002
92	Koyal (a)	Parawat Singh S/o Sumer Singh	150	1998
93	Koyal (b)	Pratap Singh S/o Roop Singh	150	1997
94	Koyal (c)	Deendayal S/o Megharaj Singh	140	2001
95	Koyal (d)	Jagmal Singh S/o Hem Singh	116.7	1998
96	Dhuria (a)	Mangla Ram S/o Rupa Ram	110.8	1994
97	Dhuria (b)	Heera Lal S/o Kana Ram	118.2	1996
98	Dhuria (c)	Banna Ram S/o Suja Ram	160.8	1999
99	Khangar (a)	Raja Ram S/o Sukan Singh	145.8	1992
100	Khangar (b)	Suraj Singh S/o Maan Singh	155.6	1996

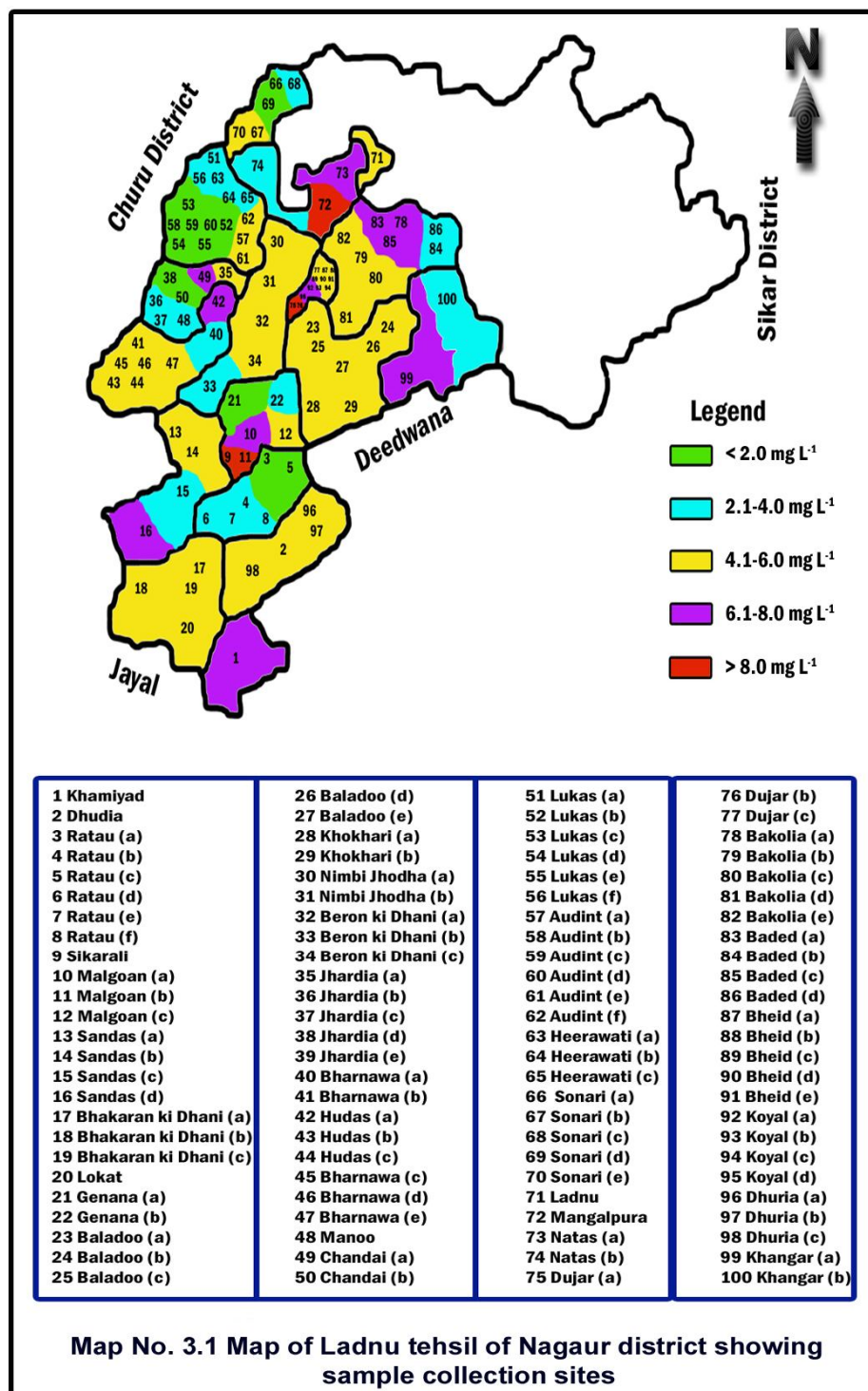


Table 3.2 Details of twenty sites selected under five categories of fluoride for monitoring work

Categories	Range of fluoride (mgL ⁻¹)	Sample No.	Name of villages	Name of farmers	Water table depth (m)	Year of start
I	< 2.0	1	Ratau (a)	Tulsi Ram S/o Bhairamal	66.7	1997
		2	Ratau (c)	Pema Ram S/o Gobind Ram	70.0	2000
		3	Genana (b)	Jhoomar Mal S/o Inder Chand	100.0	1997
		4	Audint (c)	Maloo Ram S/o Sona Ram	250.0	1988
II	2.1-4.0	5	Sandas (b)	Shimbhu Puri S/o Bhairu Puri	80.0	2005
		6	Jhardia (c)	Indra Ram S/o Surata Ram	113.3	1996
		7	Lukas (a)	Chhoga Ram S/o Bhinwa Ram	166.7	2003
		8	Lukas (b)	Anna Ram S/o Dhudha Ram	183.3	1998
III	4.1-6.0	9	Baladoo (a)	Sona Ram S/o Narayan Ram	100.0	1994
		10	Baladoo (b)	Balu Ram S/o Labhu Ram	86.7	1993
		11	Nimbi Jhodha (a)	Narayan Ram S/o Kana Ram	113.3	1998
		12	Nimbi Jhodha (b)	Rashraj Singh S/o Umed Singh	116.7	2003
IV	6.1-8.0	13	Natas (b)	Tola Ram S/o Bhaira Ram	120.0	2002
		14	Dujar (c)	Hardayal S/o Girdhari Lal	166.7	1990
		15	Bakolia (b)	Hardayal S/o Pema Ram	150.0	1990
		16	Bakolia (c)	Kishana Ram S/o Ganpat Ram	106.7	2004
V	> 8.0	17	Sikarali	Pema Ram S/o Hemmant Ram	73.3	1998
		18	Malgoan (b)	Surja Ram S/o Khinya Ram	121.3	1998
		19	Mangalpura	Dula Ram S/o Sohan Lal	100.0	1998
		20	Dujar (b)	Hira Lal S/o Budha Ram	133.3	2001

3.3 Methods of Water, Soil and Plant Analysis

S. No.	Properties	Procedure	Reference
Water Analysis			
1	pH	Potentiometric method using pH meter	Richards (1954)
2	EC	Using Solubridge method	Richards (1954)
3	SAR	$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\text{Ca}^{2+} + \text{Mg}^{2+}}/2}$	Richards (1954)
4	$\text{Ca}^{2+} + \text{Mg}^{2+}$	Versenate titration	Richards (1954)
5	Na^+ and K^+	Flame photometry	Richards (1954)
6	RSC	$\text{RSC (meqL}^{-1}\text{)} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$	Richards (1954)
7	ESP	$\text{ESP} = \frac{\text{Ex. Na}^+ (\text{Cmol (P}^+) \text{ kg}^{-1})}{\text{CEC (cmol (P}^+) \text{ kg}^{-1})} \times 100$	Richards (1954)
8	CO_3^{2-} and HCO_3^-	Titration with standard H_2SO_4 (Method No.12)	Richards (1954)
9	Cl^-	Titration will be carried out with standard AgNO_3 solution (Method No. 13)	Richards (1954)
10	Fluoride	Ion- selective electrode	Villa (1979)
Soil Analysis			
1	pH ₂ (1:2 soil water suspension)	Potentiometric method using pH meter	Richards (1954)
2	EC ₂ (1:2 soil water suspension)	Using solubridge method	Richards (1954)
3	Organic carbon	Walkely and Black wet digestion method	Piper (1950)
4	Available N	By alkaline KMnO_4 method	Subbiah and Asija (1956)
5	Available P	Olsen's "P" extraction method	Olsen's <i>et al.</i> (1954)

S. No.	Properties	Procedure	Reference
6	Available K	Neutral normal ammonium acetate extraction and Flame photometry	Richards (1954)
7	Fluoride	0.01M CaCl_2 extractable using ion selective electrode	Lassern and Widdowson (1971)
Plant Analysis			
1	i) Digestion of plant sample	i) Wet digestion of plant samples with H_2SO_4 and H_2O_2 was carried out for determination of nitrogen content. ii) Samples with diacid digestion mixture HNO_3 HClO_4 (9:4).	Jackson (1973) Johnson and Ulrich (1959)
2	Nitrogen	Colorimetric method using Spectronic-20./ spectro-photometer	Snell and Snell (1949)
3	Phosphorus	Vandomlybdo phosphoric acid yellow colour method	Jackson (1973)
4	Potassium	Flame photometer method	Jackson (1973)
5	Fluoride	Ion-selective electrode	Villa (1979)
6	Oil content	Soxhlet's extraction method	AOAC (1960)
7	Protein content	Protein content in seed (%) = Nitrogen (%) X 6.25	AOAC (1960)
8	Chlorophyll	Grinding of leaf sample was done in 80 % acetone and resultant intensity was measured by spectro-photometer	Arnon (1949)

3.4 Statistical analysis

The data obtained for different parameters of soil, water and plant analysis were statistically analyzed for correlation and regression using the procedures given by Snedecor and Cochran (1967).

4. RESULTS AND DISCUSSION

The groundwater, soil and plant samples collected from different villages of Ladnu tehsil of Nagaur district for investigation entitled **“Status of Fluoride in underground irrigation water of Ladnu teshil (Nagaur District) and its effect on Wheat and Mustard”** were analyzed for various parameters and put to statistical analysis to draw inferences. Efforts have also been made to discuss the significant events or those assuming a definite pattern in respect of various parameters studied, so as to establish cause and effect relationship in the light of available scientific evidences. The results obtained have been presented and discussed in this chapter under the following heads:

4.1 Characterization of groundwaters and soils of Ladnu tehsil

4.1.1 Quality assessment of groundwater

4.1.1.1 pH

4.1.1.2 Electrical conductivity

4.1.1.3 Cationic composition

4.1.1.4 Anionic composition

4.1.1.5 Residual sodium carbonate (RSC)

4.1.1.6 Sodium adsorption ratio (SAR)

4.1.2 Characterization of soils

4.1.2.1 pH₂

4.1.2.2 Electrical conductivity (EC₂)

4.1.2.3 Organic carbon

4.1.2.4 Available nitrogen

4.1.2.5 Available phosphorus

4.1.2.6 Available potassium

4.1.2.7 Fluoride

4.1.2.8 Sodium adsorption ratio (SAR)

4.1.2.9 Exchangeable sodium percentage (ESP)

4.2 Categorization of groundwaters of Ladnu tehsil on the basis of fluoride content

4.2.1 Gram panchayat wise fluoride content in groundwaters of Ladnu tehsil

4.2.2 Classification of groundwaters on fluoride basis

4.3 Interrelationship of soil fluoride with various soil and water parameters

4.3.1 Interrelationship of soil fluoride with soil parameters

4.3.2 Interrelationship of soil fluoride with water parameters

4.4 Impact of different categories of fluoride irrigation waters on soil and water parameters

4.4.1 Soil parameters

4.4.1.1 pH₂

4.4.1.2 Electric conductivity (EC₂)

4.4.1.3 Organic carbon

4.4.1.4 Available nitrogen

4.4.1.5 Available phosphorus

4.4.1.6 Available potassium

4.4.1.7 Fluoride

4.4.1.8 Sodium adsorption ratio (SAR)

4.4.1.9 Exchangeable sodium percentage (ESP)

4.4.2 Water parameters

4.4.2.1 pH

4.4.2.2 Electrical conductivity

4.4.2.3 Cationic composition

4.4.2.4 Anionic composition

4.4.2.5 Residual sodium carbonate (RSC)

4.4.2.6 Sodium adsorption ratio (SAR)

4.5 Evaluation of soil fluoride buildup under wheat and mustard

4.5.1 Soil fluoride buildup under wheat crop

4.5.1 Soil fluoride buildup under mustard crop

4.6 Impact of different categories of fluoride waters on quality of wheat and mustard

4.6.1 Wheat quality parameters at 30 DAS and harvest

4.6.1 Mustard quality parameters at 30 DAS and harvest

4.1 Characterization of groundwaters and soils of Ladnu tehsil

Water and soil are the basic natural resources for agriculture and economic development of the nation. The salt affected soils in arid and semi arid regions usually occur in association with normal soils. The contributing factors for the formation of these soils are low rainfall, high temperature, high evaporation, presence of salts at some depths in soil profile and use of poor quality waters for irrigation.

4.1.1 Quality assessment of groundwater

All natural waters contain varying concentrations of dissolved salts due to dissolution of minerals in rocks and decomposing plant materials. The concentration and nature of salts present in irrigation

water determine its quality. The nature of salts in irrigation water, sometimes, may be more important than the total amount of salts. Chemical composition of groundwater is one of the prime factors which decide the suitability of water for domestic, industrial and agricultural purposes. The quality of irrigation water has always been recognized as an important factor for the development of salinity and alkalinity in the soil. Based on chemical analysis of water, if necessary precautions are taken in irrigation and soil management, then, even waters of doubtful quality can be used without serious damage to soils and crops. Therefore, for a better judgment about the quality of irrigation water, it is essential to have a chemical analysis of water.

4.1.1.1 pH

A perusal of data presented in table 4.1 and appendix-I revealed that the pH of ground irrigation water of Ladnu tehsil varied from 7.50 to 8.50 with an average value of 8.06. The maximum value of 8.50 was observed with the water of Sandas (b) and Baladoo (a) and minimum value of 7.50 was registered in Bharnawa (a) village. A perusal of the results clearly indicated that pH of water in the studied area is slightly alkaline in nature, which is indicative of dominance of alkaline earth carbonates in the soil of the area. These results get support from the findings of Satyanarayana *et al.* (1967), Sood *et al.* (1998), Verma *et al.* (2003), Ojha and Golani (2005), Sabal and Khan (2008), Yadav *et al.* (2009), Dave *et al.* (2010) and Khan and Ravi Kumar (2013)

4.1.1.2 Electrical Conductivity (EC)

The electrical conductivity of ground irrigation water of Ladnu tehsil ranged between 2.23 to 8.10 dS m⁻¹ with mean value of 3.87 dS m⁻¹ (Table 4.1 and Appendix-I). The maximum electrical conductivity (8.10 dS m⁻¹) was recorded at Bheid (e) village and minimum (2.23 dS m⁻¹) at Bakolia (b) village. Results clearly indicated that the groundwater quality of studied area is poor and prolonged use of such

**Table 4.1 Characterization of soil and groundwater samples
collected from Ladnu tehsil**

Characteristics	Minimum	Maximum	Average
Water Characteristics			
pH	7.50	8.50	8.06
EC (dS m ⁻¹)	2.23	8.10	3.87
Ca ²⁺ (me L ⁻¹)	1.60	5.80	3.43
Mg ²⁺ (me L ⁻¹)	3.40	9.00	5.50
Na ⁺ (me L ⁻¹)	13.94	71.79	29.57
K ⁺ (me L ⁻¹)	0.05	0.43	0.16
F ⁻ (mg L ⁻¹)	1.60	8.80	4.47
CO ₃ ²⁻ +HCO ₃ ⁻ (me L ⁻¹)	6.80	16.80	10.72
Cl ⁻ (me L ⁻¹)	10.60	57.00	24.33
SO ₄ ²⁻ (me L ⁻¹)	0.10	41.10	3.62
RSC (me L ⁻¹)	0.20	7.20	1.79
SAR	6.30	33.84	13.90
Soil Characteristics			
pH ₂	7.30	8.70	8.02
EC ₂ (dS m ⁻¹)	0.26	2.93	0.54
O.C. (%)	0.07	0.25	0.15
N (kg ha ⁻¹)	85.03	239.15	144.33
P (kg P ₂ O ₅ ha ⁻¹)	10.10	18.60	15.07
K (kg K ₂ O ha ⁻¹)	122.45	295.68	200.05
F ⁻ (mg kg ⁻¹)	0.40	2.80	1.11
SAR	0.95	19.63	2.18
ESP	0.14	21.69	1.85

waters only lead to formation of saline or alkali soils. The results of the present investigation are in line with the findings of Lal *et al.* (1998), Verma *et al.* (2003) Sabal and Khan (2008), Yadav *et al.* (2009), Dave *et al.* (2010) and Khan and Ravi Kumar (2013).

4.1.1.3 Cationic composition

The water samples of study area were analysed for composition of cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and results are presented in table 4.1 and appendix-II. The soluble cations Ca^{2+} , Mg^{2+} , Na^+ and K^+ of irrigation water ranged between 1.60 to 5.80, 3.40 to 9.00, 13.94 to 71.79 and 0.05 to 0.43 me L^{-1} with mean values of 3.43, 5.50, 29.57, and 0.16 me L^{-1} respectively, in Ladnu teshil. The maximum value of Ca^{2+} (5.80 me L^{-1}) was recorded at Ratau (d) and Sandas (c) villages, Mg^{2+} (9.00 me L^{-1}) at Bhakaran ki dhani (b), Na^+ (71.79 me L^{-1}) at Bhaid (e) and K^+ (0.43 me L^{-1}) at Audint (c) villages. The minimum value of Ca^{2+} (1.60 me L^{-1}) at Genana (a), Jhardia (e) and Hudasa (a) villages, Mg^{2+} (3.40 me L^{-1}) at Sonari (c), Na^+ (13.94 me L^{-1}) at Heerawati (a) and K^+ (0.05 me L^{-1}) was recorded at Natas (a) and Koyal (b) villages. In general Na^+ was found dominant cation in these irrigation waters followed by Mg^{2+} , Ca^{2+} and K^+ . High sodium in irrigation water causes crusting of seed beds thereby reducing the supply of oxygen and also creates hindrance in the availability of other ions. The results of the present investigation are in accordance with the findings of Singh *et al.* (1995), Lal *et al.* (1998), Bagoria (2002), Gupta *et al.* (2006), Yadav *et al.* (2009) and Ambade and Rao (2012).

4.1.1.4 Anionic composition

It is evident from the data presented in table 4.1 and appendix-III that the soluble anions F^- , $\text{CO}_3^{2-} + \text{HCO}_3^-$, Cl^- and SO_4^{2-} of irrigation waters ranged between 1.60 to 8.80 mg L^{-1} , 6.80 to 16.80, 10.60 to 57.00 and 0.10 to 41.10 me L^{-1} with mean values of 4.47 mg L^{-1} , 10.72, 24.33 and 3.62 me L^{-1} , respectively. The maximum F content (8.80 mg

L⁻¹) was observed at Sikarali village and minimum (1.60 mg L⁻¹) at Ratau (a), Ratau (c), Ratau (d), Genana (b), Jhardia (d), Audint (a), Audint (c), Audint (d), Audint (e), Audint (f), Heerawati (a), Heerawati (b), Sonari (b) and Sonari (c) villages. The maximum HCO₃⁻ + CO₃²⁻ content of 16.80 me L⁻¹ was recorded at Sandas (c) and minimum (6.80 me L⁻¹) at Jhardia (b) village. The maximum Cl⁻ of 57.00 me L⁻¹ was observed at Sikarali and minimum (10.60 me L⁻¹) at Bhaid (c) village, whereas maximum SO₄²⁻ (41.10 me L⁻¹) at Bheid (d) and minimum (0.10 me L⁻¹) was recorded at Ratau (b), Ratau (c), Khokhari (b), Beron ki dhani (b), Jhardia (b), Audint (b) and Bakolia (b) villages. Chloride was observed as dominant anion in underground irrigation waters in Ladnu tehsil of Nagaur district followed by carbonate and bicarbonate, sulphate and fluoride. Similar results were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

4.1.1.5 Residual sodium carbonate (RSC)

The RSC indicates the excess of carbonate and bicarbonate ions over calcium and magnesium ions in irrigation water. The data presented in table 4.1 and appendix-I revealed that RSC values of irrigation water of Ladnu teshil varied from 0.20 to 7.20 me L⁻¹ with an average value of 1.79 me L⁻¹. The maximum value of 7.20 me L⁻¹ was observed at Bharnawa (e) village whereas, minimum value of 0.20 me L⁻¹ was registered at Ratau (d), Ratau (e), Malgoan (c), Sandas (a), Baladoo (a), Khokhari (a), Jhardia (b), Bharnawa (a), Chundai (a), Heerawati (c), Ladnu, Dujar (b) and Bheid (e) villages. The prolonged use of high RSC water immobilized soluble calcium and magnesium in soil by precipitating them as carbonates, consequently the concentration of sodium in soil solution and exchange complex increases, which ultimately leads to formation of alkali or sodic soils. Results of Mehta (1970), Singh *et al.* (1995), Prasad *et al.* (1996), Singh and Singh (1997), Oswal (1999), Ram (2003), Gupta *et al.* (2006)

Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013) are also in confirmation to the present results.

4.1.1.6 Sodium adsorption ratio (SAR)

The data presented in table 4.1 and appendix-I clearly indicates that the SAR values of irrigation water of Ladnu tehsil ranged between 6.30 to 33.84 with an average value of 13.90. The maximum value of 33.84 was observed at Bheid (e) village and minimum value of 6.30 at Heerawati (a) village. Higher SAR values in irrigation water of studied area could be ascribed to dominance of sodium ion over calcium and magnesium, which again evidently indicate higher concentration of carbonates and bicarbonates in the groundwaters. The results of the present investigation are in accordance with the findings of Paliwal and Maliwal (1971), Wapda (1974), Sharma and Mondal (1981), Ram (1996), Oswal (1999), Ram (2003), Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

4.1.2 Characterization of soils

For optimum utilization of available land resources on sustainable basis, characterization of soils regarding their potentials and limitations is important.

4.1.2.1 pH₂

Soil reaction is an indicative of the activities of H⁺ and OH⁻ ions in soil solution. Soil reaction (pH₂) is one of the most important properties of soil because it controls the availability of nutrients, microbial activity and physical conditions of soils up to a great extent.

A perusal of data (Table 4.1 and Appendix-IV) revealed that the pH₂ of soils of Ladnu tehsil varied from 7.30 to 8.70 with an average value of 8.02. The maximum value of soil pH₂ (8.70) was observed at Dudia, Beron ki Dhani (c) and Baded (b) villages and minimum value of 7.30 was observed at Jhardia (d), Bhurnawa (e), Lukas (a) and Lukas (e) villages. The 47 per cent soils were observed lower and 53 per cent

higher of average value. The pH₂ of study area were varied from normal to alkaline. Accumulation of bases especially Na⁺ under low rainfall conditions seemed to be the primary reason for alkaline soil reaction. These findings are in close conformity with the findings of Chhabra *et al.* (1980), Deo *et al.* (1993), Dhura Ram (1998), Prakash (2001), Sharma *et al.* (2004), Romar *et al.* (2009), Paul *et al.* (2011) and Saxena and Rani (2012)

4.1.2.2 Electric conductivity (EC₂)

Electrical conductivity of soils is a measure of the total concentration of soluble salts. The electrical conductivity (EC₂) of soils of Ladnu tehsil varied from 0.26 to 2.93 dS m⁻¹ with mean value of 0.54 dS m⁻¹ (Table 4.1 and Appendix-IV). The highest electrical conductivity (2.93 dS m⁻¹) was observed at Khamiyad village and lowest (0.26 dS m⁻¹) at Sonari (b) village. The 31 per cent samples were observed lower and 69 per cent higher of average value of EC₂. It was evident from the data that EC₂ in most of samples was less than 1 dSm⁻¹ which probably be due to low salt content in waters for irrigation and coarse texture of soils, whereas, higher values of EC₂ of soils were might be due to high evaporation demand of the arid-ecosystem due to prevailing high temperature and low rainfall and irrigating the soils with comparatively poor quality undergroundwaters. Similar results have been reported by Khandelwal and Lal (1991), Deo *et al.* (1993), Chandrasekharan *et al.* (1994), Kameriya (1995), Lal *et al.* (1998), Sharma (2002), Gupta (2003), Holanda filho *et al.* (2011) and Saxena and Rani (2012).

4.1.2.3 Organic carbon

The organic carbon content not only plays an important role in increasing cation exchange capacity, aggregation, water holding capacity and fertility status of soils but also contributes to a great deal, both directly and indirectly by influencing many physico-chemical

properties of soils. The data presented in table 4.1 and appendix-IV clearly indicates that organic carbon content in soils of Ladnu tehsil ranged between 0.07 to 0.25 per cent with an the average value of 0.15 per cent. The maximum value (0.25) was observed at Audint (e) village and minimum (0.07) at Dhuria (b) village. The 61 per cent samples of the study area were lower and 39 per cent were higher than average organic carbon value of the area. The organic carbon content of both surface and sub surface soils had been found low. The low organic carbon content of these soils could be ascribed to occasional addition of organic materials, scanty natural vegetations and poor decomposition due to low rainfall and rapid oxidation due to high summer temperature and wind erosion. The similar results were also reported by Kumar and Seth (1983), Dutta and Joshi (1989), Aggarwal and Kumar (1994), Dhura Ram (1998) and Prakash (2001).

4.1.2.4 Available nitrogen

A perusal of data (Table 4.1 and Appendix-IV) revealed that the available nitrogen status of soils of Ladnu tehsil varied from 85.03 to 239.15 kg ha⁻¹ with the mean value of 144.33 kg ha⁻¹. The highest value (239.15 kg ha⁻¹) was observed at Audint (e) village and lowest (88.03 kg ha⁻¹) at Dhuria (b) village. Thus, soils of the studied area were found to be low in available nitrogen content due to less addition of organic matter and nitrogenous fertilizers, poor nutrient capacity of the soil and high summer temperature. The similar results were also reported by Kumar and Seth (1983), Dutta and Joshi (1989), Aggarwal and Kumar (1994), Dhura Ram (1998) and Prakash (2001).

4.1.2.5 Available phosphorus

The data presented in table 4.1 and appendix-IV indicates that the available phosphorus content in soils of Ladnu tehsil varied from 10.10 to 18.60 kg ha⁻¹ with the mean value 15.07 kg ha⁻¹. The maximum available phosphorus (18.60 kg ha⁻¹) was recorded at

Bhakaran ki Dhani (c) village and minimum (10.10 kg ha^{-1}) at Sandas (c) village. Thus, soils of the study area were found to be medium in available phosphorus content. Similar finding were also reported by Kumar and Seth (1983), Singh and Sharma (1984), Akabri *et al.* (1993), Kameariya (1995) and Dhura Ram (1998)

4.1.2.6 Available potassium

A perusal of data (Table 4.1 and Appendix-IV) reveal that the available potassium content in soils of Ladnu tehsil varied from 122.45 to $295.68 \text{ kg ha}^{-1}$ with mean value of $200.05 \text{ kg ha}^{-1}$. The maximum available potassium ($295.68 \text{ kg ha}^{-1}$) was observed at Ladnu village and minimum ($122.45 \text{ kg ha}^{-1}$) at Dhudia village. As compared to the average available potassium in study area 48 per cent higher values of available potassium and 52 per cent lower values of available potassium were recorded. These results are in conformity with finding of Joshi and Ghonsikar (1981), Sharma (1993), Dhura Ram (1998), Lal *et al.* (1998), Oswal (1999) and Singh (2005).

4.1.2.7 Fluoride

It is evident from the data presented in table 4.1 and appendix-V that the fluoride content in soils of Ladnu tehsil ranged between 0.40 to 2.80 mg kg^{-1} with a mean value of 1.11 mg kg^{-1} . The maximum value (2.80 mg kg^{-1}) was observed at Sikarali village and minimum (0.40 mg kg^{-1}) at Baladoo (d) village. The 32 per cent samples were higher and 68 per cent samples were from lower of average value. The results are in accordance with the findings of Sinsinwar *et al.* (1981), Grewal and Dhaiya (1992), Bagoria (2002), Okibe *et al.* (2010) and Paul *et al.* (2011).

4.1.2.8 Sodium adsorption ratio (SAR)

The data (Table 4.1 and Appendix-V) clearly indicated that the SAR in soils of Ladnu tehsil ranged between 0.95 to 19.63 with mean value of 2.18 . The maximum value (19.63) was observed at Khamiyad

village and minimum (0.95) at Sonari(d) village. The 38 per cent samples higher and 62 per cent samples were observed lower from the average value. The SAR values increased with an increase in pH and EC of soils which probably may be due to dominance of soluble Na^+ over Ca^{2+} and Mg^{2+} contents. Similar results were also reported by Khandelwal and Lal (1991), Deo *et al.* (1993), Ram (1998), Lal *et al.* (1998), Oswal (1999), Sharma (2002), Dhura Ram (2003), Sharma (2004), Holanda Filho *et al.* (2011) and Saxena and Rani (2012).

4.1.2.9 Exchangeable sodium percentage (ESP)

It is evident from the data presented in table 4.1 and appendix-V that the ESP in soils of Ladnu tehsil varied from 0.14 to 21.69 with the mean value of 1.85. The maximum value (21.69) was observed at Khamiyad village and minimum value (0.14) at Sonari (d) village. These results are in conformity with the finding of Dhura Ram (1998), Prakash (2001), Okibe *et al.* (2010) and Paul *et al.* (2011).

4.2 Categorization of groundwaters of Ladnu tehsil on the basis of fluoride content

Problems with water quality are as serious as the problems of water availability. Natural contamination of groundwater resources by fluoride and dissolved salt is a major constraint mainly in regions characterized by arid and semi arid climates. The fluoride content of groundwaters in arid aquifers varies from < 1 to 25 mg L^{-1} . Higher fluoride content in groundwaters not only poses problems to human health but also has negative impact on crop production.

4.2.1 Gram panchayat wise fluoride content in groundwaters of Ladnu tehsil

Data on groundwater fluoride distribution in 31 villages of 17 Gram panchayats of Ladnu tehsil have been presented in table 4.2 and depicted in Map 4.1

Table 4.2 : Gram panchayat wise fluoride content (mg L⁻¹) in ground irrigation waters of Ladnu tehsil

S. No.	Gram panchayat	No of villages	Range	Mean	S.D.
1	Khamiyad (1)*	1	7.80	7.80	-
2	Seenwa (4)	1	5.20 - 5.90	5.58	±0.29
3	Ratau (6)	1	1.60 – 2.90	2.13	±0.70
4	Malgaon (6)	3	1.60 – 8.80	5.67	±3.29
5	Dheengsari (4)	1	3.60 – 7.80	5.38	±1.76
6	Silanwad (4)	2	4.20 – 5.40	4.60	±0.54
7	Baladoo (7)	2	4.10 – 5.40	4.70	±0.51
8	Nimbi Jhodha (5)	2	3.40 – 5.90	4.86	±1.01
9	Chanderai (8)	3	1.60 – 6.60	3.83	±1.60
10	Bharnawa (8)	2	3.30 – 6.10	4.79	±0.94
11	Audint (15)	3	1.60 – 4.50	2.67	±1.29
12	Sonari (5)	1	1.60 – 4.40	3.06	±1.47
13	Ladnu (1)	1	5.10	5.10	-
14	Mangalpura (3)	2	3.70 – 8.20	6.07	±2.26
15	Dujar (12)	3	4.10 – 8.10	5.74	±1.14
16	Bakolia (9)	2	3.70 – 7.30	5.18	±1.30
17	Sanward (2)	1	3.80 – 6.10	4.95	±1.63
	Total (100)	31	1.60 – 8.80	4.44	±1.85

* Figures in parentheses are total No. of samples collected from each gram panchayat

Data in table 4.2 clearly shows that the highest mean fluoride value of 7.80 mg L^{-1} was recorded in Khamiyad Gram panchayat followed by Mangalpura Gram panchayat (6.07 mg L^{-1}). The lowest mean value (2.13 mg L^{-1}) of fluoride was registered in Ratau Gram panchayat. Further, table also shows that a good degree of variation exists in range of fluoride content of groundwater of various Gram panchayats of studied area. The widest range of the order of $1.60 - 8.80 \text{ mg L}^{-1}$ fluoride was recorded with the waters of Malgaon Gram panchayat and narrowest range of $1.60-2.90 \text{ mg L}^{-1}$ registered with Ratau Gram panchayat. High fluoride values recorded in the areas could be due to alkaline pH and high bicarbonate concentration, which resulted in release of fluoride bearing minerals into groundwater. Similar types of results were also reported by Gupta (1986), Singh *et al.* (1987), Datta *et al.* (1996), Bagoria (2002), Ojha and Golani (2005), Yadav *et al.* (2009), Gautam *et al.* (2011) and Ambade and Rao (2012).

4.2.2 Classification of groundwaters on fluoride basis

All the water samples collected from the area under study were categorized into five classes on the basis of fluoride content. The desirable or permissible limits of groundwater fluoride for plants are yet not well established, therefore, keeping in mind the maximum permissible limit of fluoride for drinking water (1.5 mg L^{-1}) as prescribed by Indian Council of Medical Research and the average range of fluoride in plants ($2-20 \text{ mg kg}^{-1}$ dry weight basis), groundwater of the studied area were categorized into five classes viz., < 2.0 , $2.1-4.0$, $4.1-6.0$, $6.1 - 8.0$ and $> 8.0 \text{ mg F L}^{-1}$.

Data on distribution of groundwater samples under different fluoride categories are presented Gram panchayat wise in table 4.3, fig. 4.1 and depicted in map 4.1. It is clear that majority of waters (47 per cent) in Ladnu tehsil belong to category 4.1 to 6.0 mg L^{-1} fluoride

and least (4 per cent) in the more than 8 mg L⁻¹ fluoride. Further, it is clear that 69 per cent groundwater samples of Ladnu tehsil had fluoride content between 2.1 to 6.0 mg L⁻¹, whereas other two categories *i.e.* less than 2 mg L⁻¹ fluoride and fluoride between 6.1 to 8.0 mg L⁻¹ had only 14 per cent and 13 per cent waters, respectively. Similar findings

Table 4.3 : Categorization of ground irrigation water of Ladnu tehsil on the basis of fluoride content

S. No.	Gram Panchayat	Per cent distribution of groundwater samples in five fluoride categories				
		< 2.0 mg L ⁻¹	2.1- 4.0 mg L ⁻¹	4.1- 6.0 mg L ⁻¹	6.1- 8.0 mg L ⁻¹	> 8.0 mg L ⁻¹
1	Khamiyad	-	-	-	100.00	-
2	Seenwa	-	-	100.00	-	-
3	Ratau	50.00	50.00	-	-	-
4	Malgaon	16.60	16.60	16.60	16.60	33.3
5	Dheengsari	-	25.00	50.00	25.00	-
6	Silanwad	-	-	100.00	-	-
7	Baladoo	-	-	100.00	-	-
8	Nimbi Jhodha	-	20.00	80.00	-	-
9	Chanderai	12.50	62.50	12.50	12.50	-
10	Bharnawa	-	12.50	75.00	12.50	-
11	Audint	46.60	33.30	20.00	-	-
12	Sonari	40.00	20.00	40.00	-	-
13	Ladnu	-	-	100.00	-	-
14	Mangalpura	-	33.30	-	33.30	33.3
15	Dujar	-	-	66.60	25.00	8.33
16	Bakolia	-	22.20	44.40	33.30	-
17	Sanward	-	50.00	-	50.00	-

were also reported by Gupta (1986), Singh *et al.* (1987), Datta *et al.* (1996), Bagoria (2002), Ojha and Golani (2005), Yadav *et al.* (2009), Gautam *et al.* (2011) and Ambade and Rao (2012).

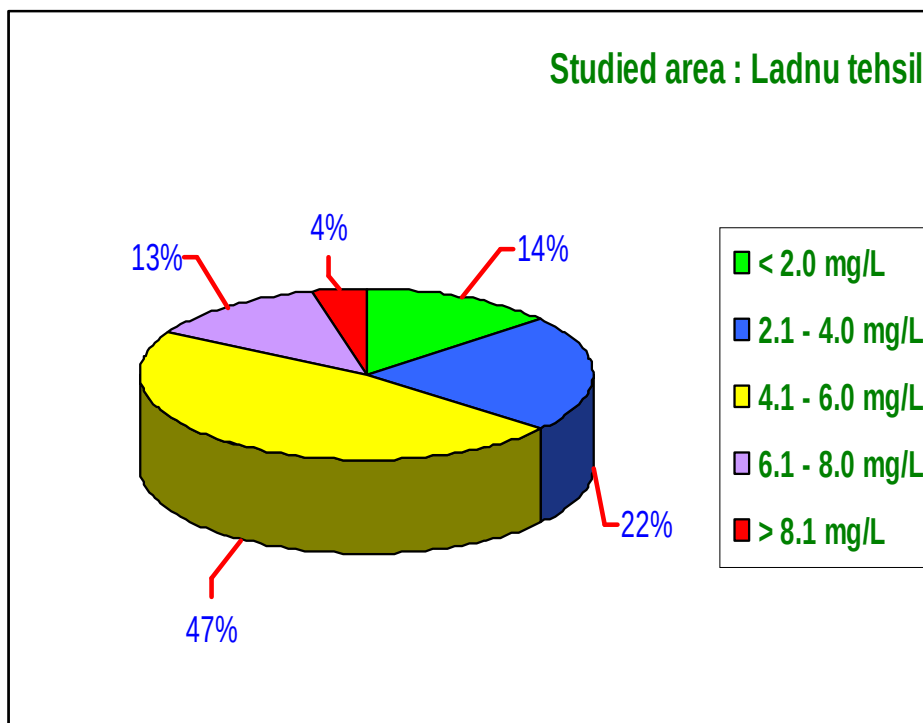


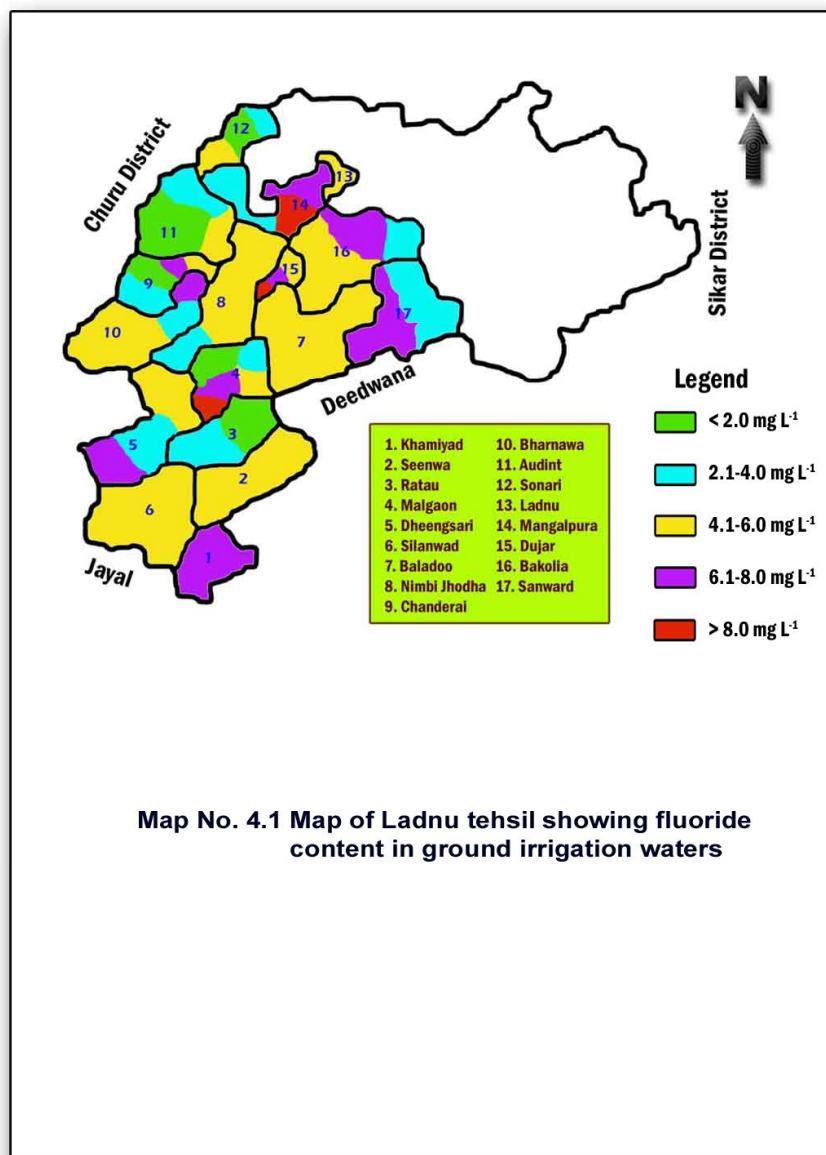
Fig. 4.1 : per cent distribution of ground water samples under different fluoride categories

4.3 Interrelationship of soil fluoride with various soil and water parameters

The relationship of soil fluoride content with various chemical constituents of soil and groundwater were worked out and presented in table 4.4 and fig. (4.2, 4.3, 4.4 and 4.5).

4.3.1 Interrelationship of soil fluoride with soil parameters

In order to understand the type of relation between soil fluoride and some of the chemical parameters of soil under study, correlation studies were conducted and the results so obtained are presented and discussed in the preceeding paragraphs:



pH₂, EC₂ and Organic Carbon

The correlation coefficient worked out between soil fluoride and pH₂, EC₂ and organic carbon of soil are presented in table 4.4. and fig. 4.2.

The correlation coefficient ($r=0.243^*$) between soil fluoride and pH₂, evidently showed a significant and positive relationship. This could be ascribed to adsorptive capacity of fluoride with cations like sodium and calcium, which have the potential of retaining and releasing fluoride at the appropriate geochemical conditions. In alkaline environment, the fluoride ion can be easily liberated from their ore because OH⁻ and F⁻ ions have similar radii. The present findings are in the line of findings of Chhabra *et al.* (1980), Okibe *et al.* (2010) Paul *et al.* (2011) and Saxena and Rani (2012)

Further perusal of data presented in table 4.4 clearly indicates that correlation coefficient between soil fluoride and EC₂ was of the order of $r=0.215^*$, which evidently shows a significant and positive relationship between soil fluoride and soil EC₂. But, a negative and non significant relationship was observed between soil fluoride and soil organic carbon. This might be due to very low organic carbon to affect the retention of fluoride in soil. Results get support from the findings of Singh and Randhawa (1979), Chhabra *et al.* (1980), Dutta *et al.* (2006) and Romar *et al.* (2009).

Available major nutrients

The correlation coefficient values obtained between soil fluoride and available nitrogen, phosphorus and potassium in soils are presented in table 4.4 and fig. 4.2. A perusal of correlation coefficient values, evidently shows that just like organic carbon content of soil ($r= -0.026$), soil available nitrogen ($r= -0.036$) and soil available phosphorus ($r= -0.138$) have also shown negative and non significant relationship with soil fluoride content. But, in case of available potassium of soil

Table 4.4 Relationship of soil fluoride with various soil and water parameters

S. No	Soil Parameters	Correlation Coefficient (r)	Water Parameters	Correlation coefficient (r)
1	pH ₂	0.243*	pH	0.021
2	EC ₂ (dSm ⁻¹)	0.215*	EC(dSm ⁻¹)	0.430**
3	O.C. (%)	-0.026	F ⁻ (mg L ⁻¹)	0.728**
4	N (kg ha ⁻¹)	-0.036	Ca ²⁺ (me L ⁻¹)	0.162
5	P (kg P ₂ O ₅ ha ⁻¹)	-0.138	Mg ²⁺ (me L ⁻¹)	0.084
6	K (kg K ₂ O ha ⁻¹)	-0.257**	Na ⁺ (me L ⁻¹)	0.436**
7	F ⁻ (mg kg ⁻¹)	1.00	K ⁺ (me L ⁻¹)	-0.159
8	Ca ²⁺ (me L ⁻¹)	0.074	CO ₃ ²⁻ + HCO ₃ ⁻ (me L ⁻¹)	0.145
9	Mg ²⁺ (me L ⁻¹)	0.029	Cl ⁻ (me L ⁻¹)	0.415**
10	Na ⁺ (me L ⁻¹)	0.210*	SO ₄ ²⁻ (me L ⁻¹)	0.249*
11	CO ₃ ²⁻ +HCO ₃ ⁻ (me L ⁻¹)	0.083	RSC (me L ⁻¹)	0.008
12	Cl ⁻ (me L ⁻¹)	0.208*	SAR	0.428**
13	SO ₄ ²⁻ (me L ⁻¹)	0.175		
14	RSC (me L ⁻¹)	-0.014		
15	SAR	0.200*		
16	ESP	0.202*		

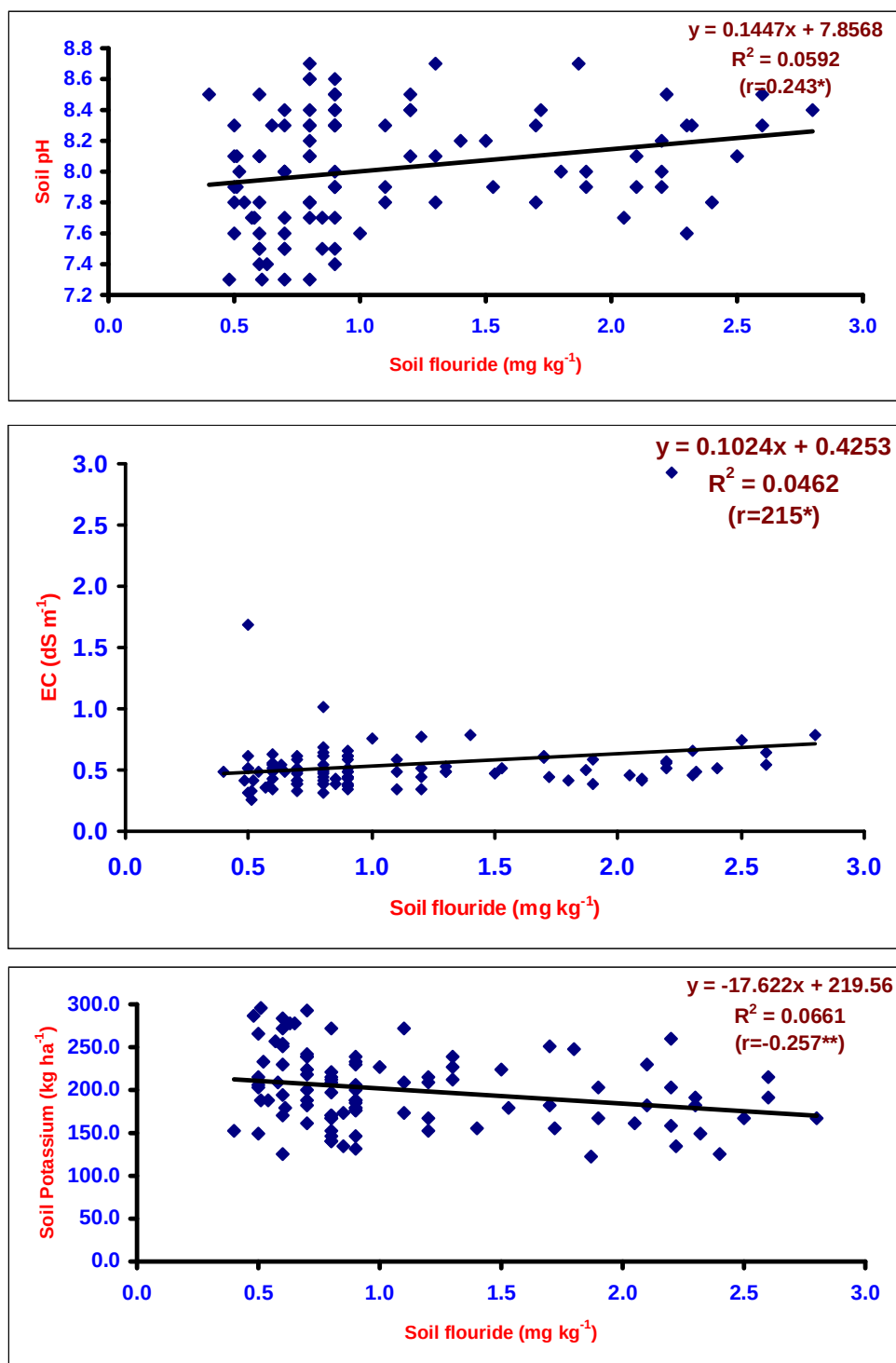


Fig. 4.2 : Relationship of soil fluoride with pH, EC and potassium of soil

negative and highly significant ($r=-0.257^{**}$), relationship was observed with soil fluoride content. The present findings are in the line of findings of Singh and Randhawa (1978), Chhabra *et al.* (1980), Bagoria (2002), Ojha and Golani (2005), Dutta *et al.* (2006), Yadav *et al.* (2009), Gautam *et al.* (2011) and Ambade and Rao (2012)

Cations

The correlation coefficient values worked out between soil fluoride and various soil cations are presented in table 4.4. and fig. 4.3. Correlation coefficient values for soil Ca^{2+} ($r=0.074$) and soil Mg^{2+} ($r=0.029$) have shown poor positive relationship whereas, soil Na^{+} ($r=0.210^{*}$) has shown significant and positive relationship with soil fluoride. This might be because fluoride bounds with calcium and magnesium in soluble form as compared to sodium, which could partly be ascribed to differential adsorbing potential of cations for fluoride at different geochemical conditions, much as high pH. These finding get support from the results of Bagoria (2002), Ojha and Golani (2005), Dutta *et al.* (2006) Yadav *et al.* (2009), Gautam *et al.* (2011) and Ambade and Rao (2012).

Anions

Relationships between soil fluoride and various anions in soil were also worked out and correlation coefficients obtained are presented in table 4.4 and fig. 4.3. The correlation coefficient values of soil fluoride and $\text{HCO}_3^{-} + \text{CO}_3^{2-}$, Cl^{-} and SO_4^{2-} were of the order of $r=0.083$, $r=0.208^{*}$ and SO_4^{2-} $r=0.175$, respectively. Though, this indicates a positive relationship between soil fluoride and various anions studied in the soil but strong relationship was obtained only with chloride ion. Similar types of results were also reported by Chhabra *et al.* (1980), Dhura Ram (1998), Prakash (2001), Okibe *et al.* (2010) and Paul *et al.* (2011).

RSC

A perusal of data in table 4.4 shows that the correlation coefficient between soil fluoride and RSC was of the order of $r = -0.014$ which indicates a non significant and negative relationship between soil fluoride and soil RSC.

SAR

Data presented in table 4.4 and fig. 4.3 clearly indicates that a positive and significant ($r = 0.200^*$) relationship existed between soil fluoride and SAR.

ESP

The correlation coefficient worked out between soil fluoride and ESP was of the order of $r = -0.202^*$ (Table 4.4) which clearly indicates a significant and positive relationship between soil fluoride and soil ESP. The adsorption of fluoride in soils is not clearly understood. However, the most prominent factors that dictate the amount of fluoride in most of the soils are the quantity of clay minerals, soil pH and concentration of calcium and chloride in soils. Generally, greatest adsorption of fluoride by soil mineral components is always at about pH 6.0 to 7.0. High fluoride in soils having pH more than 7.0 could be attributed to more soluble fluoride salts such as NaF and KF. These results are in agreement with what had been observed by Lessern and Widdowoon (1971), Peterson and Shupe (1976) and Omuetti and Jones (1980).

4.3.2 Interrelationship of soil fluoride with water parameters

Efforts have also been made to explain, how quality of groundwater for irrigation in the study areas, affects the soil fluoride content.

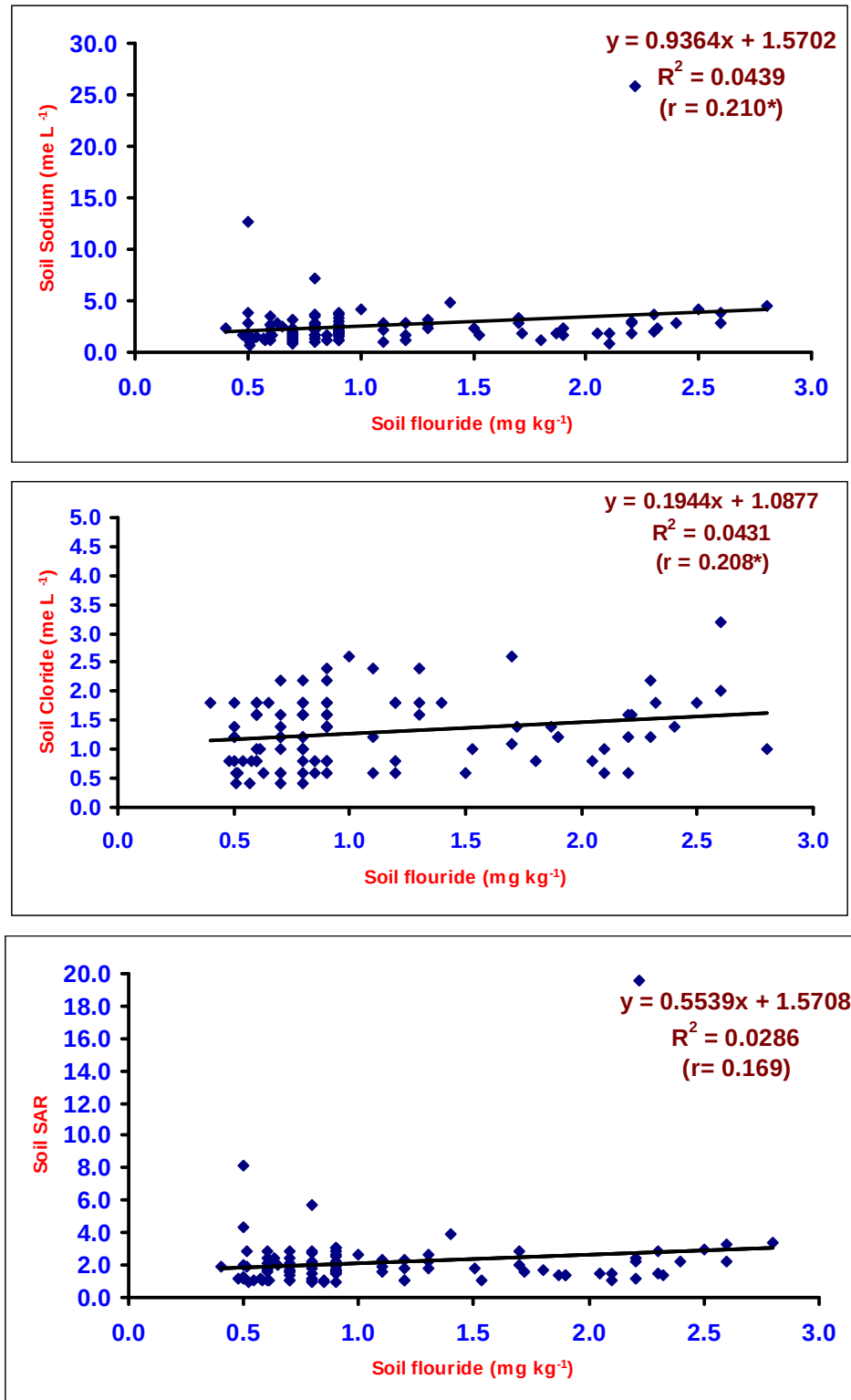


Fig. 4.3 : Relationship of soil fluoride with sodium, chloride and SAR of soil

pH and EC

A visualization of table 4.4 and fig. 4.4 apparently indicates that the correlation coefficient between soil fluoride and EC of water ($r=0.430^*$) found significant and positive, whereas the relationship of soil fluoride with pH ($r=0.021$) of water shows positive and non significant. These results get support from the findings of Satyanarayana *et al.* (1967), Sood *et al.* (1998), Verma *et al.* (2003), Ojha and Golani (2005), Sabal and Khan (2008), Yadav *et al.* (2009), Dave *et al.* (2010) and Khan and Ravi Kumar (2013).

Fluoride

Data presented in table 4.4 and fig. 4.4 clearly indicates that soil F has a highly positive and significant ($r=0.728^{**}$) relationship with fluoride in groundwater. Fluoride is a mobile ion and its retention in soil depends on the amount, rate and quality of water penetrating into the soil zone. Similar results were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

Cations

The correlation coefficient values of water cations, presented in table 4.4 and fig. 4.4, evidently shows that water Ca^{2+} ($r=0.162$) and Mg^{2+} ($r=0.084$) shows positive and water Na^+ ($r=0.436^{**}$) all have positive and significant relationship with soil fluoride but in case of K^+ it was found negative and non significant ($r=-0.159$). The results of the present investigation are in accordance with the findings of Singh *et al.* (1995), Lal *et al.* (1998), Bagoria (2002), Gupta *et al.* (2006), Yadav *et al.* (2009) and Ambade and Rao (2012).

Anions

The correlation coefficient values between water fluoride and $\text{HCO}_3^- + \text{CO}_3^{2-}$, Cl^- and SO_4^{2-} were in the order of $r=0.145$, $r=0.415^{**}$

and SO_4^{2-} $r=0.249^*$ respectively (Table 4.4 and Fig. 4.5). This clearly indicates a positive and significant correlation between soil fluoride and chloride and sulphate anions studied in the water samples. Similar results were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

RSC

The correlation coefficient between soil fluoride and water RSC was $r=0.008$ (Table 4.4) which shows a positive but non significant relationship between soil fluoride and water RSC. Results of Mehta (1970), Singh *et al.* (1995), Prasad *et al.* (1996), Singh and Singh (1997), Oswal (1999), Ram (2003), Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013) are also in confirmation to present results.

SAR

Data presented in table 4.4 and figure 4.5 clearly indicates that soil fluoride content was positively and significantly ($r=0.428^{**}$) related with SAR of water. The results of the present investigation are in accordance with the findings of Oswal (1999), Ram (2003), Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

4.4 Impact of different categories of fluoride irrigation waters on soil and water parameters under wheat and mustard crops:

For sustainable use of high fluoride waters, information regarding changes in soil and water qualities due to prolonged use of these waters is essential. Therefore, in the present case on the basis of fluoride content groundwaters used for irrigation were categorized into five classes and from each class, four sites were selected. At each site both wheat and mustard crops were grown for two consecutive years.

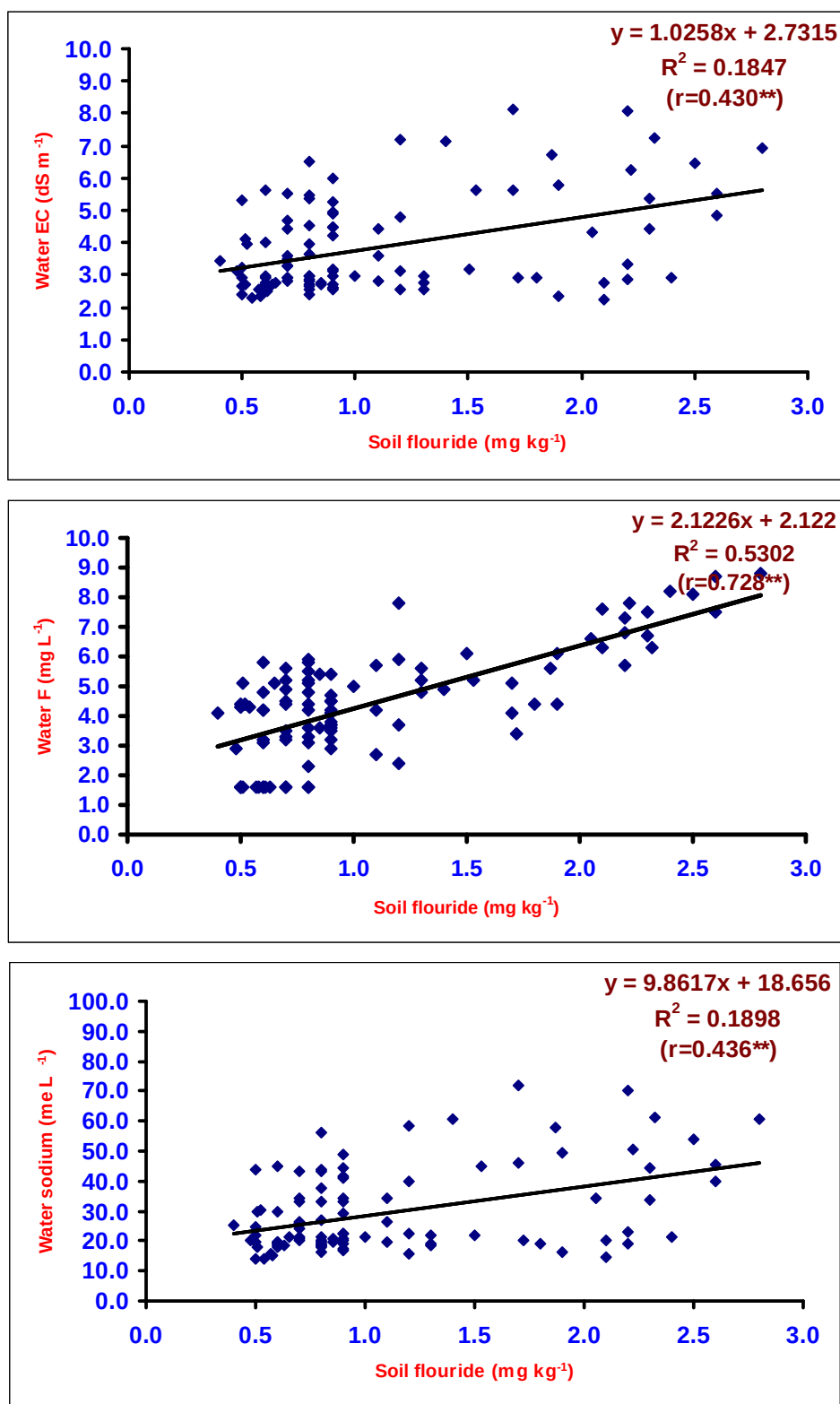


Fig. 4.4 : Relationship of soil fluoride with EC, fluoride and sodium of ground water

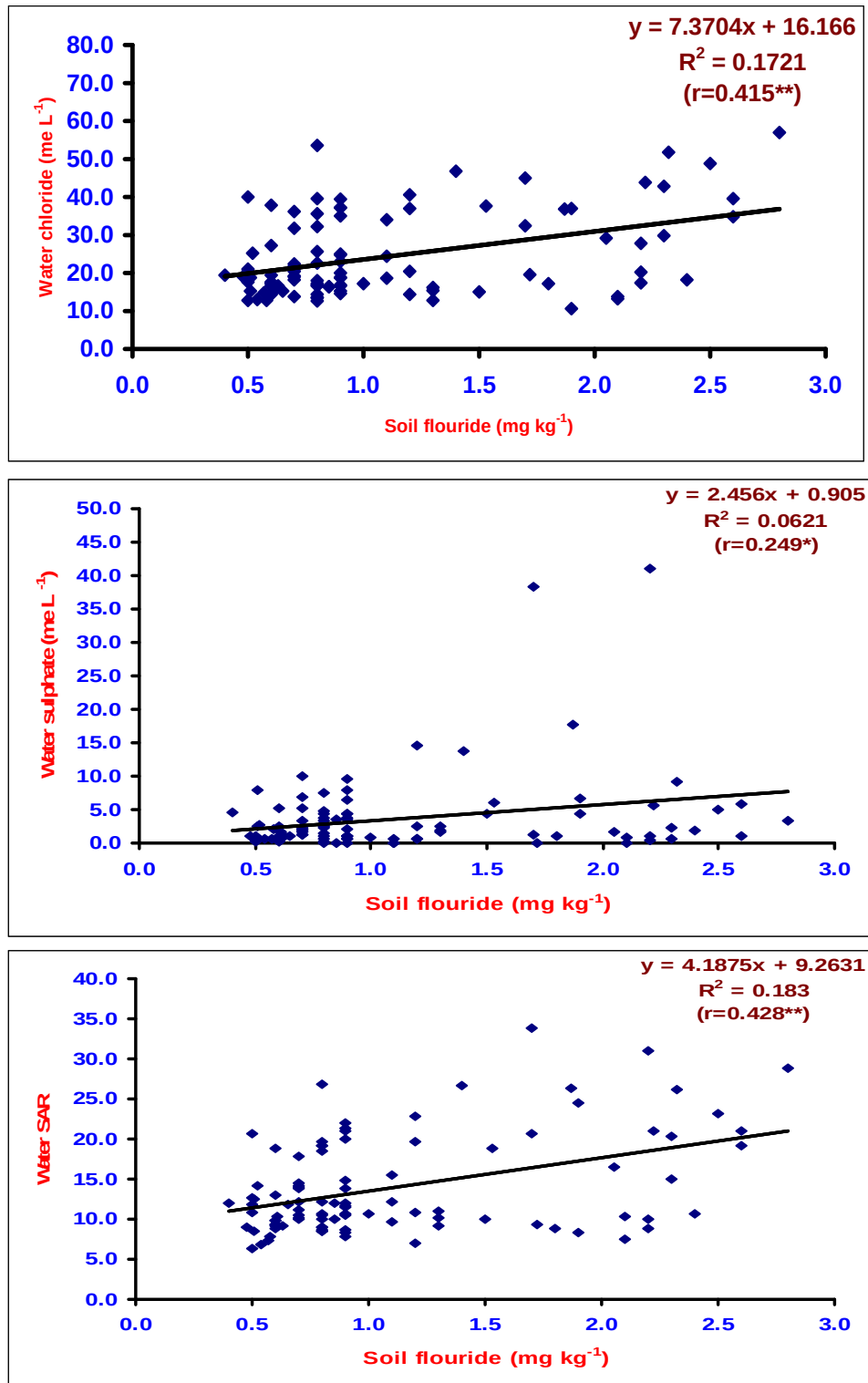


Fig. 4.5 : Relationship of soil fluoride with water chloride, sulphate and SAR of ground water

4.4.1 Soil parameters

To see the change in soil parameters due to irrigation with different categories of fluoride waters, after every crop soil samples were taken and analyzed for important parameters. Results obtained regarding effect of different categories of fluoride waters on various soil parameters under both the crops are presented in the succeeding paragraphs.

4.4.1.1 pH₂

Data presented in table 4.5 and fig. 4.6 shows that average initial soil pH₂ value of the area, ranged from 7.70 to 8.53 which changed after two years of mustard cultivation from 8.40 to 8.55, whereas, in case of wheat the soil pH₂ values after two years of cultivation ranged between 8.13 to 8.68. The maximum initial soil pH₂ value of 8.60 was recorded at Natas (b), Sikarali and Malgoan (b) villages in the fluoride water category 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. After two years of mustard cultivation the maximum pH₂ value of 9.20 was observed at Bakolia (b) village in the fluoride water category 6.1-8.0 mg L⁻¹, whereas in case of wheat maximum soil pH₂ value of 9.20 was recorded at Dujar (c) village in 6.1-8.0 mg L⁻¹ fluoride water category. The minimum initial soil pH₂ value of 7.30 was recorded at Audint (c) village in < 2.0 mg L⁻¹ fluoride water category. After two consecutive years of crops cultivation minimum soil pH₂ value of 7.90 was observed at Bakolia (c) village in 6.1-8.0 mg L⁻¹ fluoride water category in mustard crop while, in wheat pH₂ value of 7.90 was observed at Lukas (a) village in 2.1-4.0 mg L⁻¹ fluoride water category.

Further, perusal of data in table 4.5 and fig. 4.6 clearly indicate that there is increasing trend of soil pH₂ with the successive increase in groundwater fluoride, during both the years. High concentration of fluoride could be attributed to presence of more soluble fluoride salts

like sodium fluoride, which might have contributed towards accumulation of bases especially Na^+ under low rainfall conditions

Table 4.5 : Effect of groundwater fluoride on pH₂ of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	8.10	8.20	8.40	8.30	8.00
	Ratau (c)	7.90	8.40	8.10	8.50	8.40
	Genana (b)	7.50	7.80	8.00	8.40	8.10
	Audint (c)	7.30	8.00	8.20	8.40	8.00
	Maximum	8.10	8.40	8.40	8.50	8.40
	Minimum	7.30	7.80	8.00	8.30	8.00
	Average	7.70	8.10	8.18	8.40	8.13
2.1 – 4.0	Sandas (b)	7.50	7.80	8.60	8.30	8.80
	Jhardia (c)	7.40	8.00	8.10	8.60	7.80
	Lukas (a)	7.80	8.30	8.30	8.80	8.30
	Lukas (b)	8.30	8.50	8.50	8.10	8.90
	Maximum	8.30	8.50	8.60	8.80	8.90
	Minimum	7.40	7.80	8.10	8.10	7.80
	Average	7.75	8.15	8.38	8.45	8.45
4.1 – 6.0	Baladoo (a)	8.10	8.30	8.40	8.60	8.70
	Baladoo (b)	8.30	8.50	8.70	8.20	8.30
	Nimbi Jhodha (a)	8.10	8.40	7.80	8.70	8.90
	Nimbi Jhodha (b)	8.00	8.20	8.80	8.50	8.60
	Maximum	8.30	8.50	8.80	8.70	8.90
	Minimum	8.00	8.20	7.80	8.20	8.30
	Average	8.13	8.35	8.43	8.50	8.63
6.1 – 8.0	Natas (b)	8.60	8.50	8.50	8.40	8.40
	Dujar (c)	7.90	8.30	8.60	8.60	9.20
	Bakolia (b)	8.10	8.20	8.30	9.20	8.50
	Bakolia (c)	8.00	8.40	8.60	7.90	8.40
	Maximum	8.60	8.50	8.60	9.20	9.20
	Minimum	7.90	8.20	8.30	7.90	8.40
	Average	8.15	8.35	8.50	8.53	8.63
>8.0	Sikarali	8.60	8.50	8.50	8.40	8.70
	Malgoan (b)	8.60	8.70	9.00	8.70	8.50
	Mangalpura	8.40	8.40	8.20	8.50	8.90
	Dujar (b)	8.50	8.60	8.30	8.60	8.60
	Maximum	8.60	8.70	9.00	8.70	8.90
	Minimum	8.40	8.40	8.20	8.40	8.50
	Average	8.53	8.55	8.50	8.55	8.68

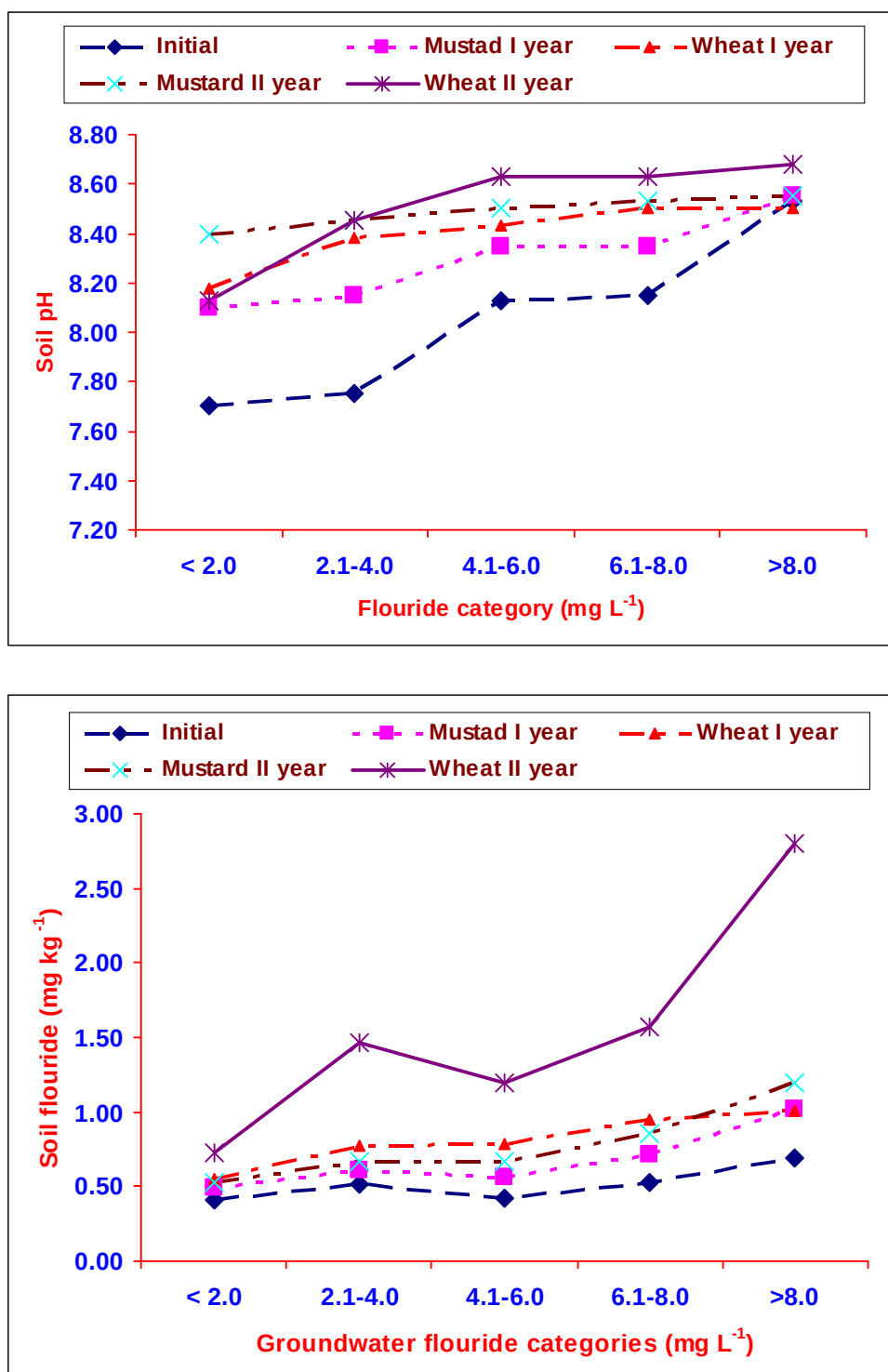


Fig. 4.6 : Effect of ground water fluoride on pH and EC of soil under mustard and wheat

there by more alkaline soil reaction. These findings are in close conformity with the findings of Chhabra *et al.* (1980), Deo *et al.* (1993), Dhura Ram (1998), Prakash (2001), Sharma *et al.* (2004), Romar *et al.* (2009), Paul *et al.* (2011) and Saxena and Rani (2012)

4.4.1.2 Electric conductivity (EC₂)

A perusal of data (Table 4.6) revealed that average initial soil EC₂ value of the area ranged from 0.38 to 0.62 dS m⁻¹ which changed after two years of mustard cultivation it ranged from 0.42 to 0.64 dS m⁻¹ whereas, in case of wheat, soil EC₂ values ranged between 0.46 to 0.67 dS m⁻¹. The maximum initial soil EC₂ value of 0.79 dS m⁻¹ was recorded at Genana (b) village in the fluoride water category < 2.0 mg L⁻¹. After two years of mustard cultivation the maximum EC₂ value of 0.78 dS m⁻¹ was observed at Sikarali village in the fluoride water category > 8.0 mg L⁻¹, whereas in case of wheat maximum soil EC₂ value of 0.83 dS m⁻¹ was recorded at Sikarali village in > 8.0 mg L⁻¹ fluoride water category. The minimum initial soil EC₂ value of 0.34 dS m⁻¹ was recorded at Baladoo (b) village in 4.1-6.0 mg L⁻¹ fluoride water category. After two consecutive years of crops cultivation, the minimum soil EC₂ value of 0.39 dS m⁻¹ was observed at Baladoo (b) village in 4.1-6.0 mg L⁻¹ fluoride water category in mustard, while in wheat the minimum soil EC₂ value of 0.43 dS m⁻¹ was observed at Baladoo (a) village in 4.1-6.0 mg L⁻¹ fluoride water category.

Further, perusal of data recorded in both the years and presented in table 4.6 clearly indicate that there is no definite trend of soil EC₂ values with respect to groundwater fluoride categories. Similar results have been reported by Khandelwal and Lal (1991), Deo *et al.* (1993), Chandrasekharan *et al.* (1994), Kameariya (1995), Lal *et al.* (1998), Sharma (2002), Gupta (2003), Holanda filho *et al.* (2011) and Saxena and Rani (2012).

Table: 4.6 Effect of groundwater fluoride on EC₂ (dS m⁻¹) of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	0.69	0.68	0.71	0.70	0.75
	Ratau (c)	0.47	0.49	0.48	0.51	0.51
	Genana (b)	0.79	0.76	0.81	0.77	0.78
	Audint (c)	0.54	0.55	0.56	0.58	0.63
	Maximum	0.79	0.76	0.81	0.77	0.78
	Minimum	0.47	0.49	0.48	0.51	0.51
	Average	0.62	0.62	0.64	0.64	0.67
2.1 – 4.0	Sandas (b)	0.52	0.53	0.54	0.55	0.58
	Jhardia (c)	0.52	0.54	0.57	0.57	0.59
	Lukas (a)	0.43	0.43	0.46	0.46	0.47
	Lukas (b)	0.48	0.48	0.51	0.52	0.50
	Maximum	0.52	0.54	0.57	0.57	0.59
	Minimum	0.43	0.43	0.46	0.46	0.47
	Average	0.49	0.50	0.52	0.53	0.54
4.1 – 6.0	Baladoo (a)	0.39	0.38	0.43	0.41	0.43
	Baladoo (b)	0.34	0.36	0.44	0.39	0.49
	Nimbi Jhodha (a)	0.39	0.40	0.41	0.43	0.47
	Nimbi Jhodha (b)	0.39	0.41	0.42	0.44	0.46
	Maximum	0.39	0.41	0.44	0.44	0.49
	Minimum	0.34	0.36	0.41	0.39	0.43
	Average	0.38	0.39	0.43	0.42	0.46
6.1 – 8.0	Natas (b)	0.55	0.55	0.59	0.57	0.62
	Dujar (c)	0.55	0.56	0.59	0.58	0.62
	Bakolia (b)	0.52	0.56	0.57	0.57	0.68
	Bakolia (c)	0.49	0.52	0.58	0.56	0.62
	Maximum	0.55	0.56	0.59	0.58	0.68
	Minimum	0.49	0.52	0.57	0.56	0.62
	Average	0.53	0.55	0.58	0.57	0.64
>8.0	Sikarali	0.75	0.76	0.81	0.78	0.83
	Malgoan (b)	0.46	0.48	0.48	0.49	0.51
	Mangalpura	0.41	0.41	0.43	0.42	0.45
	Dujar (b)	0.57	0.59	0.62	0.61	0.66
	Maximum	0.75	0.76	0.81	0.78	0.83
	Minimum	0.41	0.41	0.43	0.42	0.45
	Average	0.55	0.56	0.59	0.57	0.61

4.4.1.3 Organic carbon (O.C.)

The average per cent organic carbon content (Table 4.7) of initial soil of the area ranged from 0.14 to 0.18 per cent which changed after two years in mustard cultivation ranged from 0.13 to 0.20 per cent, whereas in case of wheat, it ranged between 0.13 to 0.17 per cent. The maximum initial soil O.C. value of 0.21 per cent was recorded at Nimbi Jhodha (a) and Nimbi Jhodha (b) villages in the fluoride water category 4.1-6.0 mg L⁻¹. After two years of mustard cultivation the maximum O.C. value of 0.26 per cent was observed at Bakolia (b) village in the fluoride water category 6.1-8.0 mg L⁻¹, whereas in case of wheat maximum soil O.C. value of 0.22 per cent was recorded at Lukas (b) village in 2.1-4.0 mg L⁻¹ fluoride water category. The minimum initial soil O.C. value of 0.08 per cent was recorded at Natas (b) village in the fluoride water category 6.1-8.0 mg L⁻¹. After two consecutive years of crop cultivation minimum O.C. value of 0.09 per cent was observed at Sandas (b) village in 2.1-4.0 mg L⁻¹ fluoride water category in mustard crop, while in wheat minimum O.C. value of 0.06 per cent was recorded at Sikarali village in > 8.0 mg L⁻¹ fluoride water category.

A critical examination of data presented in table 4.7 apparently indicates that there is no definite trend in soil O.C. values was noticed with respect to groundwater fluoride categories. The similar results were also reported by Kumar and Seth (1983), Dutta and Joshi (1989), Aggarwal and Kumar (1994), Dhura Ram (1998), Prakash (2001), Bagoria (2002), Okibe et al. (2010) and Paul et al. (2011).

Table: 4.7 Effect of groundwater fluoride on per cent organic carbon content of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	0.14	0.15	0.20	0.13	0.13
	Ratau (c)	0.12	0.19	0.13	0.15	0.16
	Genana (b)	0.18	0.25	0.20	0.20	0.12
	Audint (c)	0.14	0.15	0.10	0.16	0.20
	Maximum	0.18	0.25	0.20	0.20	0.20
	Minimum	0.12	0.15	0.10	0.13	0.12
	Average	0.14	0.19	0.16	0.16	0.15
2.1 – 4.0	Sandas (b)	0.15	0.07	0.07	0.09	0.20
	Jhardia (c)	0.18	0.10	0.13	0.15	0.17
	Lukas (a)	0.17	0.15	0.15	0.17	0.10
	Lukas (b)	0.12	0.15	0.13	0.16	0.22
	Maximum	0.18	0.15	0.15	0.17	0.22
	Minimum	0.12	0.07	0.07	0.09	0.10
	Average	0.15	0.12	0.12	0.14	0.17
4.1 – 6.0	Baladoo (a)	0.14	0.10	0.20	0.14	0.17
	Baladoo (b)	0.15	0.22	0.15	0.23	0.19
	Nimbi Jhodha (a)	0.21	0.20	0.09	0.21	0.15
	Nimbi Jhodha (b)	0.21	0.10	0.10	0.12	0.18
	Maximum	0.21	0.22	0.20	0.23	0.19
	Minimum	0.14	0.10	0.09	0.12	0.15
	Average	0.18	0.16	0.13	0.17	0.17
6.1 – 8.0	Natas (b)	0.08	0.19	0.13	0.21	0.16
	Dujar (c)	0.17	0.15	0.12	0.16	0.10
	Bakolia (b)	0.15	0.25	0.20	0.26	0.09
	Bakolia (c)	0.17	0.16	0.16	0.17	0.15
	Maximum	0.17	0.25	0.20	0.26	0.16
	Minimum	0.08	0.15	0.12	0.16	0.09
	Average	0.14	0.19	0.15	0.20	0.13
>8.0	Sikarali	0.17	0.10	0.07	0.11	0.06
	Malgoan (b)	0.15	0.09	0.10	0.10	0.16
	Mangalpura	0.17	0.16	0.20	0.18	0.17
	Dujar (b)	0.14	0.10	0.15	0.13	0.13
	Maximum	0.17	0.16	0.20	0.18	0.17
	Minimum	0.14	0.09	0.07	0.10	0.06
	Average	0.15	0.11	0.13	0.13	0.13

4.4.1.4 Available nitrogen

It is evident from the data (Table 4.8) that average initial soil available nitrogen value of the area ranged from 139.50 to 170.26 kg ha⁻¹ which changed after two years of mustard cultivation from 125.51 to 193.08 kg ha⁻¹ whereas, in case of wheat, the average initial soil nitrogen values ranged between 120.73 to 166.59 kg ha⁻¹. The maximum initial soil nitrogen value of 202.74 kg ha⁻¹ was recorded at Nimbi Jhodha (b) village in the fluoride water category 4.1-6.0 mg L⁻¹, respectively. After two consecutive years of mustard cultivation the maximum nitrogen value of 251.10 kg ha⁻¹ was observed at Bakolia (b) village in the fluoride water category 6.1-8.0 mg L⁻¹, whereas in case of wheat maximum soil nitrogen value of 210.90 kg ha⁻¹ was recorded at Lukas (b) village in 2.1-4.0 mg L⁻¹ fluoride water category. The minimum initial soil nitrogen value of 100.44 kg ha⁻¹ was recorded at Natas (b) village in 6.1-8.0 mg L⁻¹ fluoride water category. After two consecutive years of crop cultivation minimum soil nitrogen value of 86.89 kg ha⁻¹ was observed at Sandas (b) village in 2.1-4.0 mg L⁻¹ fluoride water category in mustard crop while, in wheat minimum soil nitrogen value of 57.93 kg ha⁻¹ was recorded at Sikarali village in > 8.0 mg L⁻¹ fluoride water category.

A perusal of data of both years presented in table 4.8 clearly indicates that there is no definite trend occurred in soil nitrogen values with respect to groundwater fluoride categories. The similar results were also reported by Kumar and Seth (1983), Dutta and Joshi (1989), Aggarwal and Kumar (1994), Dhura Ram (1998), Prakash (2001), Bagoria (2002), Okibe *et al.* (2010) and Paul *et al.* (2011).

4.4.1.5 Available phosphorus

The average available phosphorus status (Table 4.9) of initial soil of the area ranged from 14.60 to 16.81 kg ha⁻¹ which changed

Table 4.8: Effect of groundwater fluoride on available Nitrogen (kg ha⁻¹) of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	132.86	144.82	193.09	125.51	125.51
	Ratau (c)	119.57	183.43	125.51	144.82	154.47
	Genana (b)	172.72	241.36	196.84	193.09	115.85
	Audint (c)	132.86	144.82	96.54	154.47	196.84
	Maximum	172.72	241.36	196.84	193.09	196.84
	Minimum	119.57	144.82	96.54	125.51	115.85
	Average	139.50	178.61	152.99	154.47	148.17
2.1 – 4.0	Sandas (b)	146.14	67.58	67.58	86.89	193.09
	Jhardia (c)	172.72	98.42	125.51	144.82	164.12
	Lukas (a)	159.43	144.82	144.82	164.12	96.54
	Lukas (b)	119.57	144.82	125.51	154.47	210.90
	Maximum	172.72	144.82	144.82	164.12	210.90
	Minimum	119.57	67.58	67.58	86.89	96.54
	Average	149.47	113.91	115.85	137.57	166.16
4.1 – 6.0	Baladoo (a)	132.86	96.54	193.09	135.16	164.12
	Baladoo (b)	146.14	212.40	144.82	222.05	183.43
	Nimbi Jhodha (a)	199.29	196.84	84.36	202.74	144.82
	Nimbi Jhodha (b)	202.74	96.54	98.42	115.85	173.97
	Maximum	202.74	212.40	193.09	222.05	183.43
	Minimum	132.86	96.54	84.36	115.85	144.82
	Average	170.26	150.58	130.17	168.95	166.59
6.1 – 8.0	Natas (b)	100.44	183.43	126.54	202.74	154.47
	Dujar (c)	159.43	144.82	112.48	154.47	96.54
	Bakolia (b)	146.14	241.36	196.84	251.01	86.89
	Bakolia (c)	159.43	154.47	154.66	164.12	145.00
	Maximum	159.43	241.36	196.84	251.01	154.47
	Minimum	100.44	144.82	112.48	154.47	86.89
	Average	141.36	181.02	147.63	193.08	120.73
>8.0	Sikarali	159.43	98.42	67.58	106.20	57.93
	Malgoan (b)	146.14	86.89	96.54	96.54	154.47
	Mangalpura	159.43	154.47	196.84	173.78	164.12
	Dujar (b)	132.86	96.54	140.60	125.51	125.51
	Maximum	159.43	154.47	196.84	173.78	164.12
	Minimum	132.86	86.89	67.58	96.54	57.93
	Average	149.47	109.08	125.39	125.51	125.51

**Table: 4.9 Effect of groundwater fluoride on available Phosphorus
(kg P₂O₅ ha⁻¹) of soil under mustard and wheat**

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	14.83	16.89	15.01	16.95	15.76
	Ratau (c)	14.68	16.22	14.10	16.63	16.29
	Genana (b)	14.51	16.44	14.79	16.77	16.49
	Audint (c)	14.36	15.79	14.12	15.93	16.47
	Maximum	14.83	16.89	15.01	16.95	16.49
	Minimum	14.36	15.79	14.10	15.93	15.76
	Average	14.60	16.33	14.51	16.57	16.25
2.1 – 4.0	Sandas (b)	14.30	15.12	14.62	15.65	17.73
	Jhardia (c)	15.52	16.29	15.88	16.78	17.44
	Lukas (a)	15.88	15.92	16.77	16.23	14.17
	Lukas (b)	15.61	15.83	15.63	16.12	16.43
	Maximum	15.88	16.29	16.77	16.78	17.73
	Minimum	14.30	15.12	14.62	15.65	14.17
	Average	15.33	15.79	15.73	16.20	16.44
4.1 – 6.0	Baladoo (a)	15.25	16.08	17.37	16.45	17.42
	Baladoo (b)	18.09	17.00	15.46	17.67	16.99
	Nimbi Jhodha (a)	17.02	16.69	16.51	17.10	15.88
	Nimbi Jhodha (b)	16.89	14.52	16.35	15.43	17.84
	Maximum	18.09	17.00	17.37	17.67	17.84
	Minimum	15.25	14.52	15.46	15.43	15.88
	Average	16.81	16.07	16.42	16.66	17.03
6.1 – 8.0	Natas (b)	16.38	16.91	16.47	17.38	14.23
	Dujar (c)	16.47	16.93	14.56	17.63	15.76
	Bakolia (b)	14.68	15.08	15.79	15.97	15.46
	Bakolia (c)	14.86	16.43	14.86	17.10	15.82
	Maximum	16.47	16.93	16.47	17.63	15.82
	Minimum	14.68	15.08	14.56	15.97	14.23
	Average	15.60	16.34	15.42	17.02	15.32
>8.0	Sikarali	15.51	15.88	14.20	16.23	15.29
	Malgoan (b)	16.37	14.41	17.70	15.14	16.26
	Mangalpura	15.73	16.03	17.81	16.98	16.86
	Dujar (b)	14.24	15.88	15.84	16.46	14.70
	Maximum	16.37	16.03	17.81	16.98	16.86
	Minimum	14.24	14.41	14.20	15.14	14.70
	Average	15.46	15.55	16.39	16.20	15.78

after two years of mustard cultivation from 16.20 to 17.02 kg ha⁻¹, whereas, in case of wheat the soil phosphorus values ranged between 15.32 to 17.03 kg ha⁻¹. The maximum initial soil phosphorus value of 18.09 kg ha⁻¹ was recorded at Baladoo (b) village in the fluoride water category 4.1-6.0 mg L⁻¹. After two consecutive years of mustard cultivation the maximum soil phosphorus value of 17.67 kg ha⁻¹ was recorded at Baladoo (b) village in the fluoride water category 4.1-6.0 mg L⁻¹, whereas in case of wheat maximum soil phosphorus value of 17.84 kg ha⁻¹ was recorded at Nimbi Jhodha (b) village in 4.1-6.0 mg L⁻¹ fluoride water category. The minimum initial soil phosphorus value of 14.24 kg ha⁻¹ was recorded at Dujar (b) village in > 8.0 mg L⁻¹ fluoride water category. After two consecutive years of crop cultivation minimum soil phosphorus value of 15.14 kg ha⁻¹ was observed at Malgoan (b) village in >8.0 mg L⁻¹ fluoride water category in mustard crop, while in wheat minimum soil phosphorus value of 14.17 kg ha⁻¹ was recorded at Lukas (a) village in 2.1- 4.0 mg L⁻¹ fluoride water category.

Further, perusal of data for both the years in table 4.9 clearly indicates that there is no definite trend observed in soil phosphorus values with respect to groundwater fluoride categories. Similar finding were also reported by Kumar and Seth (1983), Singh and Sharma (1984), Akabri *et al.* (1993), Kameariya (1995), Dhura Ram (1998) Bagoria (2002), Okibe *et al.* (2010) and Paul *et al.* (2011).

4.4.1.6 Available potassium

A perusal of data (Table 4.10) revealed that average initial soil available potassium value of the area ranged from 165.76 to 211.31 kg ha⁻¹ which changed after two years of mustard cultivation ranged from 172.74 to 253.38 kg ha⁻¹, whereas, in case of wheat the soil potassium values ranged between 196.94 to 237.67 kg ha⁻¹. The maximum initial soil potassium value of 277.76 kg ha⁻¹ was recorded at Dujar (c) village

**Table: 4.10 Effect of groundwater fluoride on available Potassium
(kg K₂O ha⁻¹) of soil under mustard and wheat**

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	140.37	173.56	133.17	178.86	181.90
	Ratau (c)	140.37	156.18	136.37	165.45	189.57
	Genana (b)	167.25	161.61	162.35	169.89	212.87
	Audint (c)	215.04	172.46	206.80	176.75	203.41
	Maximum	215.04	173.56	206.80	178.86	212.87
	Minimum	140.37	156.18	133.17	165.45	181.90
	Average	165.76	165.95	159.68	172.74	196.94
2.1 – 4.0	Sandas (b)	188.16	200.43	183.18	203.56	232.11
	Jhardia (c)	149.33	170.86	144.63	173.74	200.07
	Lukas (a)	170.24	183.52	164.84	186.21	180.32
	Lukas (b)	200.11	161.91	191.47	164.67	218.63
	Maximum	200.11	200.43	191.47	203.56	232.11
	Minimum	149.33	161.91	144.63	164.67	180.32
	Average	176.96	179.18	171.03	182.04	207.78
4.1 – 6.0	Baladoo (a)	221.01	179.93	212.37	183.36	194.35
	Baladoo (b)	209.07	165.56	201.13	169.23	246.97
	Nimbi Jhodha (a)	173.23	213.46	168.83	215.87	240.39
	Nimbi Jhodha (b)	241.92	242.43	232.38	245.44	268.98
	Maximum	241.92	242.43	232.38	245.44	268.98
	Minimum	173.23	165.56	168.83	169.23	194.35
	Average	211.31	200.35	203.68	203.47	237.67
6.1 – 8.0	Natas (b)	229.97	229.77	221.33	234.47	203.38
	Dujar (c)	277.76	258.11	263.14	260.39	227.39
	Bakolia (b)	125.44	248.51	119.50	251.28	207.40
	Bakolia (c)	149.33	264.09	144.74	267.39	222.10
	Maximum	277.76	264.09	263.14	267.39	227.39
	Minimum	125.44	229.77	119.50	234.47	203.38
	Average	195.63	250.12	187.18	253.38	215.07
>8.0	Sikarali	167.25	210.06	158.96	213.67	229.19
	Malgoan (b)	182.19	239.23	172.50	244.12	208.10
	Mangalpura	182.19	229.98	174.25	234.64	216.51
	Dujar (b)	203.09	189.47	194.60	194.23	220.38
	Maximum	203.09	239.23	194.60	244.12	229.19
	Minimum	167.25	189.47	158.96	194.23	208.10
	Average	183.68	217.18	175.08	221.66	218.54

in the fluoride water category 6.1-8.0 mg L⁻¹. After two consecutive years of mustard cultivation the maximum potassium value of 267.39 kg ha⁻¹ was recorded at Bakolia (c) village in the fluoride water category 6.1-8.0 mg L⁻¹, whereas in case of wheat maximum soil potassium value of 268.98 kg ha⁻¹ was recorded at Nimbi Jhodha (b) village in 4.1-6.0 mg L⁻¹ fluoride water category. The minimum initial soil potassium value of 125.44 kg ha⁻¹ was recorded at Bakolia (b) village in 6.1-8.0 mg L⁻¹ fluoride water category. After two consecutive years of crops cultivation minimum soil potassium value of 164.67 kg ha⁻¹ was observed at Lukas (b) village in 2.1-4.0 mg L⁻¹ fluoride water category in mustard, while in wheat minimum soil potassium value of 180.32 kg ha⁻¹ was recorded at Lukas (a) village in 2.1- 4.0 mg L⁻¹ fluoride water category.

Further, perusal of data presented in table 4.10 clearly indicates that there is no definite trend found in available soil potassium values with respect to groundwater fluoride categories. These results are in conformity with finding of Joshi and Ghonsikar (1981), Sharma (1993), Dhura Ram (1998), Lal *et al.* (1998), Oswal (1999) Singh (2005), Dutta *et al.* (2006) and Romar *et al.* (2009).

4.4.1.7 Fluoride

Data (Table 4.11 and fig. 4.6) shows that average initial soil fluoride value of the area ranged from 0.41 to 0.69 mg kg⁻¹ which changed after two years of mustard cultivation ranged from 0.53 to 1.19 mg kg⁻¹ whereas, in case of wheat, the soil fluoride values ranged between 0.73 to 2.80 mg kg⁻¹. The maximum initial soil fluoride value of 0.97 mg kg⁻¹ was recorded at Sikarali village in the fluoride water category > 8.0 mg L⁻¹, respectively. After two years of mustard cultivation the maximum fluoride value of 1.35 mg kg⁻¹ was observed at Sikarali village in the fluoride water category > 8.0 mg L⁻¹, whereas in case of wheat maximum soil fluoride value of 4.25 mg kg⁻¹ was recorded at Sikarali village in > 8.0 mg L⁻¹ fluoride water category. The

Table: 4.11 Effect of groundwater fluorid on soil Fluoride (mg kg⁻¹) under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	0.12	0.20	0.24	0.28	0.36
	Ratau (c)	0.56	0.65	0.71	0.67	0.91
	Genana (b)	0.37	0.44	0.54	0.46	0.84
	Audint (c)	0.58	0.65	0.69	0.70	0.78
	Maximum	0.58	0.65	0.71	0.70	0.91
	Minimum	0.12	0.20	0.24	0.28	0.36
	Average	0.41	0.49	0.55	0.53	0.73
2.1 – 4.0	Sandas (b)	0.54	0.62	0.67	0.66	0.96
	Jhardia (c)	0.58	0.70	0.83	0.74	1.10
	Lukas (a)	0.31	0.39	0.72	0.46	1.03
	Lukas (b)	0.61	0.72	0.86	0.81	1.49
	Maximum	0.61	0.72	0.86	0.81	1.49
	Minimum	0.31	0.39	0.67	0.46	0.96
	Average	0.51	0.61	0.77	0.67	1.46
4.1 – 6.0	Baladoo (a)	0.35	0.46	0.79	0.56	0.95
	Baladoo (b)	0.51	0.65	0.90	0.75	1.10
	Nimbi Jhodha (a)	0.19	0.33	0.50	0.45	1.05
	Nimbi Jhodha (b)	0.64	0.80	0.97	0.90	1.65
	Maximum	0.64	0.80	0.97	0.90	1.65
	Minimum	0.19	0.33	0.50	0.45	0.95
	Average	0.42	0.56	0.79	0.67	1.19
6.1 – 8.0	Natas (b)	0.13	0.30	0.54	0.45	0.96
	Dujar (c)	0.57	0.73	0.93	0.85	1.35
	Bakolia (b)	0.56	0.75	1.12	0.90	1.66
	Bakolia (c)	0.87	1.10	1.21	1.21	2.32
	Maximum	0.87	1.10	1.21	1.21	2.32
	Minimum	0.13	0.30	0.54	0.45	0.96
	Average	0.53	0.72	0.95	0.85	1.57
>8.0	Sikarali	0.97	1.21	1.21	1.35	4.25
	Malgoan (b)	0.64	0.90	0.90	1.07	2.81
	Mangalpura	0.51	0.85	0.85	1.03	1.31
	Dujar (b)	0.65	1.10	1.10	1.30	2.84
	Maximum	0.97	1.21	1.21	1.35	4.25
	Minimum	0.51	0.85	0.85	1.03	1.31
	Average	0.69	1.02	1.01	1.19	2.80

minimum initial soil fluoride value of 0.12 mg kg^{-1} was recorded at Ratau (a) village in the fluoride water category $< 2.0 \text{ mg kg}^{-1}$. After two consecutive years of crop cultivation minimum soil fluoride value of 0.28 mg kg^{-1} was observed at Ratau (a) village in $< 2.0 \text{ mg L}^{-1}$ fluoride water category in mustard crop, while in wheat minimum soil fluoride value of 0.36 mg kg^{-1} was recorded at Ratau (a) village in $< 2.0 \text{ mg L}^{-1}$ fluoride water category.

Further, perusal of data in table 4.11 and figure 4.6 clearly indicates that there is an increase in soil fluoride values with an increase in the groundwater fluoride categories. These results are in conformity to the findings of Sinsinwar *et al.* (1981), Grewal and Dhaiya (1992), Bagoria (2002), Okibe *et al.* (2010), Paul *et al.* (2011) and Saxena and Rani (2012)

4.4.1.8 Sodium adsorption ratio (SAR)

Data (Table 4.12) revealed that average initial soil SAR value of the study area ranged from 1.02 to 2.45 which changed after two years of mustard cultivation from 1.15 to 1.95, whereas in case of wheat, the soil SAR values ranged between 1.76 to 3.16. The maximum initial soil SAR value of 3.46 was recorded at Genana (b) village in the fluoride water category $< 2.0 \text{ mg L}^{-1}$. After two years of mustard cultivation the maximum SAR value of 2.67 was observed at Nimbi Jhodha (b) village in the fluoride water category $4.0\text{-}6.0 \text{ mg L}^{-1}$, whereas in case of wheat maximum soil SAR value of 4.87 was recorded at Genana (b) village in $< 2.0 \text{ mg L}^{-1}$ fluoride water category. The minimum initial soil SAR value of 0.86 was recorded at Lukas (a) village in $2.1\text{-}4.0 \text{ mg L}^{-1}$ fluoride water category. After two consecutive years of mustard cultivation minimum soil SAR value of 0.56 was observed at Mangalpura village in $> 8.0 \text{ mg L}^{-1}$ fluoride water category, while in case of wheat cultivation minimum soil SAR value of 0.81 was observed at Mangalpura village in $> 8.0 \text{ mg L}^{-1}$ fluoride water category.

Table: 4.12 Effect of groundwater fluoride on SAR of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	2.04	2.03	2.24	2.15	3.85
	Ratau (c)	1.83	1.11	2.67	1.23	1.47
	Genana (b)	3.46	1.41	3.80	1.82	4.87
	Audint (c)	2.45	1.83	1.44	2.04	2.45
	Maximum	3.46	2.03	3.80	2.15	4.87
	Minimum	1.83	1.11	1.44	1.23	1.47
	Average	2.45	1.60	2.54	1.81	3.16
2.1 – 4.0	Sandas (b)	1.79	2.03	1.02	1.09	1.07
	Jhardia (c)	1.37	1.61	2.18	1.84	1.65
	Lukas (a)	0.86	0.89	0.97	1.03	3.87
	Lukas (b)	0.87	1.97	2.38	2.15	1.20
	Maximum	1.79	2.03	2.38	2.15	3.87
	Minimum	0.86	0.89	0.97	1.03	1.07
	Average	1.22	1.62	1.64	1.53	1.95
4.1 – 6.0	Baladoo (a)	1.13	1.10	0.96	1.34	1.12
	Baladoo (b)	0.90	1.59	0.95	2.13	2.75
	Nimbi Jhodha (a)	0.92	1.35	1.22	1.65	1.60
	Nimbi Jhodha (b)	1.13	3.54	1.24	2.67	1.57
	Maximum	1.13	3.54	1.24	2.67	2.75
	Minimum	0.90	1.10	0.95	1.34	1.12
	Average	1.02	1.89	1.09	1.95	1.76
6.1 – 8.0	Natas (b)	2.19	1.48	2.67	1.83	2.22
	Dujar (c)	2.53	0.95	0.93	1.42	2.46
	Bakolia (b)	1.47	0.50	2.17	0.94	3.54
	Bakolia (c)	2.01	1.02	2.36	1.32	1.86
	Maximum	2.53	1.48	2.67	1.83	3.54
	Minimum	1.47	0.50	0.93	0.94	1.86
	Average	2.05	0.99	2.03	1.38	2.52
>8.0	Sikarali	3.21	0.78	2.98	1.06	2.47
	Malgoan (b)	1.76	0.66	0.87	0.94	1.00
	Mangalpura	1.80	0.77	1.28	0.56	0.81
	Dujar (b)	2.44	1.75	2.99	2.05	3.54
	Maximum	3.21	1.75	2.99	2.05	3.54
	Minimum	1.76	0.66	0.87	0.56	0.81
	Average	2.30	0.99	2.03	1.15	1.95

Further, perusal of data for both the years in table 4.12 clearly shows that there was no definite trend observed for soil SAR values with respect to groundwater fluoride categories. The SAR values increased with an increase in pH and EC of soils which be due to dominance of soluble Na^+ over Ca^{2+} and Mg^{2+} contents. Similar results were also reported by Khandelwal and Lal (1991), Deo *et al.* (1993), Ram (1998), Lal *et al.* (1999), Oswal (1999), Sharma (2002), Ram (2003), Sharma (2005), Holanda Filho *et al.* (2011) and Saxena and Rani (2012).

4.4.1.9 Exchangeable sodium percentage (ESP)

A perusal of data (Table 4.13) showed that average initial soil ESP value of the study area ranged from 0.25 to 2.28, which changed after two years of mustard cultivation and ranged from 0.81 to 1.19, whereas in case of wheat the soil ESP values ranged between 0.82 to 1.98. The maximum initial soil ESP value of 3.70 was recorded at Genana (b) village in the fluoride water category $< 2.0 \text{ mg L}^{-1}$. After two years of mustard cultivation, the maximum soil ESP value of 2.43 was observed at Nimbi Jhodha (b) village in the fluoride water category $4.0\text{-}6.0 \text{ mg L}^{-1}$, whereas in case of wheat, maximum soil ESP value of 2.45 was recorded at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride water category. The minimum initial soil ESP value of 0.01 was recorded at Lukas (a) village in $2.1\text{-}4.0 \text{ mg L}^{-1}$ fluoride water category. After two consecutive years of cultivation minimum soil ESP value of 0.32 and 0.11 was observed at Baladoo (a) and Nimbi Jhodha (a) villages in $4.1\text{-}6.0 \text{ mg L}^{-1}$ fluoride water category in mustard and in wheat crops, respectively.

Further, perusal of data for both the years in table 4.13 clearly indicates that there is no definite trend existed soil ESP values with respect to groundwater fluoride categories. An irregular trend of increase and decrease of soil ESP with soil depth was observed in

Table: 4.13 Effect of groundwater fluoride on ESP of soil under mustard and wheat

Fluoride (mg L ⁻¹) Category	Name of Village	Initial	First year		Second year	
			Mustard	Wheat	Mustard	Wheat
< 2.0	Ratau (a)	1.72	1.71	2.00	1.23	1.21
	Ratau (c)	1.42	0.38	2.61	0.98	0.98
	Genana (b)	3.70	0.81	4.16	0.76	1.25
	Audint (c)	2.30	1.43	0.86	1.03	1.17
	Maximum	3.70	1.71	4.16	1.23	1.25
	Minimum	1.42	0.38	0.86	0.76	0.98
	Average	2.28	1.08	2.41	1.00	1.15
2.1 – 4.0	Sandas (b)	1.36	1.71	0.24	1.98	2.36
	Jhardia (c)	0.76	1.10	1.92	0.67	1.24
	Lukas (a)	0.01	0.05	0.18	0.73	0.56
	Lukas (b)	0.02	1.62	2.20	1.32	0.47
	Maximum	1.36	1.71	2.20	1.98	2.36
	Minimum	0.01	0.05	0.18	0.67	0.47
	Average	0.54	1.12	1.14	1.18	1.16
4.1 – 6.0	Baladoo (a)	0.41	0.37	0.16	0.32	1.34
	Baladoo (b)	0.07	1.07	0.14	0.82	1.20
	Nimbi Jhodha (a)	0.10	0.73	0.54	1.21	0.11
	Nimbi Jhodha (b)	0.41	3.81	0.57	2.43	0.65
	Maximum	0.41	3.81	0.57	2.43	1.34
	Minimum	0.07	0.37	0.14	0.32	0.11
	Average	0.25	1.49	0.35	1.19	0.82
6.1 – 8.0	Natas (b)	1.93	0.91	2.61	1.45	0.59
	Dujar (c)	2.42	0.14	0.11	0.75	1.07
	Bakolia (b)	0.90	0.53	1.90	0.34	1.34
	Bakolia (c)	1.67	0.24	2.17	0.71	1.05
	Maximum	2.42	0.91	2.61	1.45	1.34
	Minimum	0.90	0.14	0.11	0.34	0.59
	Average	1.73	0.46	1.69	0.81	1.01
>8.0	Sikarali	3.36	0.11	3.04	0.82	2.45
	Malgoan (b)	1.31	0.29	0.02	1.43	2.01
	Mangalpura	1.38	0.13	0.62	0.68	1.41
	Dujar (b)	2.29	1.30	3.05	0.97	2.04
	Maximum	3.36	1.30	3.05	1.43	2.45
	Minimum	1.31	0.11	0.02	0.68	1.41
	Average	2.09	0.46	1.68	0.97	1.98

most of the soils. These results are in conformity with the finding of Dhura Ram (1998), Prakash (2001), Okibe *et al.* (2010) and Paul *et al.* (2011).

4.4.2 Water parameters

An attempt has been made to study the changes in groundwater quality with time and to work out the possible relationship between groundwater fluoride content with other chemical constituents of the water. Results as obtained are presented in the succeeding paragraphs.

4.4.2.1 pH

Data regarding change in pH of groundwater under different categories of fluoride, during the study period are presented in table 4.14 and fig. 4.7. Data revealed that average pH of groundwater at sowing time ranged from 8.18 to 8.20, 8.25 to 8.35, 8.45 to 8.45, 8.48 to 8.83 and 9.03 to 9.25 during first year and second year in the fluoride category $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest in the respective fluoride category the pH of groundwater ranged from 8.43 to 8.53, 8.55 to 8.88, 8.60 to 8.70, 8.93 to 8.85 and 9.35 to 9.28 during first and second year. The maximum pH value of 9.40 at Bakolia (c) in fluoride category of $6.1 \text{ to } 8.0 \text{ mg L}^{-1}$ and 9.50 at Sikarali in fluoride category more than 8.0 mg L^{-1} were recorded at sowing during first and second year, respectively. At harvest, maximum pH value of 9.60 at Sikarali in fluoride category more than 8.0 mg L^{-1} and pH value of 9.60 in Bakolia (c) in $6.1 \text{ to } 8.0 \text{ mg L}^{-1}$ category of fluoride were observed during first and second year, respectively. The minimum pH value of 8.0 at Ratau (c) and 8.10 at Genana (b) and Sandas (b) were recorded with $< 2.0 \text{ mg L}^{-1}$ at sowing during first and second year, respectively. Similarly, at

Table: 4.14 pH of ground irrigation water under different fluoride categories

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	8.10	8.40	8.20	8.40
	Ratau (c)	8.00	8.50	8.30	8.50
	Genana (b)	8.10	8.20	8.10	8.60
	Audint (c)	8.50	8.60	8.20	8.60
	Maximum	8.50	8.60	8.30	8.60
	Minimum	8.00	8.20	8.10	8.40
	Average	8.18	8.43	8.20	8.53
2.1 – 4.0	Sandas (b)	8.10	8.30	8.10	8.80
	Jhardia (c)	8.10	8.70	8.40	8.90
	Lukas (a)	8.70	8.80	8.70	9.00
	Lukas (b)	8.10	8.40	8.20	8.80
	Maximum	8.70	8.80	8.70	9.00
	Minimum	8.10	8.30	8.10	8.80
	Average	8.25	8.55	8.35	8.88
4.1 – 6.0	Baladoo (a)	8.20	8.40	8.30	8.90
	Baladoo (b)	8.60	8.60	8.50	8.60
	Nimbi Jhodha (a)	8.80	8.80	8.60	8.70
	Nimbi Jhodha (b)	8.20	8.60	8.40	8.60
	Maximum	8.80	8.80	8.60	8.90
	Minimum	8.20	8.40	8.30	8.60
	Average	8.45	8.60	8.45	8.70
6.1 – 8.0	Natas (b)	8.20	8.90	8.90	9.10
	Dujar (c)	8.30	8.60	8.50	8.40
	Bakolia (b)	8.00	8.70	8.60	8.30
	Bakolia (c)	9.40	9.50	9.30	9.60
	Maximum	9.40	9.50	9.30	9.60
	Minimum	8.00	8.60	8.50	8.30
	Average	8.48	8.93	8.83	8.85
>8.0	Sikarali	9.30	9.60	9.50	9.50
	Malgoan (b)	9.10	9.50	9.40	9.50
	Mangalpura	9.20	9.40	9.30	9.20
	Dujar (b)	8.50	8.90	8.80	8.90
	Maximum	9.30	9.60	9.50	9.50
	Minimum	8.50	8.90	8.80	8.90
	Average	9.03	9.35	9.25	9.28

harvest minimum pH of 8.20 at Genana (b) and 8.30 at Bakolia (b) were recorded with fluoride category $< 2 \text{ mg L}^{-1}$ during first and second year, respectively.

Further, critical examination of data in table 4.14 and fig. 4.7 clearly indicates that with an increase in fluoride content of groundwater, pH of groundwater also increased. With the successive increase in fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$, and $> 8.0 \text{ mg L}^{-1}$ fluoride the average pH increased from 8.18 to 8.25, 8.45, 8.48 and 9.03 respectively, at sowing time of crop. Similar, trend was observed during second year also. The increase of average pH of groundwater was recorded from 8.45 to 8.55, 8.60, 8.93 and 9.35 at harvest during first year with the increase in fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$, and $> 8.0 \text{ mg L}^{-1}$. Similar, trend was also observed during second year study. Solubility of fluoride in groundwater differ from one type of mineral to another. Most of the fluoride minerals are sparingly soluble in water under normal temperature and pressure conditions. However, under certain physio-chemical condition, dissolution activity may become faster (Saxena and Ahmed 2001). Since alkaline medium is more favorable for fluoride dissolution, therefore, in the present case high fluoride content waters were observed with high pH values. Similar type of results were also reported by Satyanarayana *et al.* (1967), Sood *et al.* (1998), Verma *et al.* (2003), Ojha and Golani (2005), Sabal and Khan (2008), Yadav *et al.* (2009), Dave *et al.* (2010) and Khan and Ravi Kumar (2013).

4.4.2.2 Electrical conductivity (EC)

The change in EC of groundwater during study period, under different categories of fluoride is presented in table 4.15 and fig. 4.7. A critical examination of data showed that average EC of groundwater at sowing time changed from 2.78 to 3.07 dS m^{-1} , 2.95 to 3.50 dS m^{-1} , 3.46 to 4.06 dS m^{-1} , 4.43 to 4.81 dS m^{-1} and 5.46 to 6.30 dS m^{-1} during

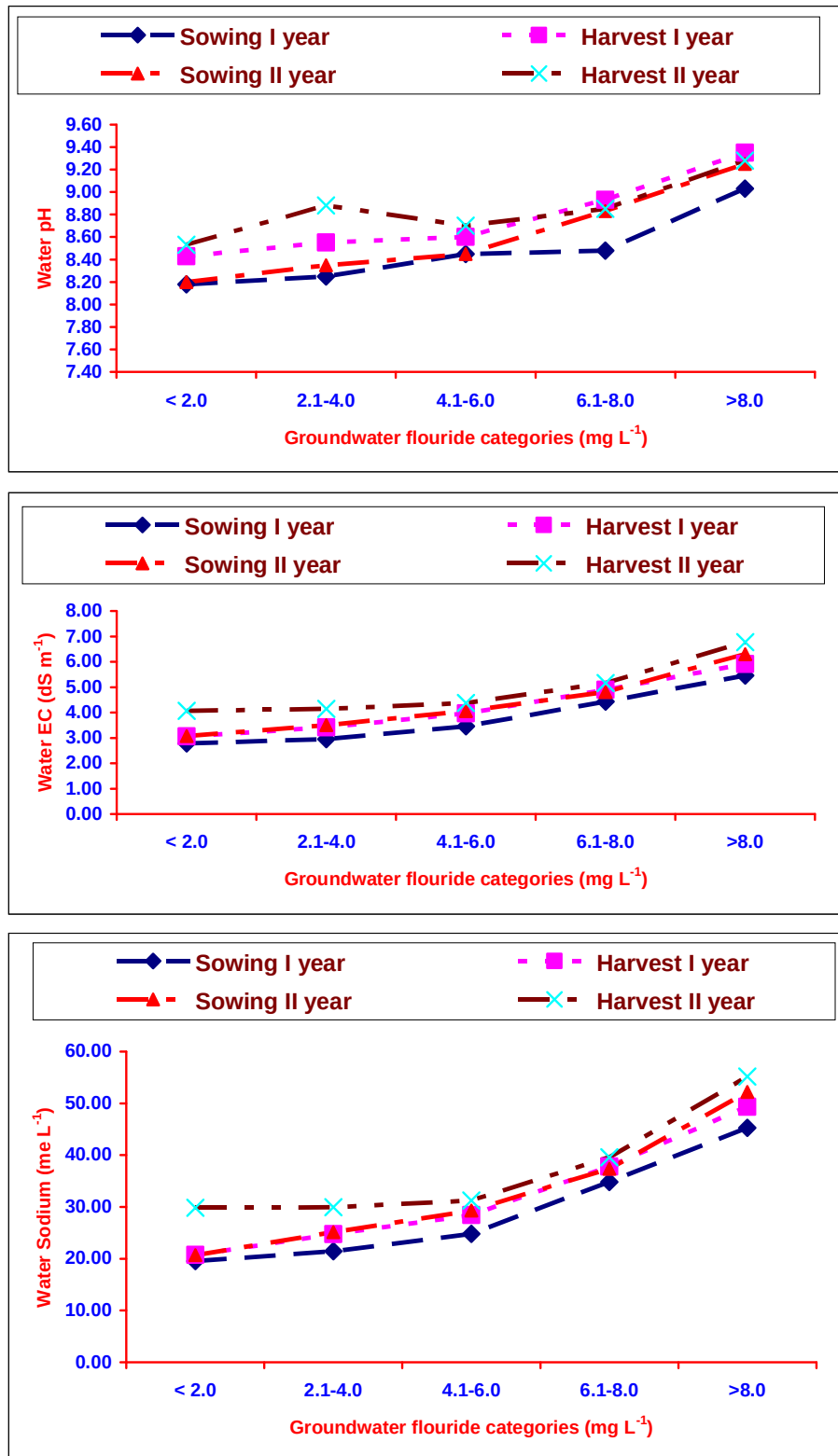


Fig. 4.7: pH, EC and sodium of different ground water fluoride categories during two years of study

Table: 4.15 EC (dS m⁻¹) of ground irrigation water under different fluoride categories

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	2.97	3.11	3.19	4.53
	Ratau (c)	2.79	3.12	3.07	4.24
	Genana (b)	2.72	3.14	3.15	3.87
	Audint (c)	2.65	2.87	2.87	3.64
	Maximum	2.97	3.14	3.19	4.53
	Minimum	2.65	2.87	2.87	3.64
	Average	2.78	3.06	3.07	4.07
2.1 – 4.0	Sandas (b)	3.17	3.28	3.22	3.65
	Jhardia (c)	2.74	2.92	3.07	3.99
	Lukas (a)	3.30	4.21	4.32	5.14
	Lukas (b)	2.59	3.21	3.38	3.79
	Maximum	3.30	4.21	4.32	5.14
	Minimum	2.59	2.92	3.07	3.65
	Average	2.95	3.41	3.50	4.14
4.1 – 6.0	Baladoo (a)	3.80	4.93	4.94	5.43
	Baladoo (b)	3.56	3.92	4.24	4.47
	Nimbi Jhodha (a)	3.51	3.75	3.82	4.21
	Nimbi Jhodha (b)	2.95	3.26	3.23	3.40
	Maximum	3.80	4.93	4.94	5.43
	Minimum	2.95	3.26	3.23	3.40
	Average	3.46	3.97	4.06	4.38
6.1 – 8.0	Natas (b)	5.37	5.81	5.37	5.91
	Dujar (c)	2.23	2.93	3.02	3.24
	Bakolia (b)	2.86	2.96	2.96	3.32
	Bakolia (c)	7.26	7.91	7.88	8.15
	Maximum	7.26	7.91	7.88	8.15
	Minimum	2.23	2.93	2.96	3.24
	Average	4.43	4.90	4.81	5.16
>8.0	Sikarali	6.48	6.92	7.92	8.22
	Malgoan (b)	6.95	7.14	7.69	7.95
	Mangalpura	5.52	5.93	5.95	6.21
	Dujar (b)	2.90	3.65	3.62	4.69
	Maximum	6.95	7.14	7.92	8.22
	Minimum	2.90	3.65	3.62	4.69
	Average	5.46	5.91	6.30	6.77

first and second year in the fluoride category $< 2.0 \text{ mg L}^{-1}$, $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest EC of groundwater changed from 3.06 to 4.07 dS m^{-1} , 3.41 to 4.14 dS m^{-1} , 3.97 to 4.38 dS m^{-1} , 4.90 to 5.16 dS m^{-1} and 5.91 to 6.77 dS m^{-1} from first year to second year in the respective fluoride category. At sowing, maximum EC of 7.26 dS m^{-1} at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L^{-1} and 7.92 dS m^{-1} at Sikarali in $> 8.0 \text{ mg L}^{-1}$ category of fluoride were observed during first and second year, respectively. At harvest maximum EC value of 7.91 dS m^{-1} at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L^{-1} and 8.22 dS m^{-1} at Sikarali in $> 8.0 \text{ mg L}^{-1}$ category of fluoride were observed during first and second year, respectively. At sowing the minimum EC of 2.23 dS m^{-1} was observed at Dujar (c) during first year in 6.1 to 8.0 fluoride category, while 2.87 dS m^{-1} was observed at Audint (c) during second year, which falls under fluoride category of $< 2 \text{ mg L}^{-1}$ and at harvest 2.87 dS m^{-1} was observed at Audint (c) during first year in $< 2 \text{ mg L}^{-1}$ fluoride category, while 3.24 dS m^{-1} was observed at Dujar (c) during second year, which falls under fluoride category of 6.1 to 8.0 mg L^{-1} .

A perusal of data for both the years in table 4.15 and fig. 4.7 clearly indicates that there is an increase in EC of water with an increase in fluoride content of groundwater. With the successive increase in fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$, and $> 8.0 \text{ mg L}^{-1}$ fluoride, the average EC increased from 2.78 to 2.95 , 3.46 , 4.43 and 5.46 dS m^{-1} , at sowing. Similar trend was observed during second year. Increase in average EC of groundwater was recorded from 3.06 to 3.41 , 3.97 , 4.90 and 5.91 dS m^{-1} at harvest, during first year with the increase in fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$, and $> 8.0 \text{ mg L}^{-1}$, respectively. Similar trend was also observed during second year. Increase in EC of groundwater with the increase in fluoride content of groundwater may be ascribed to increased ionic

concentration, which could have influenced fluoride solubility, especially due to presence of excessive sodium bicarbonate in groundwater. The findings of Lal *et al.* (1998) and Verma *et al.* (2003) Sabal and Khan (2008), Yadav *et al.* (2009), Dave *et al.* (2010) and Khan and Ravi Kumar (2013) are also in line of the present results.

4.4.2.3 Cationic composition

Calcium + Magnesium: A perusal of data regarding change in $\text{Ca}^{2+} + \text{Mg}^{2+}$ of groundwaters under different categories of fluoride, during the study period are presented in table 4.16. The data shows that average $\text{Ca}^{2+} + \text{Mg}^{2+}$ of groundwater at sowing changed from 8.10 to 9.78 me L^{-1} , 7.90 to 9.70 me L^{-1} , 9.60 to 11.08 me L^{-1} , 9.35 to 10.54 me L^{-1} , and 9.20 to 10.58 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, 2.1-4.0 mg L^{-1} , 4.1-6.0 mg L^{-1} , 6.1-8.0 mg L^{-1} and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest also $\text{Ca}^{2+} + \text{Mg}^{2+}$ of groundwater changed from 9.65 to 10.58 me L^{-1} , 9.14 to 11.25 me L^{-1} , 11.03 to 12.30 me L^{-1} , 11.05 to 11.70 me L^{-1} , and 9.61 to 12.23 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, 2.1-4.0 mg L^{-1} , 4.1-6.0 mg L^{-1} , 6.1-8.0 mg L^{-1} and $> 8.0 \text{ mg L}^{-1}$, respectively. At sowing, the maximum $\text{Ca}^{2+} + \text{Mg}^{2+}$ of 11.20 me L^{-1} was observed at Sandas (b) in fluoride category of 2.1 to 4.0 mg L^{-1} and 14.70 me L^{-1} at Baladoo (a) with 4.1-6.0 mg L^{-1} fluoride category during first and second year, respectively whereas, at harvest, the $\text{Ca}^{2+} + \text{Mg}^{2+}$ of 14.50 me L^{-1} was recorded at Baladoo (a) during first year in 4.1 to 6.0 mg L^{-1} fluoride category and 16.40 mg L^{-1} at Sikarali during second year of $> 8.0 \text{ mg L}^{-1}$ fluoride category. At sowing the minimum $\text{Ca}^{2+} + \text{Mg}^{2+}$ of 6.20 me L^{-1} was observed at Jhardia (c) in fluoride category of 2.1 to 4.0 mg L^{-1} during first year, while 8.10 me L^{-1} was observed at Aundint (c) during second year under fluoride category of $< 2 \text{ mg L}^{-1}$ and at harvest, 7.15 me L^{-1} was observed at Jhardia (c) in fluoride category of 2.1 to 4.0 mg L^{-1} during first year, while 9.40 me L^{-1} was observed at

Table: 4.16 $\text{Ca}^{2+} + \text{Mg}^{2+}$ (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	8.20	10.01	10.90	11.10
	Ratau (c)	9.40	10.70	10.20	11.00
	Genana (b)	8.20	9.70	9.90	10.40
	Audint (c)	6.60	8.20	8.10	9.81
	Maximum	9.40	10.70	10.90	11.10
	Minimum	6.60	8.20	8.10	9.81
	Average	8.10	9.65	9.78	10.58
2.1 – 4.0	Sandas (b)	11.20	11.80	10.40	11.40
	Jhardia (c)	6.20	7.15	9.40	11.10
	Lukas (a)	7.00	8.80	9.60	11.70
	Lukas (b)	7.20	8.80	9.40	10.80
	Maximum	11.20	11.80	10.40	11.70
	Minimum	6.20	7.15	9.40	10.80
	Average	7.90	9.14	9.70	11.25
4.1 – 6.0	Baladoo (a)	10.20	14.50	14.70	15.80
	Baladoo (b)	9.60	9.80	10.20	11.80
	Nimbi Jhodha (a)	9.00	10.20	10.60	12.00
	Nimbi Jhodha (b)	9.60	9.60	8.80	9.60
	Maximum	10.20	14.50	14.70	15.80
	Minimum	9.00	9.60	8.80	9.60
	Average	9.60	11.03	11.08	12.30
6.1 – 8.0	Natas (b)	9.40	11.90	10.80	11.80
	Dujar (c)	7.60	9.60	9.70	11.20
	Bakolia (b)	9.40	10.30	9.10	10.20
	Bakolia (c)	11.00	12.40	12.55	13.60
	Maximum	11.00	12.40	12.55	13.60
	Minimum	7.60	9.60	9.10	10.20
	Average	9.35	11.05	10.54	11.70
>8.0	Sikarali	10.80	11.60	13.96	16.40
	Malgoan (b)	8.80	9.80	10.53	12.20
	Mangalpura	9.40	8.52	8.57	9.40
	Dujar (b)	7.80	8.50	9.24	10.90
	Maximum	10.80	11.60	13.96	16.40
	Minimum	7.80	8.50	8.57	9.40
	Average	9.20	9.61	10.58	12.23

Mangalpura during second year under fluoride category of $> 8.0 \text{ mg L}^{-1}$.

Further, perusal of data for both the years in table 4.16 clearly indicate the there is no definite trend of water $\text{Ca}^{2+} + \text{Mg}^{2+}$ values with respect to groundwater fluoride categories. The relative proportion of all cations and anions of water might have played important role in solubilization of fluoride, therefore no definite trend was observed with $\text{Ca}^{2+} + \text{Mg}^{2+}$. The results are in accordance to the findings of Singh *et al.* (1995), Lal *et al.* (1998), Bagoria (2002), Gupta *et al.* (2006), Yadav *et al.* (2009) and Ambade and Rao (2012).

Sodium : Data regarding variations in Na^+ under different categories of groundwater fluoride, during the study period are presented in table 4.17 and fig. 4.7. Data indicated that average Na^+ of groundwater at sowing changed from 19.54 to 20.70 me L^{-1} , 21.47 to 25.10 me L^{-1} , 24.80 to 29.31 me L^{-1} , 34.80 to 37.35 me L^{-1} and 45.29 to 52.18 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest also Na^+ of groundwater changed from 20.74 to 29.86 me L^{-1} , 24.75 to 29.96 me L^{-1} , 28.45 to 31.24 me L^{-1} , 37.80 to 39.61 me L^{-1} , and 49.32 to 55.20 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, $2.1\text{-}4.0 \text{ mg L}^{-1}$, $4.1\text{-}6.0 \text{ mg L}^{-1}$, $6.1\text{-}8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At sowing, the Maximum Na^+ of 61.39 me L^{-1} was observed at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L^{-1} during first year and 16.16 me L^{-1} at Malgoan (b) during second year in $> 8.0 \text{ mg L}^{-1}$ fluoride category and at harvest Na^+ of 66.46 and 67.59 me L^{-1} was observed at Bakolia (c) in during first and second year, respectively, in 6.1 to 8.0 mg L^{-1} fluoride category. At sowing, the minimum Na^+ of 14.60 me L^{-1} was observed at Dujar (c) in fluoride category of $6.1\text{-}8.0 \text{ mg L}^{-1}$ during first year, while 20.29 me L^{-1} was observed at Bakolia (b) during second year, under fluoride category of $6.1\text{-}8.0 \text{ mg L}^{-1}$. At harvest, minimum Na^+ of 19.10 me L^{-1}

Table: 4.17 Na⁺ (me L⁻¹) of ground irrigation water under different fluoride categories

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	21.41	20.99	20.89	34.06
	Ratau (c)	18.40	20.38	20.37	31.24
	Genana (b)	18.57	21.22	21.09	27.72
	Audint (c)	19.78	20.35	20.44	26.40
	Maximum	21.41	21.22	21.09	34.06
	Minimum	18.40	20.35	20.37	26.40
	Average	19.54	20.74	20.70	29.86
2.1 – 4.0	Sandas (b)	20.38	20.84	21.63	24.89
	Jhardia (c)	21.06	21.87	21.10	28.54
	Lukas (a)	25.87	33.14	33.43	39.49
	Lukas (b)	18.58	23.16	24.25	26.91
	Maximum	25.87	33.14	33.43	39.49
	Minimum	18.58	20.84	21.10	24.89
	Average	21.47	24.75	25.10	29.96
4.1 – 6.0	Baladoo (a)	27.63	34.60	34.49	38.25
	Baladoo (b)	25.86	29.23	32.02	32.67
	Nimbi Jhodha (a)	25.93	27.11	27.39	29.85
	Nimbi Jhodha (b)	19.79	22.86	23.34	24.20
	Maximum	27.63	34.60	34.49	38.25
	Minimum	19.79	22.86	23.34	24.20
	Average	24.80	28.45	29.31	31.24
6.1 – 8.0	Natas (b)	44.18	46.04	42.72	47.05
	Dujar (c)	14.60	19.58	20.37	21.05
	Bakolia (b)	19.03	19.10	20.29	22.73
	Bakolia (c)	61.39	66.46	66.00	67.59
	Maximum	61.39	66.46	66.00	67.59
	Minimum	14.60	19.10	20.29	21.05
	Average	34.80	37.80	37.35	39.61
>8.0	Sikarali	53.88	57.45	65.08	65.61
	Malgoan (b)	60.56	61.41	66.16	67.02
	Mangalpura	45.62	50.58	50.71	52.40
	Dujar (b)	21.10	27.84	26.77	35.76
	Maximum	60.56	61.41	66.16	67.02
	Minimum	21.10	27.84	26.77	35.76
	Average	45.29	49.32	52.18	55.20

was observed at Bakolia (b) during first year, while 21.05 me L⁻¹ at Dujar (c) during second year, under fluoride category of 6.1 to 8.0 mg L⁻¹.

A critical examination of data in table 4.17 and fig. 4.7 clearly indicate that with an increase in fluoride content of groundwater, sodium content of groundwater also increased. With the successive increase in fluoride category from < 2.0 mg L⁻¹ to 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹, and > 8.0 mg L⁻¹ fluoride the average Na⁺ increased from 19.54 to 21.47, 24.80, 34.80 and 45.29 me L⁻¹ during first year and 20.70 to 25.10, 29.31, 37.35 and 52.18 me L⁻¹ during second year, respectively, at sowing. Similarly, at harvest the increase in sodium content was of the magnitude of 20.74 to 24.75, 28.45, 37.80 and 49.32 me L⁻¹ during first year and 29.86 to 29.96, 31.24, 39.61 and 55.20 me L⁻¹ during second year in the fluoride categories, < 2.0 mg L⁻¹ to 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹, and > 8.0 mg L⁻¹, respectively. As expected NaF being more soluble, high fluoride concentrations were observed with increased sodium content in groundwater. Similar results were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Bagoria (2002), Gupta *et al.* (2006), Yadav *et al.* (2009) and Ambade and Rao (2012).

Potassium: Data regarding variation in K⁺ of groundwaters under different categories of fluoride, during the study period are presented in table 4.18. Data shows that average K⁺ of groundwater at sowing changed from 0.19 to 0.23 me L⁻¹, 0.13 to 0.17 me L⁻¹, 0.15 to 0.19 me L⁻¹, 0.15 to 0.19 me L⁻¹ and 0.14 to 0.20 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At harvest also K⁺ of groundwater changed from 0.21 to 0.27 me L⁻¹, 0.16 to 0.22 me L⁻¹, 0.18 to 0.23 me L⁻¹, 0.18 to 0.25 me L⁻¹ and 0.18 to 0.25 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and >8.0 mg L⁻¹, respectively. At

Table 4.18: K^+ (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	0.09	0.10	0.11	0.14
	Ratau (c)	0.10	0.12	0.13	0.16
	Genana (b)	0.43	0.48	0.51	0.58
	Audint (c)	0.13	0.15	0.16	0.19
	Maximum	0.43	0.48	0.51	0.58
	Minimum	0.09	0.10	0.11	0.14
	Average	0.19	0.21	0.23	0.27
2.1 – 4.0	Sandas (b)	0.13	0.16	0.17	0.21
	Jhardia (c)	0.15	0.18	0.20	0.26
	Lukas (a)	0.13	0.16	0.17	0.21
	Lukas (b)	0.12	0.14	0.15	0.19
	Maximum	0.15	0.18	0.20	0.26
	Minimum	0.12	0.14	0.15	0.19
	Average	0.13	0.16	0.17	0.22
4.1 – 6.0	Baladoo (a)	0.18	0.20	0.21	0.25
	Baladoo (b)	0.14	0.17	0.18	0.23
	Nimbi Jhodha (a)	0.17	0.19	0.21	0.25
	Nimbi Jhodha (b)	0.11	0.14	0.16	0.20
	Maximum	0.18	0.20	0.21	0.25
	Minimum	0.11	0.14	0.16	0.20
	Average	0.15	0.18	0.19	0.23
6.1 – 8.0	Natas (b)	0.12	0.16	0.18	0.25
	Dujar (c)	0.10	0.12	0.13	0.15
	Bakolia (b)	0.17	0.20	0.21	0.27
	Bakolia (c)	0.21	0.24	0.25	0.31
	Maximum	0.21	0.24	0.25	0.31
	Minimum	0.10	0.12	0.13	0.15
	Average	0.15	0.18	0.19	0.25
>8.0	Sikarali	0.12	0.15	0.16	0.19
	Malgoan (b)	0.14	0.19	0.21	0.28
	Mangalpura	0.18	0.20	0.22	0.30
	Dujar (b)	0.11	0.16	0.19	0.24
	Maximum	0.18	0.20	0.22	0.30
	Minimum	0.11	0.15	0.16	0.19
	Average	0.14	0.18	0.20	0.25

sowing the maximum K^+ of 0.43 and 0.51 $me\ L^{-1}$ was observed at Genana (b) in fluoride category of $< 2.0\ mg\ L^{-1}$ during first and second year, respectively. At harvest maximum K^+ of 0.48 $me\ L^{-1}$ and 0.58 $me\ L^{-1}$ was observed at Genana (b) in $< 2.0\ mg\ L^{-1}$ fluoride category during first and second year. At sowing, the minimum K^+ of 0.09 and 0.11 $me\ L^{-1}$ was observed at Ratau (a) during both the years in $< 2\ mg\ L^{-1}$ fluoride category and at harvest 0.10 and 0.14 $me\ L^{-1}$ at Ratau (a) in $< 2\ mg\ L^{-1}$ fluoride category during first and second year.

Further, perusal of data for both the years (Table 4.18) clearly indicates that there is no definite trend of water K^+ values with respect to groundwater fluoride category. The relative proportion of other cations might have dominated the dissolution behavior of fluoride therefore no specific trend resulted with potassium ion. The present observations are in accordance with the results reported by Singh *et al.* (1995), Lal *et al.* (1998), Bagoria (2002), Gupta *et al.* (2006), Yadav *et al.* (2009) and Ambade and Rao (2012).

4.4.2.4 Anionic composition

Fluoride: Data regarding change in fluoride content of groundwater during two years of study under five different categories of fluoride are presented in table 4.19 and fig. 4.8. Data shows that average fluoride of groundwater at sowing increased from 1.33 to 1.73 $mg\ L^{-1}$, 3.25 to 3.53 $mg\ L^{-1}$, 5.40 to 5.75 $mg\ L^{-1}$, 6.85 to 7.15 $mg\ L^{-1}$ and 8.45 to 8.50 $mg\ L^{-1}$ from first year to second year, in fluoride category $< 2.0\ mg\ L^{-1}$, 2.1-4.0 $mg\ L^{-1}$, 4.1-6.0 $mg\ L^{-1}$, 6.1-8.0 $mg\ L^{-1}$ and $> 8.0\ mg\ L^{-1}$, respectively. At harvest also fluoride content of groundwater increased from 1.73 to 2.05 $mg\ L^{-1}$, 3.60 to 4.13 $mg\ L^{-1}$, 5.80 to 6.10 $mg\ L^{-1}$, 7.33 to 7.63 $mg\ L^{-1}$ and 8.58 to 8.83 $mg\ L^{-1}$ from first year to second year, in fluoride category $< 2.0\ mg\ L^{-1}$, 2.1-4.0 $mg\ L^{-1}$, 4.1-6.0 $mg\ L^{-1}$, 6.1-8.0 $mg\ L^{-1}$ and $> 8.0\ mg\ L^{-1}$, respectively. The maximum fluoride of 8.80 $mg\ L^{-1}$ was observed at Malgoan (b) at sowing during both the years in $> 8.0\ mg\ L^{-1}$ fluoride category while 8.90 $mg\ L^{-1}$ and

Table 4.19: F (mg L⁻¹) of ground irrigation water under different fluoride categories

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	1.60	1.90	1.90	2.20
	Ratau (c)	1.30	1.80	1.70	2.30
	Genana (b)	1.20	1.60	1.70	1.90
	Audint (c)	1.20	1.60	1.60	1.80
	Maximum	1.60	1.90	1.90	2.30
	Minimum	1.20	1.60	1.60	1.80
	Average	1.33	1.73	1.73	2.05
2.1 – 4.0	Sandas (b)	3.60	3.80	3.60	4.20
	Jhardia (c)	3.00	3.30	3.30	4.10
	Lukas (a)	3.30	3.50	3.50	4.30
	Lukas (b)	3.10	3.80	3.70	3.90
	Maximum	3.60	3.80	3.70	4.30
	Minimum	3.00	3.30	3.30	3.90
	Average	3.25	3.60	3.53	4.13
4.1 – 6.0	Baladoo (a)	5.70	5.80	5.70	5.90
	Baladoo (b)	4.80	5.40	5.40	5.70
	Nimbi Jhodha (a)	5.20	5.60	5.50	6.00
	Nimbi Jhodha (b)	5.90	6.40	6.40	6.80
	Maximum	5.90	6.40	6.40	6.80
	Minimum	4.80	5.40	5.40	5.70
	Average	5.40	5.80	5.75	6.10
6.1 – 8.0	Natas (b)	7.50	8.10	8.10	8.30
	Dujar (c)	6.30	6.50	6.40	6.80
	Bakolia (b)	7.30	7.80	7.40	8.40
	Bakolia (c)	6.30	6.90	6.70	7.00
	Maximum	7.50	8.10	8.10	8.40
	Minimum	6.30	6.50	6.40	6.80
	Average	6.85	7.33	7.15	7.63
>8.0	Sikarali	8.10	8.20	8.10	8.60
	Malgoan (b)	8.80	8.90	8.80	9.00
	Mangalpura	8.70	8.80	8.80	8.90
	Dujar (b)	8.20	8.40	8.30	8.80
	Maximum	8.80	8.90	8.80	9.00
	Minimum	8.10	8.20	8.10	8.60
	Average	8.45	8.58	8.50	8.83

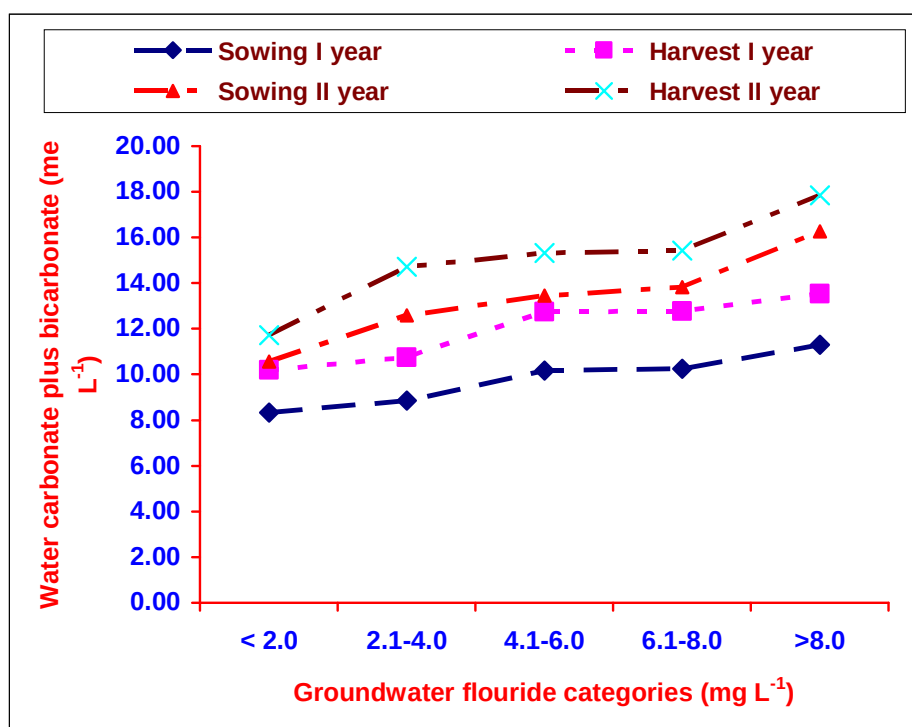
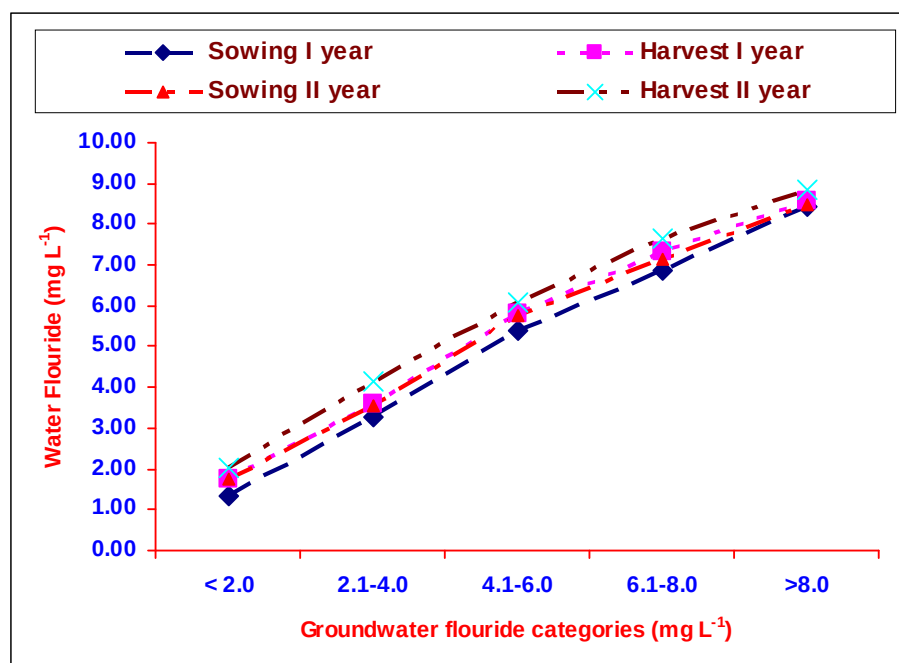


Fig . 4.8 : Fluoride and carbonate plus bicarbonate of different fluoride categories of ground water

9.00 mg L⁻¹ at harvest at Malgoan (b) in > 8.0 mg L⁻¹ fluoride category during both first and second year, respectively. At sowing, the minimum fluoride of 1.20 mg L⁻¹ and 1.60 mg L⁻¹ was observed at Genana (b) and Audint (c) villages during both the years, while at harvest, 1.60 mg L⁻¹ and 1.80 mg L⁻¹ found at Audint (c) during both the years, in < 2 mg L⁻¹ fluoride category.

An examination of data in table 4.19 and fig. 4.8, evidently shows that the fluoride content of groundwater increased from first year of sowing to second year harvesting in all the five categories of fluoride. However, the magnitude of increase in average fluoride content varied from 0.38 to 0.88 mg L⁻¹. The lowest increase in average fluoride (0.38 mg L⁻¹) was observed with the groundwater of fluoride category > 8.0 mg L⁻¹, whereas in the other fluoride categories the increase varied between 0.70 to 0.88 mg L⁻¹ which clearly indicate that the rate of increase in fluoride content is much faster in the groundwaters having fluoride content up to 8.0 mg L⁻¹ as compared to water having fluoride content more than 8.0 mg L⁻¹. Similar results were also reported by Gupta (1986), Singh *et al.* (1987), Datta *et al.* (1996), Bagoria (2002), Ojha and Golani (2005), Yadav *et al.* (2009), Gautam *et al.* (2011) and Ambade and Rao (2012).

CO₃²⁻ + HCO₃⁻ : Data regarding variations in CO₃²⁻ + HCO₃⁻ of groundwaters under different categories of fluoride, during the study periods are presented in table 4.20 and fig. 4.8. Data indicates that average CO₃²⁻ + HCO₃⁻ of ground water at sowing changed from 8.33 to 10.57 me L⁻¹, 8.85 to 12.60 me L⁻¹, 10.18 to 13.45 me L⁻¹, 10.25 to 13.83 me L⁻¹, 11.30 to 17.85 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At harvest also CO₃²⁻ + HCO₃⁻ of groundwater changed from 10.20 to 11.73 me L⁻¹, 10.75 to 14.73 me L⁻¹, 12.75 to 15.33 me L⁻¹, 12.78 to 15.43 me L⁻¹ and 13.53 to 17.85 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-

Table 4.20: $\text{CO}_3^{2-} + \text{HCO}_3^-$ (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	8.40	10.60	11.80	12.60
	Ratau (c)	9.50	11.10	10.80	11.80
	Genana (b)	8.40	10.10	10.40	11.10
	Audint (c)	7.00	9.00	9.26	11.40
	Maximum	9.50	11.10	11.80	12.60
	Minimum	7.00	9.00	9.26	11.10
	Average	8.33	10.20	10.57	11.73
2.1 – 4.0	Sandas (b)	11.80	12.70	12.70	14.20
	Jhardia (c)	7.40	9.70	13.20	15.30
	Lukas (a)	8.30	10.70	12.90	15.80
	Lukas (b)	7.90	9.90	11.60	13.60
	Maximum	11.80	12.70	13.20	15.80
	Minimum	7.40	9.70	11.60	13.60
	Average	8.85	10.75	12.60	14.73
4.1 – 6.0	Baladoo (a)	11.10	17.40	16.40	17.80
	Baladoo (b)	10.10	11.09	12.90	14.70
	Nimbi Jhodha (a)	9.20	11.10	13.40	15.20
	Nimbi Jhodha (b)	10.30	11.40	11.10	13.60
	Maximum	11.10	17.40	16.40	17.80
	Minimum	9.20	11.09	11.10	13.60
	Average	10.18	12.75	13.45	15.33
6.1 – 8.0	Natas (b)	9.70	12.90	13.80	15.90
	Dujar (c)	8.10	11.40	12.80	14.50
	Bakolia (b)	10.90	12.40	12.80	14.40
	Bakolia (c)	12.30	14.40	15.90	16.90
	Maximum	12.30	14.40	15.90	16.90
	Minimum	8.10	11.40	12.80	14.40
	Average	10.25	12.78	13.83	15.43
>8.0	Sikarali	13.90	15.30	18.20	21.20
	Malgoan (b)	10.40	13.30	14.62	17.20
	Mangalpura	11.10	13.10	17.90	16.60
	Dujar (b)	9.80	12.40	14.40	16.40
	Maximum	13.90	15.30	18.20	21.20
	Minimum	9.80	12.40	14.40	16.40
	Average	11.30	13.53	16.28	17.85

4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At sowing, the maximum CO₃²⁻ + HCO₃⁻ of 13.90 me L⁻¹ and 18.20 me L⁻¹ was observed at Sikarali with > 8.0 mg L⁻¹ fluoride category during first and second year and at harvest, the maximum CO₃²⁻ + HCO₃⁻ of 17.40 me L⁻¹ was observed at Baladoo (a) in fluoride category of 6.1 to 8.0 mg L⁻¹ during first year and 21.20 me L⁻¹ at Sikarali during second year in > 8.0 mg L⁻¹ fluoride category. At sowing, the minimum CO₃²⁻ + HCO₃⁻ of 7.0 and 9.26 me L⁻¹ was observed at Audint (c) in fluoride category of < 2.0 mg L⁻¹ during first and second year and at harvest, the minimum CO₃²⁻ + HCO₃⁻ of 9.00 me L⁻¹ was observed at Audint (c) during first year, while 11.10 me L⁻¹ at Genana (b) during second year in both under fluoride category of < 2.0 mg L⁻¹

Further, critical examination of data in table 4.20 and fig. 4.8 clearly indicates that with increase in fluoride content of groundwater CO₃²⁻ + HCO₃⁻ of groundwater also increased. With the successive increase in fluoride category from < 2.0 mg L⁻¹ to 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹, and > 8.0 mg L⁻¹ fluoride the average CO₃²⁻ + HCO₃⁻ increased from 8.33, 8.85, 10.18, 10.25 and 11.30 me L⁻¹, respectively, at sowing. Similarly, trend was also observed during second year and 10.20, 10.75, 12.75, 12.78 and 13.53 me L⁻¹ at harvest during first year. Similar, trend was also observed during second year. Increased fluoride concentration with the increase CO₃²⁻ + HCO₃⁻ content in groundwater might have due to enhanced dissociation activity of fluoride particularly in the presence of high sodium. Results reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013) are also in agreement to present findings.

Chlorine: Data regarding variations in Cl⁻ under different categories of groundwaters fluoride, during the study period are presented in table 4.21. Data shows that average Cl⁻ of groundwater at sowing changed

Table 4.21: Cl^- (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	15.60	16.29	16.60	19.80
	Ratau (c)	18.00	19.20	19.40	23.30
	Genana (b)	16.60	17.40	17.80	20.80
	Audint (c)	17.60	18.60	18.80	21.80
	Maximum	18.00	19.20	19.40	23.30
	Minimum	15.60	16.29	16.60	19.80
	Average	16.95	17.87	18.15	21.43
2.1 – 4.0	Sandas (b)	16.60	17.60	17.80	19.20
	Jhardia (c)	16.40	18.20	16.70	19.80
	Lukas (a)	19.20	21.80	24.60	27.80
	Lukas (b)	14.40	17.30	19.90	21.30
	Maximum	19.20	21.80	24.60	27.80
	Minimum	14.40	17.30	16.70	19.20
	Average	16.65	18.73	19.75	22.03
4.1 – 6.0	Baladoo (a)	26.60	30.40	30.80	30.40
	Baladoo (b)	25.40	26.20	26.65	27.80
	Nimbi Jhodha (a)	21.80	23.40	23.60	24.60
	Nimbi Jhodha (b)	16.80	17.40	18.10	19.30
	Maximum	26.60	30.40	30.80	30.40
	Minimum	16.80	17.40	18.10	19.30
	Average	22.65	24.35	24.79	25.53
6.1 – 8.0	Natas (b)	42.80	43.20	39.40	41.60
	Dujar (c)	13.80	15.40	15.80	17.40
	Bakolia (b)	17.40	16.70	16.20	17.50
	Bakolia (c)	51.80	53.30	53.50	56.40
	Maximum	51.80	53.30	53.50	56.40
	Minimum	13.80	15.40	15.80	17.40
	Average	31.45	32.15	31.23	33.23
>8.0	Sikarali	48.80	52.20	53.40	57.20
	Malgoan (b)	57.00	51.60	53.60	55.60
	Mangalpura	39.60	43.20	40.60	43.30
	Dujar (b)	18.20	21.20	21.40	24.60
	Maximum	57.00	52.20	53.60	57.20
	Minimum	18.20	21.20	21.40	24.60
	Average	40.90	42.05	42.25	45.18

from 16.95 to 18.15 me L⁻¹, 16.65 to 19.75 me L⁻¹, 22.65 to 24.79 me L⁻¹, 31.45 to 31.23 me L⁻¹ and 40.90 to 42.25 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At harvest also Cl⁻ of groundwater changed from 17.87 to 21.43 me L⁻¹, 18.73 to 22.03 me L⁻¹, 24.35 to 25.53 me L⁻¹, 32.15 to 33.23 me L⁻¹ and 42.05 to 45.18 me L⁻¹ from first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At sowing, the maximum Cl⁻ of 57.0 me L⁻¹ and 53.60 me L⁻¹ was observed at malgoan (b) in fluoride category of > 8.0 mg L⁻¹ during first and second year and at harvest, the maximum Cl⁻ of 51.30 me L⁻¹ was observed at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L⁻¹ during first year and 57.20 me L⁻¹ was observed at Sikarali in fluoride category of > 8.0 mg L⁻¹ during second year. At sowing, the minimum Cl⁻ of 13.80 me L⁻¹ and 15.80 me L⁻¹ was observed at Dujar (c) during first and second year in 6.1 to 8.0 mg L⁻¹ fluoride category and at harvest, the minimum Cl⁻ of 15.40 me L⁻¹ and 17.40 me L⁻¹ was observed at Dujar (c) during first and second year in 6.1-8.0 mg L⁻¹ fluoride category.

Further, perusal of data for both the years presented in table 4.21 clearly indicates that there is no definite trend observed in of water Cl⁻ values with respect to groundwater fluoride category. This could be explained in the light of differential solubility behaviors of different anions in water. Similar results were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

Sulphate: Data regarding variations in SO₄²⁻ of groundwaters under different categories of fluoride, during the study period are presented in table 4.22. Data shows that average SO₄²⁻ of groundwater at sowing changed from 2.55 to 1.99 me L⁻¹, 4.00 to 2.63 me L⁻¹, 1.73 to 2.84 me L⁻¹, 2.60 to 3.03 me L⁻¹ and 2.43 to 4.42 me L⁻¹ from first year to second

Table 4.22: SO_4^{2-} (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	5.70	4.21	3.50	12.90
	Ratau (c)	0.40	0.90	0.50	7.30
	Genana (b)	2.20	3.90	3.30	6.80
	Audint (c)	1.90	1.10	0.64	3.20
	Maximum	5.70	4.21	3.50	12.90
	Minimum	0.40	0.90	0.50	3.20
	Average	2.55	2.53	1.99	7.55
2.1 – 4.0	Sandas (b)	3.30	2.50	1.70	3.10
	Jhardia (c)	3.60	1.30	0.80	4.80
	Lukas (a)	5.50	9.60	5.70	7.80
	Lukas (b)	3.60	4.90	2.30	3.00
	Maximum	5.50	9.60	5.70	7.80
	Minimum	3.30	1.30	0.80	3.00
	Average	4.00	4.58	2.63	4.68
4.1 – 6.0	Baladoo (a)	0.30	1.50	4.20	6.10
	Baladoo (b)	0.10	1.91	2.85	2.20
	Nimbi Jhodha (a)	4.10	3.00	1.20	2.30
	Nimbi Jhodha (b)	2.40	3.80	3.10	1.10
	Maximum	4.10	3.80	4.20	6.10
	Minimum	0.10	1.50	1.20	1.10
	Average	1.73	2.55	2.84	2.93
6.1 – 8.0	Natas (b)	1.20	2.00	0.50	1.60
	Dujar (c)	0.40	2.50	1.60	0.50
	Bakolia (b)	0.30	0.50	0.60	1.30
	Bakolia (c)	8.50	11.40	9.40	8.20
	Maximum	8.50	11.40	9.40	8.20
	Minimum	0.30	0.50	0.50	0.50
	Average	2.60	4.10	3.03	2.90
>8.0	Sikarali	2.10	1.70	7.60	3.80
	Malgoan (b)	2.10	6.50	8.68	6.70
	Mangalpura	4.50	3.00	1.00	2.20
	Dujar (b)	1.00	2.90	0.40	5.90
	Maximum	4.50	6.50	8.68	6.70
	Minimum	1.00	1.70	0.40	2.20
	Average	2.43	3.53	4.42	4.65

year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, $2.1-4.0 \text{ mg L}^{-1}$, $4.1-6.0 \text{ mg L}^{-1}$, $6.1-8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest also SO_4^{2-} of groundwater changed from 2.53 to 7.55 me L^{-1} , 4.58 to 4.68 me L^{-1} , 2.55 to 2.93 me L^{-1} , 4.10 to 2.90 me L^{-1} and 3.53 to 4.65 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, $2.1-4.0 \text{ mg L}^{-1}$, $4.1-6.0 \text{ mg L}^{-1}$, $6.1-8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$, respectively. At sowing the maximum SO_4^{2-} of 8.50 and 9.40 me L^{-1} was observed at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L^{-1} during first and second year and at harvest the maximum SO_4^{2-} of 11.40 me L^{-1} was observed at Bakolia (c) in fluoride category of $6.1-8.0 \text{ mg L}^{-1}$ during first year and 12.90 me L^{-1} at Ratau (a) during second year in $< 2.0 \text{ mg L}^{-1}$ fluoride category. At sowing the minimum SO_4^{2-} of 0.10 me L^{-1} was observed at Baladoo (b) during first year in 4.1 to 6.0 mg L^{-1} fluoride category, while 0.40 me L^{-1} was observed at Dujar (b) during second year under fluoride category of $< 8.0 \text{ mg L}^{-1}$ and at harvest the minimum SO_4^{2-} of 0.50 me L^{-1} was observed at Bakolia (b) during first year in 6.1 to 8.0 mg L^{-1} fluoride category, while 0.50 me L^{-1} was observed at Dujar (c) during second year in fluoride category of $6.1-8.0 \text{ mg L}^{-1}$.

Further, perusal of data for both the years (Table 4.22) clearly indicates that there is no definite trend existed in water SO_4^{2-} values with respect to groundwater fluoride category. Higher dissociation activity of $\text{CO}_3 + \text{HCO}_3$ might have affected the solubility behaviors of fluoride in groundwater with other anions. Similar observations were also reported by Singh *et al.* (1995), Lal *et al.* (1998), Shahid *et al.* (2008) Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

4.4.2.5 Residual Sodium carbonate (RSC)

The variations in RSC of groundwaters during study period under different categories of fluoride are presented in table 4.23. Data indicate that average RSC of groundwater at sowing increased from

Table 4.23: RSC (me L^{-1}) of ground irrigation water under different fluoride categories

Fluoride (mg L^{-1}) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	0.20	0.59	0.90	1.50
	Ratau (c)	0.10	0.40	0.60	0.80
	Genana (b)	0.20	0.40	0.50	0.70
	Audint (c)	0.40	0.80	1.16	1.59
	Maximum	0.40	0.80	1.16	1.59
	Minimum	0.10	0.40	0.50	0.70
	Average	0.23	0.55	0.79	1.15
2.1 – 4.0	Sandas (b)	0.60	0.90	2.30	2.80
	Jhardia (c)	1.20	2.55	3.80	4.20
	Lukas (a)	1.30	1.90	3.30	4.10
	Lukas (b)	0.70	1.10	2.20	2.80
	Maximum	1.30	2.55	3.80	4.20
	Minimum	0.60	0.90	2.20	2.80
	Average	0.95	1.61	2.90	3.48
4.1 – 6.0	Baladoo (a)	0.90	2.90	1.70	2.00
	Baladoo (b)	0.50	1.29	2.70	2.90
	Nimbi Jhodha (a)	0.20	0.90	2.80	3.20
	Nimbi Jhodha (b)	0.70	1.80	2.30	4.00
	Maximum	0.90	2.90	2.80	4.00
	Minimum	0.20	0.90	1.70	2.00
	Average	0.58	1.72	2.38	3.03
6.1 – 8.0	Natas (b)	0.30	1.00	3.00	4.10
	Dujar (c)	0.50	1.80	3.10	3.30
	Bakolia (b)	1.50	2.10	3.70	4.20
	Bakolia (c)	1.30	2.00	3.35	3.30
	Maximum	1.50	2.10	3.70	4.20
	Minimum	0.30	1.00	3.00	3.30
	Average	0.90	1.73	3.29	3.73
>8.0	Sikarali	3.10	3.70	4.24	4.80
	Malgoan (b)	1.60	3.50	4.09	5.00
	Mangalpura	1.70	4.58	9.33	7.20
	Dujar (b)	2.00	3.90	5.16	5.50
	Maximum	3.10	4.58	9.33	7.20
	Minimum	1.60	3.50	4.09	4.80
	Average	2.10	3.92	5.71	5.63

0.23 to 0.79 me L⁻¹, 0.95 to 2.90 me L⁻¹, 0.58 to 2.38 me L⁻¹, 0.90 to 3.29 me L⁻¹ and 2.10 to 5.71 me L⁻¹ form first to second year in the fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. At harvest also RSC of groundwater increased from 0.55 to 1.15 me L⁻¹, 1.61 to 3.48 me L⁻¹, 1.72 to 3.03 me L⁻¹, 1.73 to 3.73 me L⁻¹, and 3.92 to 5.63 me L⁻¹ form first year to second year, in fluoride category < 2.0 mg L⁻¹, 2.1-4.0 mg L⁻¹, 4.1-6.0 mg L⁻¹, 6.1-8.0 mg L⁻¹ and > 8.0 mg L⁻¹, respectively. The maximum RSC of 3.10 me L⁻¹ was observed at Sikarali in fluoride category of > 8.0 me L⁻¹ and 9.33 me L⁻¹ at Mangalpura in fluoride category of > 8.0 mg L⁻¹ during first and second year at sowing and 4.90 was observed at Baladoo (a) in fluoride category of 4.1-6.0 mg L⁻¹ and 7.20 at Mangalpura in fluoride category of > 8.0 mg L⁻¹ during first and second year at harvest. The minimum RSC of 0.10 me L⁻¹ was observed at Ratau (c) during first year, while 0.50 me L⁻¹ was observed at Genana (b) during second year at sowing and both were falls under fluoride category of < 2 mg L⁻¹ and 0.40 me L⁻¹ was observed at Ratau (c) in fluoride category of < 2.0 mg L⁻¹ during first year, while 0.70 was observed at Genana (b) in fluoride category of > 2.0 mg L⁻¹ during second year at harvest.

Further, perusal of data for both the years (Table 4.23) clearly indicates that there is an increase with RSC of water with an increase in groundwater fluoride categories. Since, the aqueous ionic concentration of groundwater mainly influences the fluoride solubility, therefore presence of excessive sodium bicarbonates in high RSC waters, might have enhanced the dissociation activity of fluoride i.e, $\text{CaF}_2 + 2\text{NaHCO}_3 \rightarrow \text{CaCO}_3 + 2\text{Na} + 2\text{F} + \text{H}_2\text{O} + \text{CO}_2$ and there by high fluoride. Results of Mehta (1970), Singh *et al.* (1995), Prasad *et al.* (1996), Singh and Singh (1997), Oswal (1999), Ram (2003), Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013) are also in confirmation to present results.

4.4.2.6 Sodium Adsorption Ratio (SAR)

Data regarding variation in SAR of groundwaters under different categories of fluoride, during the study period are presented in table 4.24. Data revealed that average SAR of groundwater of at sowing changed from 9.78 to 9.40, 11.05 to 11.42, 11.32 to 12.48, 15.71 to 15.87 and 20.95 to 22.60 me L^{-1} from first year to second year, in fluoride category $< 2.0 \text{ mg L}^{-1}$, 2.1-4.0 mg L^{-1} , 4.1-6.0 mg L^{-1} , 6.1-8.0 mg L^{-1} and $> 8.0 \text{ mg L}^{-1}$, respectively. At harvest also SAR of groundwater changed from 9.47 to 12.96, 11.75 to 12.61, 12.12 to 12.57, 15.73 to 16.06 and 22.40 to 22.38 me L^{-1} from first year to second year with the change in fluoride category $< 2.0 \text{ mg L}^{-1}$, 2.1-4.0 mg L^{-1} , 4.1-6.0 mg L^{-1} , 6.1-8.0 mg L^{-1} and $> 8.0 \text{ mg L}^{-1}$, respectively. The maximum SAR of 28.87 me L^{-1} and 28.83 me L^{-1} was recorded at Malgoan (b) in $> 8.0 \text{ mg L}^{-1}$ category of fluoride were observed during first and second year at sowing and 27.74 and 27.14 me L^{-1} SAR was observed at Bakolia (c) in fluoride category of 6.1 to 8.0 mg L^{-1} during first and second year at harvest. At sowing the minimum SAR of 7.49 me L^{-1} was observed at Dujar (c) during first year in 6.1 to 8.0 mg L^{-1} fluoride category, while 8.95 me L^{-1} at Ratau (a) during second year, in fluoride category of $< 2.0 \text{ mg L}^{-1}$ and at harvest the minimum SAR of 8.42 me L^{-1} was observed at Bakolia (b) during first year in 6.1-8.0 mg L^{-1} fluoride category, while 8.90 me L^{-1} at Dujar (c) during second year, in fluoride category of 6.1 to 8.0 mg L^{-1} .

Further, on perusal of data for both the years (Table 4.24), clearly indicates that there is an increase with water SAR values with an increase in groundwater fluoride categories. Under natural conditions high concentration of fluoride is usually attributed to more soluble fluoride salts such as NaF, KF and NH_4F , but at times other associated anions like CO_3 , HCO_3 and Cl etc. also influence the solubility behaviors of fluoride in water, therefore in the present case

Table 4.24: SAR of ground irrigation water under different fluoride categories

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		Sowing	Harvesting	Sowing	Harvesting
< 2.0	Ratau (a)	10.57	9.38	8.95	14.46
	Ratau (c)	8.49	8.81	9.02	13.32
	Genana (b)	9.17	9.64	9.48	12.16
	Audint (c)	10.89	10.05	10.16	11.92
	Maximum	10.89	10.05	10.16	14.46
	Minimum	8.49	8.81	8.95	11.92
	Average	9.78	9.47	9.40	12.96
2.1 – 4.0	Sandas (b)	8.61	8.58	9.49	10.43
	Jhardia (c)	11.96	11.57	9.73	12.11
	Lukas (a)	13.83	15.80	15.26	16.33
	Lukas (b)	9.79	11.04	11.19	11.58
	Maximum	13.83	15.80	15.26	16.33
	Minimum	8.61	8.58	9.49	10.43
	Average	11.05	11.75	11.42	12.61
4.1 – 6.0	Baladoo (a)	12.23	12.85	12.72	13.61
	Baladoo (b)	11.80	13.20	14.18	13.45
	Nimbi Jhodha (a)	12.22	12.00	11.90	12.19
	Nimbi Jhodha (b)	9.03	10.43	11.13	11.05
	Maximum	12.23	13.20	14.18	13.61
	Minimum	9.03	10.43	11.13	11.05
	Average	11.32	12.12	12.48	12.57
6.1 – 8.0	Natas (b)	20.38	18.87	18.38	19.37
	Dujar (c)	7.49	8.94	9.25	8.90
	Bakolia (b)	8.78	8.42	9.51	10.07
	Bakolia (c)	26.18	26.69	26.35	25.92
	Maximum	26.18	26.69	26.35	25.92
	Minimum	7.49	8.42	9.25	8.90
	Average	15.71	15.73	15.87	16.06
>8.0	Sikarali	23.19	23.85	24.63	22.91
	Malgoan (b)	28.87	27.74	28.83	27.14
	Mangalpura	21.04	24.51	24.50	24.17
	Dujar (b)	10.68	13.50	12.45	15.32
	Maximum	28.87	27.74	28.83	27.14
	Minimum	10.68	13.50	12.45	15.32
	Average	20.95	22.40	22.60	22.38

the relative concentration of anions might have altered the solubility of NaF. These findings are in close agreement to the observations of Paliwal and Maliwal (1971), Wapda (1974), Sharma and Mondal (1981), Ram (1996), Oswal (1999), Ram (2003), Gupta *et al.* (2006) Dave *et al.* (2010), Gautam *et al.* (2011) and Khan and Ravi Kumar (2013).

4.5 Evaluation of Soil fluoride buildup under wheat and mustard

4.5.1 Soil fluoride buildup under wheat crop

Data regarding soil fluoride build up after first and second year and total build up after completion of study period in wheat crop is presented in table 4.25 and fig. 4.9. Data revealed that the average soil fluoride build up in wheat crop varied from +0.13 to +1.36 mg kg⁻¹ and +0.29 to +1.36 mg kg⁻¹ during first and second years, respectively, under different fluoride categories. The maximum soil fluoride build up of +2.21 mg kg⁻¹ and +1.85 mg kg⁻¹ was recorded in fluoride category of > 8.0 me L⁻¹ during first and second year, respectively. The minimum soil fluoride build up of +0.11 mg kg⁻¹ and +0.14 mg kg⁻¹ was observed in < 2.0 mg L⁻¹ fluoride category during both the years.

Data regarding total soil fluoride build up after harvest of wheat crop during the study period (2007-08 and 2008-09) revealed that average total soil fluoride build up in varied from 0.32 to 2.11 mg kg⁻¹ in the different fluoride categories. The total soil build up varied from 0.20 to 0.47, 0.42 to 0.88, 0.59 to 1.01, 0.78 to 1.45 and 0.80 to 3.28 mg kg⁻¹ in fluoride category of < 2.0, 2.1-4.0, 4.1-6.0, 6.1-8.0 and > 8.0 mg L⁻¹, respectively. The maximum total soil build up of 3.28 mg kg⁻¹ was recorded in fluoride category of > 8.0 mg L⁻¹ while, the minimum of 0.20 mg kg⁻¹ was observed in fluoride category of < 2.0 mg L⁻¹.

Table 4.25 Build up of soil fluoride (mg kg^{-1}) under wheat crop irrigated with different categories of fluoride water

Fluoride (mg L^{-1}) category	Village name	First year			Second year			Build up (Two years)
		S*	H*	Build up	S*	H*	Build up	
< 2.0	Ratau (a)	0.12	0.24	+ 0.12	0.22	0.36	+ 0.14	0.24
	Ratau (c)	0.56	0.71	+ 0.15	0.67	0.91	+ 0.34	0.35
	Genana (b)	0.37	0.54	+ 0.17	0.43	0.84	+ 0.41	0.47
	Audint (c)	0.58	0.69	+ 0.11	0.51	0.78	+ 0.27	0.20
	Average	0.40	0.54	+ 0.13	0.45	0.72	+0.29	0.32
2.1 – 4.0	Sandas (b)	0.54	0.67	+ 0.13	0.49	0.96	+ 0.47	0.42
	Jhardia (c)	0.58	0.83	+ 0.25	0.62	1.10	+ 0.48	0.52
	Lukas (a)	0.31	0.72	+ 0.41	0.57	1.03	+ 0.50	0.72
	Lukas (b)	0.61	0.86	+ 0.25	0.83	1.49	+ 0.66	0.88
	Average	0.51	0.77	+0.26	0.62	1.14	+0.52	0.63
4.1 – 6.0	Baladoo (a)	0.35	0.79	+ 0.44	0.46	0.95	+ 0.49	0.60
	Baladoo (b)	0.51	0.90	+ 0.39	0.54	1.10	+ 0.56	0.59
	Nimbi Jhodha (a)	0.19	0.50	+ 0.31	0.41	1.05	+ 0.64	0.86
	Nimbi Jhodha (b)	0.64	0.97	+ 0.33	0.81	1.65	+ 0.84	1.01
	Average	0.42	0.79	+0.36	0.55	1.18	+0.63	0.76
6.1 – 8.0	Natas (b)	0.13	0.54	+ 0.41	0.49	0.96	+ 0.47	0.83
	Dujar (c)	0.57	0.93	+ 0.36	0.77	1.35	+ 0.58	0.78
	Bakolia (b)	0.56	1.12	+ 0.56	0.79	1.66	+ 0.87	1.10
	Bakolia (c)	0.87	1.21	+ 0.34	1.12	2.32	+ 1.20	1.45
	Average	0.53	0.95	+0.41	0.79	1.57	+0.78	1.04
>8.0	Sikarali	0.97	3.18	+ 2.21	2.46	4.25	+ 1.79	3.28
	Malgoan (b)	0.64	1.59	+ 0.95	0.49	2.81	+ 1.85	2.17
	Mangalpura	0.51	1.13	+ 0.62	0.66	1.31	+ 0.65	0.80
	Dujar (b)	0.65	2.34	+ 1.69	1.67	2.84	+ 1.17	2.19
	Average	0.69	2.06	+1.36	1.32	2.80	+1.36	2.11

S* = Sowing, H* = Harvesting

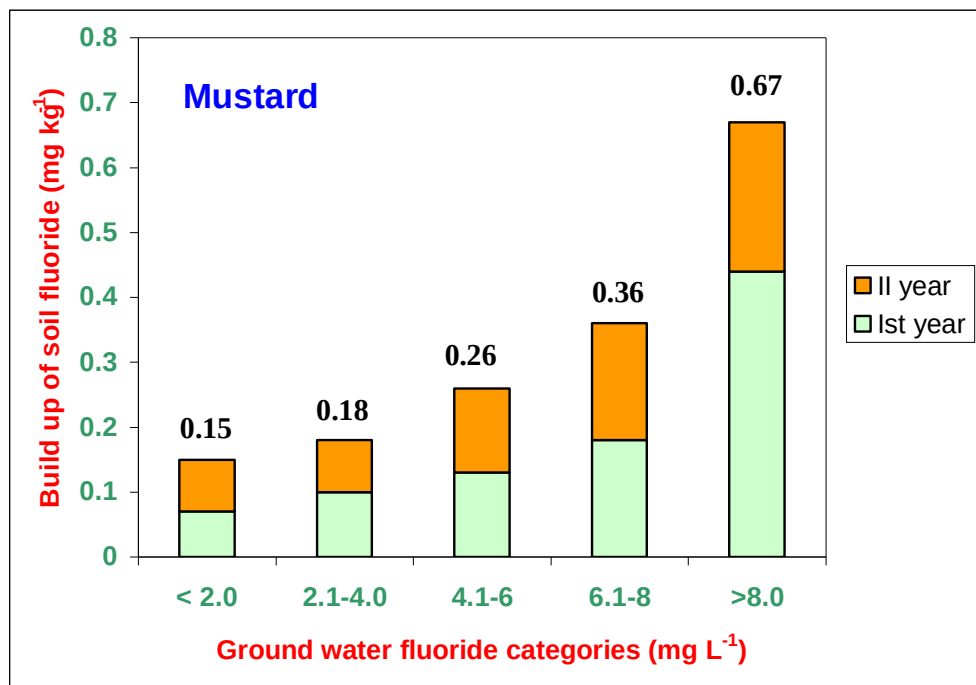
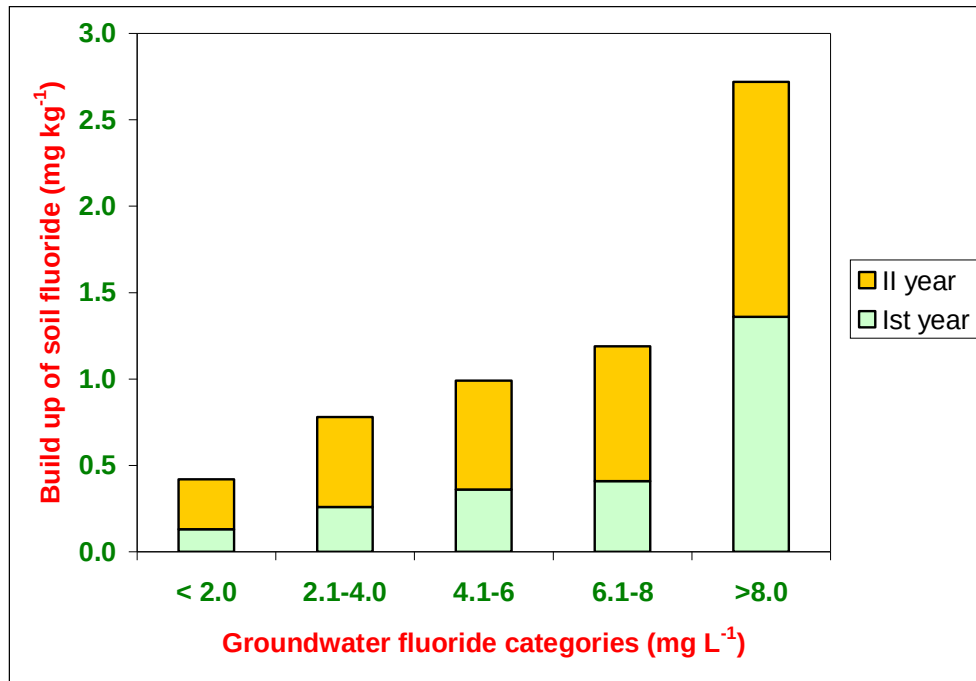
4.5.2 Soil fluoride buildup under mustard crop

Data regarding soil fluoride build up after first and second year and total build up after completion of study period in mustard crop is presented in table 4.26 and fig. 4.9. Data revealed that the average soil fluoride build up in mustard crop varied from +0.07 to +0.44 mg kg⁻¹ and +0.08 to +0.23 mg kg⁻¹ during the first and second years, respectively, under different fluoride categories. The maximum soil fluoride build up of +0.84 mg kg⁻¹ and +0.27 mg kg⁻¹ was observed in fluoride category of > 8.0 mg L⁻¹ during first and second year, respectively. The minimum soil fluoride build up of +0.07 mg kg⁻¹ in < 2.0 mg L⁻¹ fluoride category during first year and +0.06 mg kg⁻¹ in < 2.0 mg L⁻¹ and 2.1 to 4.0 mg L⁻¹ fluoride category during second year.

Data regarding total soil fluoride build up after harvest of mustard crop during the study period (2007-08 and 2008-09) revealed that average total soil fluoride build up in mustard crop varied from 0.12 to 0.49 mg kg⁻¹ in the different soil fluoride categories. In different soil fluoride categories the total soil build up varied from 0.09 to 0.16, 0.12 to 0.20, 0.21 to 0.26, 0.28 to 0.34 and 0.38 to 0.65 mg kg⁻¹ in fluoride category of < 2.0, 2.1-4.0, 4.1-6.0, 6.1-8.0 and > 8.0 mg L⁻¹, respectively. The maximum total soil build up of 0.65 mg kg⁻¹ was recorded in fluoride category of > 8.0 mg L⁻¹ while, the minimum total soil build up of 0.09 mg L⁻¹ was observed in fluoride category of < 2.0 mg L⁻¹.

4.6 Impact of different categories of fluoride waters on quality of wheat and mustard

Plants grown under high fluoride condition may suffer due to interference in the availability and uptake of essential plant nutrients. In addition, the high fluoride concentration in the soils or waters may affect certain physiological processes in plants, which ultimately affects the quality of the crops.



*Figures above bars represent total build up

Fig. 4.9 : Build up of soil fluoride (mg kg⁻¹) under wheat and mustard crops irrigated with different categories of fluoride water

Table 4.26 Build up of soil fluoride (mg kg⁻¹) under mustard crop irrigated with different categories of fluoride water

Fluoride (mg L ⁻¹) category	Village name	First year			Second year			Build up (Two years)
		S*	H*	Build up	S*	H*	Build up	
< 2.0	Ratau (a)	0.12	0.20	+ 0.08	0.18	0.28	+ 0.10	0.16
	Ratau (c)	0.56	0.65	+ 0.09	0.60	0.67	+ 0.07	0.11
	Genana (b)	0.37	0.44	+ 0.07	0.40	0.46	+ 0.06	0.09
	Audint (c)	0.58	0.65	+ 0.07	0.60	0.70	+ 0.10	0.12
	Average	0.40	0.48	+0.07	0.44	0.52	+0.08	0.12
2.1 – 4.0	Sandas (b)	0.54	0.62	+ 0.08	0.60	0.66	+ 0.06	0.12
	Jhardia (c)	0.58	0.70	+ 0.12	0.66	0.74	+ 0.08	0.16
	Lukas (a)	0.31	0.39	+ 0.09	0.37	0.46	+ 0.09	0.15
	Lukas (b)	0.61	0.72	+ 0.11	0.70	0.81	+ 0.11	0.20
	Average	0.51	0.60	+0.10	0.58	0.51	+0.08	0.18
4.1 – 6.0	Baladoo (a)	0.35	0.46	+ 0.11	0.42	0.56	+ 0.14	0.21
	Baladoo (b)	0.51	0.65	+ 0.14	0.63	0.75	+ 0.12	0.24
	Nimbi Jhodha (a)	0.19	0.33	+ 0.14	0.31	0.45	+ 0.14	0.26
	Nimbi Jhodha (b)	0.64	0.80	+ 0.16	0.76	0.90	+ 0.14	0.26
	Average	0.42	0.56	+0.13	0.53	0.66	+0.13	0.24
6.1 – 8.0	Natas (b)	0.13	0.30	+ 0.17	0.27	0.45	+ 0.18	0.32
	Dujar (c)	0.57	0.73	+ 0.16	0.68	0.85	+ 0.17	0.28
	Bakolia (b)	0.56	0.75	+ 0.18	0.71	0.90	+ 0.19	0.34
	Bakolia (c)	0.87	1.10	+ 0.23	1.00	1.21	+ 0.21	0.34
	Average	0.53	0.72	+0.18	0.66	0.85	+0.18	0.32
>8.0	Sikarali	0.97	1.21	+ 0.24	1.15	1.35	+ 0.20	0.38
	Malgoan (b)	0.64	0.90	+ 0.26	0.85	1.07	+ 0.22	0.43
	Mangalpura	0.51	0.85	+ 0.84	0.80	1.03	+ 0.23	0.52
	Dujar (b)	0.65	1.10	+ 0.45	1.07	1.30	+ 0.27	0.65
	Average	0.69	1.01	+0.44	0.96	1.18	+0.23	0.49

S* = Sowing, H* = Harvesting

4.6.1 Impact on wheat quality parameters

Fluoride occurs naturally in plants, but its concentration increases due to increase of fluoride content in the environment i.e. soil, water and atmosphere. Accumulation of fluoride in plant system varies with the plant species. Therefore, results obtained for quality parameters studied for wheat and mustard are presented, separately.

4.6.1.1 Wheat quality parameters at 30 DAS

Fluoride

Data regarding average fluoride content of wheat recorded at 30 DAS are presented in table 4.27 and fig. 4.10. Data revealed that average fluoride content of wheat at 30 DAS varied from 10.08 to 17.40 mg kg⁻¹ and 13.65 to 20.78 mg kg⁻¹ from first and second year, respectively in all the categories of groundwater fluoride. Further, as expected the maximum fluoride content of 18.60 mg kg⁻¹ was observed at Malgoan (b) village and 22.40 mg kg⁻¹ at Dujar (b) village in fluoride category > 8.0 mg L⁻¹ during first and second year, respectively. Similarly, the minimum fluoride content of 9.40 mg kg⁻¹ was observed at Audint (c) village and 10.30 mg kg⁻¹ was observed at Genana (b) village in fluoride category < 2.0 mg L⁻¹ during first and second year. An attempt has also been made to see the relationship of fluoride content in wheat plant with fluoride in water and soil (Table 4.28). From the table 4.28 is quite clear that a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Further, perusal of data in table 4.27 and fig. 4.10 clearly indicates that there is an increase in the fluoride content of plants from first year to second year in all the categories of groundwater fluoride. Increase in the concentration of cations (Table 4.16) particularly

**Table: 4.27 Fluoride and chlorophyll content of wheat at 30 DAS
irrigated with different fluoride waters**

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		F (mg kg ⁻¹)	Chlorophyll (mg g ⁻¹)	F (mg kg ⁻¹)	Chlorophyll (mg g ⁻¹)
< 2.0	Ratau (a)	11.10	1.84	16.20	1.97
	Ratau (c)	10.00	2.13	14.40	2.06
	Genana (b)	9.80	1.96	10.30	1.93
	Audint (c)	9.40	2.17	13.70	2.03
	Maximum	11.10	2.17	16.20	2.06
	Minimum	9.40	1.84	10.30	1.93
	Average	10.08	2.03	13.65	2.00
2.1 – 4.0	Sandas (b)	13.00	2.02	17.20	2.01
	Jhardia (c)	11.20	1.87	14.80	1.98
	Lukas (a)	12.30	1.92	15.60	1.81
	Lukas (b)	10.10	2.06	14.80	2.06
	Maximum	13.00	2.06	17.20	2.06
	Minimum	10.10	1.87	14.80	1.81
	Average	11.65	1.97	15.60	1.97
4.1 – 6.0	Baladoo (a)	11.50	2.12	16.80	1.93
	Baladoo (b)	12.60	1.93	18.30	1.96
	Nimbi Jhodha (a)	13.40	1.81	19.30	1.89
	Nimbi Jhodha (b)	18.30	1.96	15.20	2.02
	Maximum	18.30	2.12	19.30	2.02
	Minimum	11.50	1.81	15.20	1.89
	Average	13.95	1.96	17.40	1.95
6.1 – 8.0	Natas (b)	12.80	1.81	17.80	1.83
	Dujar (c)	14.50	1.92	18.40	2.01
	Bakolia (b)	15.30	1.93	22.10	1.99
	Bakolia (c)	17.80	1.83	20.60	1.82
	Maximum	17.80	1.93	22.10	2.01
	Minimum	12.80	1.81	17.80	1.82
	Average	15.10	1.87	19.73	1.91
>8.0	Sikarali	17.20	1.84	21.50	1.92
	Malgoan (b)	18.60	1.90	18.40	1.89
	Mangalpura	16.10	1.76	20.80	1.87
	Dujar (b)	17.70	1.76	22.40	1.78
	Maximum	18.60	1.90	22.40	1.92
	Minimum	16.10	1.76	18.40	1.78
	Average	17.40	1.82	20.78	1.87

Table 4.28 : Relationship of fluoride in wheat plant with water and soil

S.No.	Particulars	Equation	r	R ²
1.	Wheat at 30 DAS			
	Relationship of plant fluoride with water and soil fluoride			
	First year	$Y = 6.951 + 0.823 \text{ Water (F)} + 3.10 \text{ Soil (F)}$	0.871**	0.758
	Second year	$Y = 11.953 + 0.914 \text{ Water (F)} + 0.406 \text{ Soil (F)}$	0.817**	0.668
	Pooled	$Y = 9.465 + 0.776 \text{ Water (F)} + 1.773 \text{ Soil (F)}$	0.796**	0.634
2.	Wheat at Harvest			
	Relationship of fluoride in straw with water and soil fluoride			
	First year	$Y = 9.811 + 0.349 \text{ Water (F)} + 3.062 \text{ Soil (F)}$	0.676**	0.457
	Second year	$Y = 11.099 + 0.204 \text{ Water (F)} + 1.465 \text{ Soil (F)}$	0.803**	0.646
	Pooled	$Y = 11.00 + 0.381 \text{ Water (F)} + 1.038 \text{ Soil (F)}$	0.705**	0.497
3.	Wheat at Harvest			
	Relationship of fluoride in grain with water and soil fluoride			
	First year	$Y = 1.287 + 0.0396 \text{ Water (F)} + 0.313 \text{ Soil (F)}$	0.699**	0.489
	Second year	$Y = 1.434 + 0.0327 \text{ Water (F)} + 0.121 \text{ Soil (F)}$	0.759**	0.576
	Pooled	$Y = 1.416 + 0.0450 \text{ Water (F)} + 0.0911 \text{ Soil (F)}$	0.712**	0.507

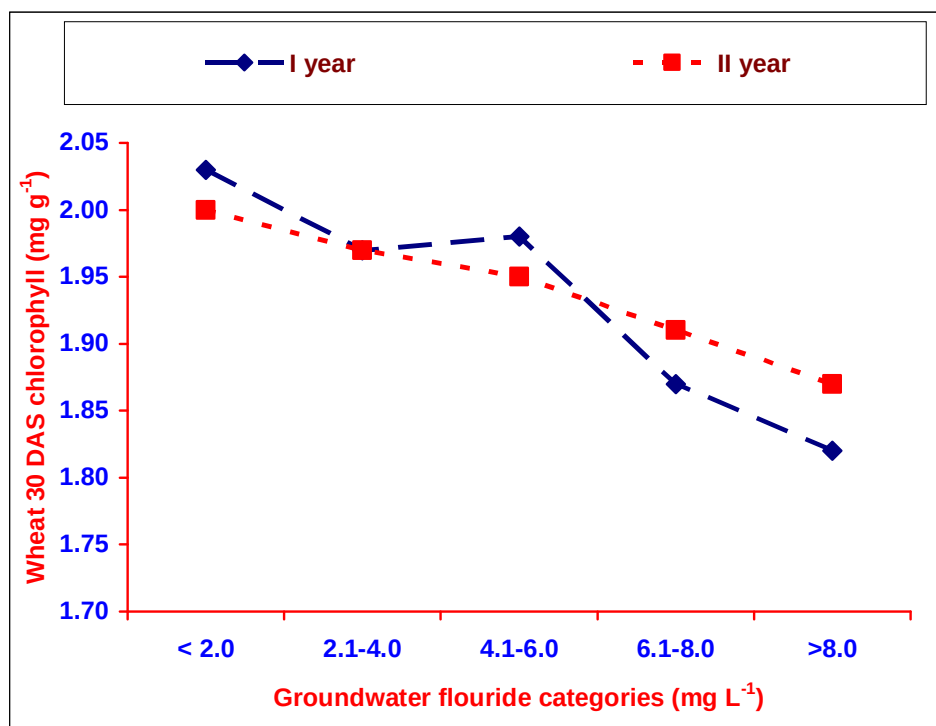
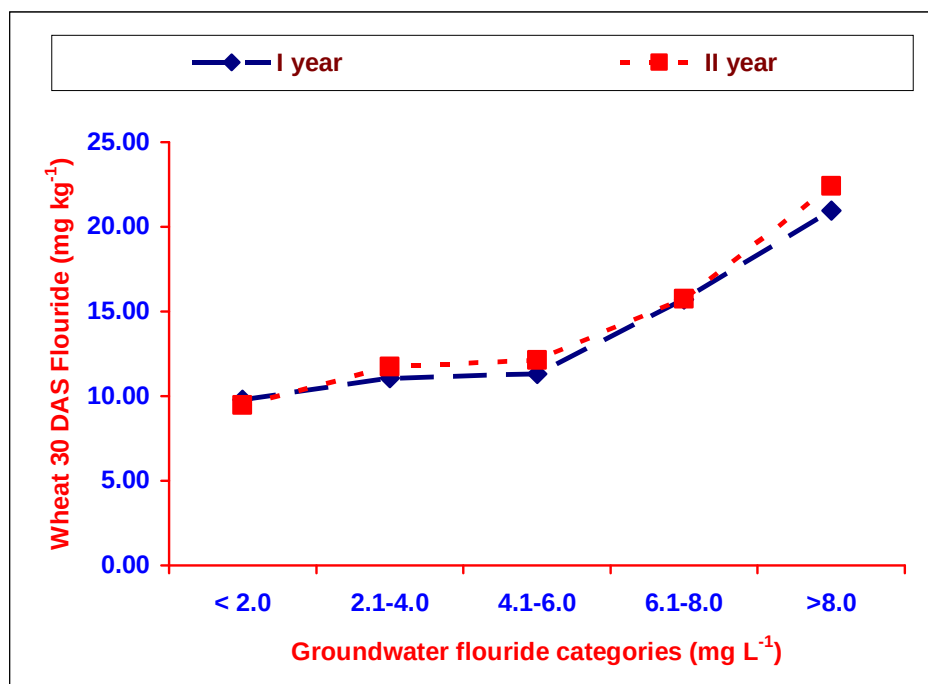


Fig. 4.10 : Fluoride and chlorophyll content of wheat at 30 DAS irrigated with different fluoride waters

sodium (Table 4.17) from first year to second year, in soil as well as in water might have helped in fluoride diffusion in early phases, possibly due to formation of the mobile fluoro-sodium complexes, thereby by higher fluoride content in plants, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Chlorophyll

Data on average chlorophyll content of wheat leaves at 30 DAS for both the years of study are presented in table 4.27 and fig. 4.10. An examination of data (Table 4.27) revealed that average chlorophyll content in wheat leaves at 30 DAS varied from 1.82 to 2.03 mg g⁻¹ and 1.87 to 2.00 mg g⁻¹ during first and second year, respectively with all the categories of groundwater fluoride. Data also revealed that the maximum chlorophyll content of 2.17 mg g⁻¹ was observed at Audint (c) village in fluoride category < 2.0 mg L⁻¹ during first year and 2.06 mg g⁻¹ at Ratau (c) and Lukas (b) villages during second year. The minimum chlorophyll content of 1.76 mg g⁻¹ was observed at Mangalpura and Dujar (b) villages in fluoride category > 8.0 mg L⁻¹ during first year and 1.78 mg g⁻¹ was recorded at Dujar (b) village in fluoride category > 8.0 mg L⁻¹ during second year.

Further, perusal of data for both the years in table 4.27 and fig. 4.10 clearly exhibit that there is decrease in chlorophyll content of wheat leaves with an increase in groundwater fluoride. Plants sensitivity to fluoride pollution is variable, but certain physiological processes are known to be markedly affected by fluoride, like decreased plant growth, chlorosis and decrease in chlorophyll. Since chloroplasts are the site of most of the fluoride accumulation, hence that might have caused decrease in chlorophyll content with the increase fluoride content of plant. Similar type of observation are also

reported by Newman (1961), Chang and Thompson (1966), Holub (1975), Maclean *et al.* (1976), Rathore (1987), Singh *et al.* (2001),

Nitrogen

Data on average nitrogen content of wheat plant at 30 DAS are presented in table 4.29. Data (Table 4.29) showed that average nitrogen content varied from 1.41 to 1.48 per cent and 1.38 to 1.49 per cent during first and second years, respectively in all categories of groundwater fluoride. Data also evidently show that the maximum nitrogen content of 1.63 per cent was observed at Lukas (a) village in fluoride category 2.1 to 4.0 mg L⁻¹ during first year and 1.78 per cent at Genana (b) village in < 2.0 mg L⁻¹ in fluoride category during second year. The minimum nitrogen content of 1.19 per cent was observed at Audint (c) village in < 2.0 mgL⁻¹ fluoride category during first year, while 1.21 per cent was observed at Bakolia (c) village in 6.1 to 8.0 mg L⁻¹ fluoride category during second year.

Further, critical examination of data for both the years in table 4.29 clearly indicates that there is no definite trend found in nitrogen content of plant with the an increase in groundwater fluoride. The published literature suggests that some physiological processes are less susceptible to fluoride concentration and nitrogen metabolism might be one of them. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Phosphorus

Average phosphorus content in wheat plant at 30 DAS during both the years of study under all the categories of groundwater fluoride is given in table 4.29. A perusal of data (Table 4.29) revealed that average phosphorus content in wheat plant at 30 DAS varied from 0.33 to 0.46 per cent and 0.32 to 0.44 per cent during first and second

**Table 4.29: Nitrogen, phosphorus and potassium content of wheat
at 30 DAS irrigated with different fluoride waters**

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		N %	P %	K%	N %	P %	K%
< 2.0	Ratau (a)	1.46	0.52	1.39	1.45	0.43	1.36
	Ratau (c)	1.36	0.45	1.31	1.37	0.49	1.31
	Genana (b)	1.72	0.39	1.42	1.78	0.41	1.39
	Audint (c)	1.19	0.48	1.29	1.31	0.43	1.43
	Maximum	1.72	0.52	1.42	1.78	0.49	1.43
	Minimum	1.19	0.39	1.29	1.31	0.41	1.31
	Average	1.43	0.46	1.35	1.48	0.44	1.37
2.1 – 4.0	Sandas (b)	1.34	0.42	1.31	1.37	0.32	1.46
	Jhardia (c)	1.45	0.39	1.25	1.47	0.37	1.29
	Lukas (a)	1.63	0.41	1.37	1.65	0.40	1.36
	Lukas (b)	1.43	0.52	1.29	1.47	0.49	1.21
	Maximum	1.63	0.52	1.37	1.65	0.49	1.46
	Minimum	1.34	0.39	1.25	1.37	0.32	1.21
	Average	1.46	0.44	1.31	1.49	0.40	1.33
4.1 – 6.0	Baladoo (a)	1.53	0.45	1.31	1.38	0.41	1.49
	Baladoo (b)	1.37	0.37	1.21	1.51	0.43	1.33
	Nimbi Jhodha (a)	1.48	0.43	1.29	1.47	0.32	1.26
	Nimbi Jhodha (b)	1.54	0.40	1.34	1.37	0.37	1.29
	Maximum	1.54	0.45	1.34	1.51	0.43	1.49
	Minimum	1.37	0.37	1.21	1.37	0.32	1.26
	Average	1.48	0.41	1.29	1.43	0.38	1.34
6.1 – 8.0	Natas (b)	1.52	0.38	1.29	1.59	0.47	1.37
	Dujar (c)	1.43	0.32	1.23	1.29	0.38	1.31
	Bakolia (b)	1.23	0.46	1.21	1.43	0.27	1.27
	Bakolia (c)	1.45	0.28	1.29	1.21	0.29	1.29
	Maximum	1.52	0.46	1.29	1.59	0.47	1.37
	Minimum	1.23	0.28	1.21	1.21	0.27	1.27
	Average	1.41	0.36	1.26	1.38	0.35	1.31
>8.0	Sikarali	1.39	0.35	1.22	1.49	0.31	1.25
	Malgoan (b)	1.47	0.33	1.20	1.45	0.36	1.27
	Mangalpura	1.53	0.32	1.19	1.56	0.27	1.41
	Dujar (b)	1.34	0.30	1.20	1.42	0.34	1.23
	Maximum	1.53	0.35	1.22	1.56	0.36	1.41
	Minimum	1.34	0.30	1.19	1.42	0.27	1.23
	Average	1.43	0.33	1.20	1.48	0.32	1.29

years, respectively in all the categories of groundwater fluoride. Data in table also shows that the maximum phosphorus content of 0.52 and 0.49 per cent was observed at Ratau (a) and Lukas (b) villages in $< 2.0 \text{ mg L}^{-1}$ and $2.1 \text{ to } 4.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum phosphorus content of 0.28 per cent was observed at Bakolia (c) village in $6.1 \text{ to } 8.0 \text{ mg L}^{-1}$ fluoride category during first year, while 0.27 per cent was observed at Bakolia (b) and Mangalpura villages in $6.1 \text{ to } 8.0 \text{ mg L}^{-1}$ and $> 8.0 \text{ mg L}^{-1}$ category of fluoride during second year.

A critical examination of data in table 4.29 amply shows that there is continuous decrease in phosphorus content of wheat plant at 30 DAS with the successive increase in groundwater fluoride. The fluoride content of wheat decreased from 0.46 per cent to 0.44, 0.41, 0.36 and 0.33 per cent during first year and from 0.44 to 0.40, 0.38, 0.35 and 0.32 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0$, $4.1\text{-}6.0$, $6.1\text{-}8.0$ and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compared to first year there is decrease in average phosphorus content of wheat during second year in all the categories of groundwater fluoride. Although, no much studies have been done on biochemical aspects of wheat as affected by fluoride content but decrease in phosphorus content of wheat with increase in fluoride content could be ascribed to fluoride induced inhibition of inorganic pyro-phosphatase and oxidation of free acids. Results obtained by Prince *et al.* (1949), Singh *et al.* (1979a), Rathore (1987), Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in line of the present observations.

Potassium

Data regarding average potassium content of wheat plant taken at 30 DAS are presented in table 4.29. The average potassium content

in wheat at 30 DAS varied from 1.20 to 1.35 per cent and 1.29 to 1.37 per cent during first and second year, respectively in all the categories of groundwater fluoride. Data further revealed that maximum potassium content of 1.42 per cent was observed at Genana (b) village in < 2.0 mg L⁻¹ fluoride category during first year and 1.49 per cent was recorded at Baladoo (a) village in 4.1 to 6.0 mg L⁻¹ fluoride category, during second year. The minimum potassium content 1.19 per cent was observed at Mangalpura village in > 8.0 mg L⁻¹ fluoride category during first year, while 1.21 per cent was observed at Lukas (b) village in 2.1 to 4.0 mg L⁻¹ fluoride category, during second year.

Further, perusal of data for both the years presented in table 4.29 clearly indicates that there is decrease in potassium content with an increase in groundwater fluoride categories. The fluoride content of wheat decreased from 1.35 per cent to 1.31, 1.29, 1.26 and 1.20 per cent during first year and from 1.37 to 1.33, 1.34, 1.31 and 1.29 per cent during second year, with the successive increase in groundwater fluoride category from < 2.0 mg L⁻¹ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and > 8.0 mg L⁻¹, respectively. Decrease in potassium content of wheat with the increase in fluoride, might be related to alteration in permeability of membranes and reduced respiration. Findings of Rathore (1987). Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006), Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in accordance with results of present investigation.

4.6.1.2 Wheat quality parameters at harvest

Fluoride in straw

Data on average fluoride content of wheat at harvest are presented in table 4.30 and fig. 4.11. Data revealed that average fluoride content in wheat at harvest varied from 11.70 to 16.35 mg kg⁻¹ and 11.85 to 16.73 mg kg⁻¹ during first and second year, respectively. Data also revealed that the maximum fluoride content of 18.70 mg kg⁻¹

Table 4.30: Fluoride in grain and straw and protein content in wheat at harvest irrigated with different fluoride waters

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		F (mg kg ⁻¹)		Protein (%)	F (mg kg ⁻¹)		Protein (%)
		Straw	Grain		Straw	Grain	
< 2.0	Ratau (a)	12.70	1.56	9.38	11.40	1.58	9.06
	Ratau (c)	13.40	1.61	9.06	14.20	1.64	8.75
	Genana (b)	10.50	1.36	10.94	11.10	1.41	10.50
	Audint (c)	10.20	1.32	9.19	10.70	1.36	8.81
	Maximum	13.40	1.61	10.94	14.20	1.64	10.50
	Minimum	10.20	1.32	9.06	10.70	1.36	8.75
	Average	11.70	1.46	9.64	11.85	1.50	9.28
2.1 – 4.0	Sandas (b)	15.20	1.87	9.31	14.90	1.88	9.13
	Jhardia (c)	11.70	1.53	9.56	12.30	1.59	9.31
	Lukas (a)	13.40	1.71	10.50	14.20	1.75	10.25
	Lukas (b)	15.30	1.89	9.94	15.60	1.93	9.81
	Maximum	15.30	1.89	10.50	15.60	1.93	10.25
	Minimum	11.70	1.53	9.31	12.30	1.59	9.13
	Average	13.90	1.75	9.83	14.25	1.79	9.63
4.1 – 6.0	Baladoo (a)	12.50	1.58	9.81	12.60	1.63	9.44
	Baladoo (b)	13.80	1.72	9.94	14.10	1.78	9.56
	Nimbi Jhodha (a)	16.10	1.96	9.56	16.30	1.98	9.19
	Nimbi Jhodha (b)	15.30	1.84	9.38	15.70	1.93	8.94
	Maximum	16.10	1.96	9.94	16.30	1.98	9.56
	Minimum	12.50	1.58	9.38	12.60	1.63	8.94
	Average	14.43	1.78	9.67	14.68	1.83	9.28
6.1 – 8.0	Natas (b)	12.50	1.61	10.25	12.90	1.65	9.88
	Dujar (c)	14.90	1.86	9.94	15.40	1.92	9.63
	Bakolia (b)	13.40	1.69	9.25	13.70	1.75	8.81
	Bakolia (c)	17.50	2.11	10.50	16.90	2.17	10.06
	Maximum	17.50	2.11	10.50	16.90	2.17	10.06
	Minimum	12.50	1.61	9.25	12.90	1.65	8.81
	Average	14.58	1.82	9.98	14.73	1.87	9.59
>8.0	Sikarali	18.70	2.16	9.25	18.90	2.19	8.88
	Malgoan (b)	15.20	1.79	9.50	15.60	1.81	9.13
	Mangalpura	14.80	1.87	10.56	15.30	1.94	10.19
	Dujar (b)	16.70	2.08	9.13	17.10	2.14	8.81
	Maximum	18.70	2.16	10.56	18.90	2.19	10.19
	Minimum	14.80	1.79	9.13	15.30	1.81	8.81
	Average	16.35	1.98	9.61	16.73	2.02	9.25

and 18.90 mg kg^{-1} was observed at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year, respectively. Similarly, the minimum fluoride content of 10.20 mg kg^{-1} and 10.70 mg kg^{-1} was observed at Audint (c) village in fluoride category $< 2.0 \text{ mg L}^{-1}$ during first and second year. An attempt has also been made to see the relationship of fluoride content in wheat plant with fluoride in water and soil (Table 4.28). From the table 4.28 it is quite clear that a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Further, perusal of data in table 4.30 and fig. 4.11 clearly indicates that there is an increase in the fluoride content of plant from first year to second year in all the categories of groundwater fluoride. Increase in the concentration of cations (Table 4.16) particularly sodium (Table 4.17) from first year to second year, in soil as well as in water might have helped in both fluoride diffusion in early phases, possibly due to formation of the mobile fluoro-sodium complexes, which ultimately resulted in higher fluoride content in plant during second year, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Fluoride in grain

Data on average fluoride content of wheat grain are presented in table 4.30 and fig. 4.11. The average fluoride content in wheat grain varied from 1.46 to 1.98 mg kg^{-1} and 1.50 to 2.02 mg kg^{-1} during first and second year, respectively. The maximum fluoride content of 2.16 mg kg^{-1} and 2.19 mg kg^{-1} was observed at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year, respectively. Similarly, the minimum fluoride content of 1.32 mg kg^{-1} and 1.36 mg kg^{-1} was observed at Audint (c) village in fluoride category $< 2.0 \text{ mg L}^{-1}$ during first and second year. An attempt has also been made to see

the relationship of fluoride content in wheat grain with fluoride in water and soil (Table 4.28). From the table 4.28 it is quite clear that a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Further examination of data also revealed that with the successive increase in the groundwater fluoride, fluoride content in wheat grain also increased during both the years, but the increase was of higher magnitude during second year. Increase in wheat grain fluoride content could be ascribed to more availability of fluoride from water (Table 4.19) and soil (Table 4.11) possibly due to formation of mobile fluoro-sodium complexes. There by higher fluoride content in plant during second year, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006), Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Protein

A critical examination of data (Table 4.30) revealed that average protein content in wheat grain varied from 9.61 to 9.98 and 9.25 to 9.63 per cent during first and second year, respectively. The maximum protein content of 10.94 per cent during first year and 10.50 per cent during second year was observed at Genana (b) village in $< 2.0 \text{ mg L}^{-1}$ fluoride category. The minimum protein content of 9.06 per cent and 8.75 per cent was observed at Ratau (c) village during first year and second year.

Further, perusal of data for both the years in table 4.30 clearly indicates that there is no definite trend observed in protein content with respect to increase in groundwater fluoride. This suggests that some physiological processes are less susceptible to fluoride concentration and nitrogen metabolism might be one of them. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

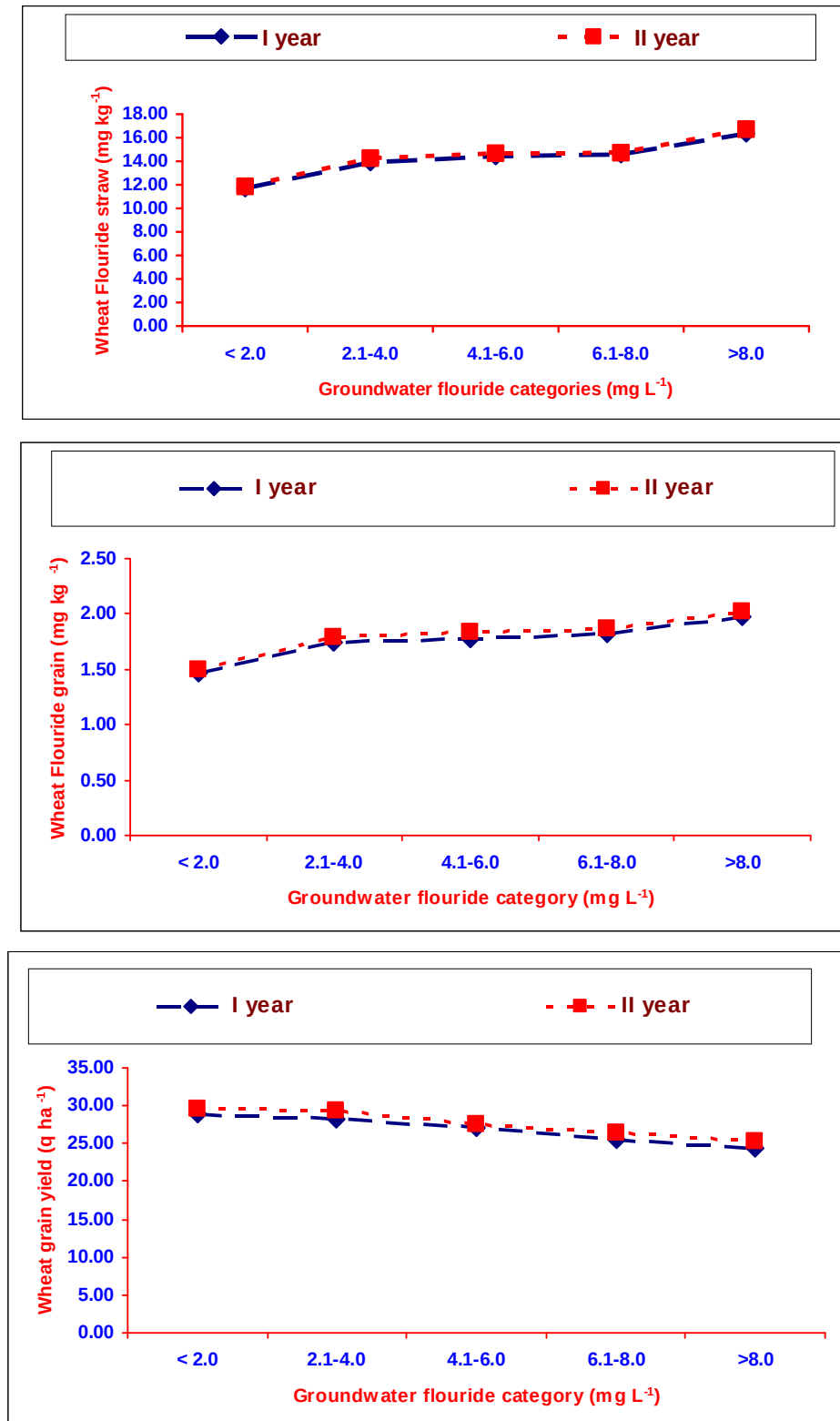


Fig. 4.11 : Fluoride content in wheat straw and grain as well as grain yield of wheat irrigated with different fluoride waters

Nitrogen

Data on average nitrogen content of wheat at harvest for both the years of study are presented in table 4.31. The average nitrogen content in wheat at harvest varied from 0.52 to 0.57 per cent and 0.54 to 0.59 per cent during first and second year, respectively. The maximum nitrogen content of 0.62 per cent was observed at Lukas (b) village in fluoride category 2.1 to 4.0 mg L⁻¹ during first year and 0.65 per cent at Dujar (b) village in fluoride category > 8.0 mg L⁻¹ during second year. The minimum nitrogen content of 0.48 per cent was observed at Audint (c), Nimbi Jhodha (a) and Bakolia (c) villages during first year and 0.51 per cent at Jhardia (c) and Nimbi Jhodha (b) villages in fluoride category 2.1 to 4.0 mg L⁻¹ and 4.1 to 6.0 mg L⁻¹ during second year.

Further, perusal of data for both the years in table 4.31 clearly indicates that there is no definite trend occurred in nitrogen content with respect to increase in groundwater fluoride. This might be less sensitiveness of nitrogen metabolism to fluoride concentration. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Phosphorus

Average phosphorus content in wheat at harvest during both the years of study under all the categories of groundwater fluoride is given in table 4.31 indicated that average phosphorus content in wheat at harvest varied from 0.19 to 0.25 per cent and 0.21 to 0.27 per cent during first and second year, respectively. The maximum phosphorus content of 0.28 and 0.31 per cent was observed at Ratau (c) village in fluoride category < 2.0 mg L⁻¹ during first and second year. The minimum phosphorus content of 0.17 per cent was observed at Malgoan (b) village in fluoride category > 8.0 mg L⁻¹ during first year and 0.19 per cent at Dujar (b) village in fluoride category > 8.0 mg L⁻¹ during second year.

Table 4.31: Nitrogen, phosphorus and potassium content in wheat at harvest irrigated with different fluoride waters

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
< 2.0	Ratau (a)	0.51	0.22	1.82	0.53	0.24	1.83
	Ratau (c)	0.55	0.28	1.64	0.52	0.31	1.67
	Genana (b)	0.53	0.24	1.73	0.58	0.27	1.76
	Audint (c)	0.48	0.25	1.72	0.52	0.25	1.71
	Maximum	0.55	0.28	1.82	0.58	0.31	1.83
	Minimum	0.48	0.22	1.64	0.52	0.24	1.67
	Average	0.52	0.25	1.73	0.54	0.27	1.74
2.1 – 4.0	Sandas (b)	0.56	0.21	1.69	0.58	0.23	1.69
	Jhardia (c)	0.52	0.23	1.72	0.51	0.27	1.72
	Lukas (a)	0.57	0.26	1.63	0.53	0.24	1.65
	Lukas (b)	0.62	0.20	1.71	0.58	0.26	1.74
	Maximum	0.62	0.26	1.72	0.58	0.27	1.74
	Minimum	0.52	0.20	1.63	0.51	0.23	1.65
	Average	0.57	0.23	1.69	0.55	0.25	1.70
4.1 – 6.0	Baladoo (a)	0.52	0.23	1.75	0.56	0.21	1.69
	Baladoo (b)	0.58	0.24	1.68	0.52	0.26	1.63
	Nimbi Jhodha (a)	0.48	0.21	1.63	0.58	0.23	1.53
	Nimbi Jhodha (b)	0.55	0.19	1.56	0.51	0.21	1.59
	Maximum	0.58	0.24	1.75	0.58	0.26	1.69
	Minimum	0.48	0.19	1.56	0.51	0.21	1.53
	Average	0.53	0.22	1.66	0.54	0.23	1.61
6.1 – 8.0	Natas (b)	0.56	0.23	1.71	0.59	0.24	1.53
	Dujar (c)	0.59	0.21	1.73	0.56	0.21	1.52
	Bakolia (b)	0.58	0.19	1.54	0.53	0.20	1.65
	Bakolia (c)	0.48	0.18	1.45	0.58	0.23	1.56
	Maximum	0.59	0.23	1.73	0.59	0.24	1.65
	Minimum	0.48	0.18	1.45	0.53	0.20	1.52
	Average	0.55	0.20	1.61	0.57	0.22	1.57
>8.0	Sikarali	0.52	0.18	1.43	0.56	0.22	1.41
	Malgoan (b)	0.58	0.17	1.47	0.53	0.23	1.43
	Mangalpura	0.59	0.19	1.56	0.61	0.21	1.68
	Dujar (b)	0.55	0.20	1.64	0.65	0.19	1.54
	Maximum	0.59	0.20	1.64	0.65	0.23	1.68
	Minimum	0.52	0.17	1.43	0.53	0.19	1.41
	Average	0.56	0.19	1.53	0.59	0.21	1.52

A critical examination of data in table 4.31 shows that there is continuous decrease in phosphorus content of wheat at harvest with the successive increase in groundwater fluoride. Fluoride content of wheat decreased from 0.25 per cent to 0.23, 0.22, 0.20 and 0.19 per cent during first year and from 0.24 to 0.25, 0.23, 0.22 and 0.21 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compare to first year there is decrease in average phosphorus content of wheat during second year in all the categories of groundwater fluoride. Although, no detail studies have been done on biochemical aspects of wheat as affected by fluoride content but decrease in phosphorus content of wheat with increase in fluoride content could be ascribed to fluoride induced inhibition of inorganic pyro-phosphatase and oxidation of free acids. Results obtained by Prince *et al.* (1949), Singh *et al.* (1979a), Rathore (1987), Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in line of the present observations.

Potassium

Data on average potassium content of wheat recorded at harvest are presented in table 4.31. Potassium content in wheat at harvest varied from 1.53 to 1.73 and 1.52 to 1.74 per cent during first and second year, respectively. Further, examination of data also revealed that the maximum potassium content of 1.82 and 1.83 per cent was observed at Ratau (a) village in fluoride category $< 2.0 \text{ mg L}^{-1}$ during first and second year. The minimum potassium content of 1.43 and 1.41 per cent was observed at Sikarali village in fluoride category $> 8.0 \text{ mg L}^{-1}$ during first and second year.

Further, perusal of data for both the years, in table 4.31 clearly indicates that there is decrease in potassium content of wheat with an increase in groundwater fluoride. The fluoride content of wheat

decreased from 1.73 per cent to 1.69, 1.66, 1.61 and 1.53 per cent during first year and from 1.74 to 1.70, 1.61, 1.57 and 1.52 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Decrease in potassium content of wheat with the increase in fluoride, might be related to altered membranes permeability and reduced respiration. Findings of Rathore (1987). Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in accordance with results of present investigation.

Grain yield of wheat

Average grain yield of wheat at harvest during both the years of study under all the categories of groundwater fluoride is given in table 4.32 and fig. 4.11. Grain yield of wheat varied from 24.5 to 28.8 and 25.3 to 29.5 q ha^{-1} from first to second year, respectively. The maximum yield of 30.0 and 31.0 q ha^{-1} was observed at Ratau (a) village in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum yield of 23.0 q ha^{-1} was observed at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year.

A critical examination of data in table 4.32 and fig. 4.11 shows that there is continuous decrease in grain yield of wheat with the successive increase in groundwater fluoride. Grain yield of wheat decreased from 28.8 q ha^{-1} to 28.3, 27.0, 25.5 and 24.5 q ha^{-1} during first year and 29.5 to 29.3, 27.5, 26.5 and 25.3 q ha^{-1} during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compare to first year there is decrease in average grain yield of wheat during second year in all the categories of groundwater fluoride. Results obtained by Verma (1979), Parmar (1988), Singh *et al.* (2001), Bagoria

Table 4.32 : Yield (q ha^{-1}) of wheat and mustard of irrigated with different fluoride waters

Fluoride (mg L^{-1}) Category	Name of Village	Wheat (q ha^{-1})		Mustard (q ha^{-1})	
		First year	Second year	First year	Second year
< 2.0	Ratau (a)	30.0	31.0	15.0	15.0
	Ratau (c)	28.0	30.0	14.0	15.0
	Genana (b)	27.0	28.0	13.0	14.0
	Audint (c)	30.0	29.0	14.0	14.0
	Maximum	30.0	31.0	15.0	15.0
	Minimum	27.0	28.0	13.0	14.0
	Average	28.8	29.5	14.0	14.5
2.1 – 4.0	Sandas (b)	28.0	29.0	14.0	15.0
	Jhardia (c)	29.0	30.0	12.0	13.0
	Lukas (a)	27.0	29.0	14.0	14.0
	Lukas (b)	29.0	29.0	12.0	13.0
	Maximum	29.0	30.0	14.0	15.0
	Minimum	27.0	29.0	12.0	13.0
	Average	28.3	29.3	13.0	13.8
4.1 – 6.0	Baladoo (a)	26.0	27.0	13.0	14.0
	Baladoo (b)	28.0	28.0	10.0	11.0
	Nimbi Jhodha (a)	25.0	27.0	13.0	13.0
	Nimbi Jhodha (b)	29.0	28.0	12.0	14.0
	Maximum	29.0	28.0	13.0	14.0
	Minimum	25.0	27.0	10.0	11.0
	Average	27.0	27.5	12.0	13.0
6.1 – 8.0	Natas (b)	25.0	26.0	11.0	11.0
	Dujar (c)	27.0	29.0	13.0	15.0
	Bakolia (b)	26.0	25.0	12.0	13.0
	Bakolia (c)	24.0	26.0	11.0	12.0
	Maximum	27.0	29.0	13.0	15.0
	Minimum	24.0	25.0	11.0	11.0
	Average	25.5	26.5	11.8	12.8
>8.0	Sikarali	23.0	23.0	10.0	11.0
	Malgoan (b)	24.0	25.0	10.0	10.0
	Mangalpura	26.0	26.0	11.0	12.0
	Dujar (b)	25.0	27.0	12.0	13.0
	Maximum	26.0	27.0	12.0	13.0
	Minimum	23.0	23.0	10.0	10.0
	Average	24.5	25.3	10.8	11.5

(2002), Choudhary *et al.* (2004), Bhardwaj (2006) and Yadav *et al.* (2012) are also in line of the present observations.

4.6.2 Impact on mustard quality parameters

While discussing the results of impact of high fluoride waters on mustard crop, efforts have been made to consider the role of plant species and management practices on accumulation of fluoride ion in plant.

4.6.2.1 Mustard quality parameters at 30 DAS

Fluoride

Data on average fluoride content of mustard at 30 DAS for both the years of study are presented in table 4.33 and fig. 4.12. The average fluoride content in mustard varied from 1.05 to 1.56 mg kg⁻¹ and 1.11 to 1.63 mg kg⁻¹ during first and second year, respectively in all the categories of groundwater fluoride. The data further revealed that the maximum fluoride content of 1.64 mg kg⁻¹ and 1.71 mg kg⁻¹ was observed at Malgoan (b) village in > 8.0 mg L⁻¹ fluoride category during first and Second year. The minimum fluoride content 1.00 mg kg⁻¹ and 1.03 mg kg⁻¹ was observed at Ratau (a) village in < 2.0 mg L⁻¹ fluoride category during first and second year. An attempt has also been made to see the relationship of fluoride content in mustard plant with fluoride in water and soil (Table 4.34). It is quite clear that a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Further, perusal of data in table 4.33 and fig. 4.12 clearly indicates that there is an increase in the fluoride content of mustard from first year to second year in all the categories of groundwater fluoride. Increase in the concentration of cations (Table 4.16) particularly sodium (Table 4.17) from first year to second year, in soil as well as in water might have helped in fluoride diffusion in early

**Table 4.33: Fluoride and chlorophyll content of mustard at 30 DAS
irrigated with different fluoride waters**

Fluoride (mg L ⁻¹) Category	Name of Village	First year		Second year	
		F (mg kg ⁻¹)	Chlorophyll (mg g ⁻¹)	F (mg kg ⁻¹)	Chlorophyll (mg g ⁻¹)
< 2.0	Ratau (a)	1.00	1.16	1.03	1.14
	Ratau (c)	1.06	1.29	1.09	1.21
	Genana (b)	1.03	1.19	1.10	1.18
	Audint (c)	1.10	1.24	1.20	1.22
	Maximum	1.10	1.29	1.20	1.22
	Minimum	1.00	1.16	1.03	1.14
	Average	1.05	1.22	1.11	1.19
2.1 – 4.0	Sandas (b)	1.02	1.25	1.00	1.24
	Jhardia (c)	1.10	1.19	1.20	1.19
	Lukas (a)	1.13	1.18	1.30	1.16
	Lukas (b)	1.17	1.14	1.40	1.13
	Maximum	1.17	1.25	1.40	1.24
	Minimum	1.02	1.14	1.00	1.13
	Average	1.11	1.19	1.23	1.18
4.1 – 6.0	Baladoo (a)	1.12	1.19	1.32	1.14
	Baladoo (b)	1.16	1.21	1.36	1.19
	Nimbi Jhodha (a)	1.21	1.16	1.42	1.14
	Nimbi Jhodha (b)	1.27	1.13	1.54	1.19
	Maximum	1.27	1.21	1.54	1.19
	Minimum	1.12	1.13	1.32	1.14
	Average	1.19	1.17	1.41	1.17
6.1 – 8.0	Natas (b)	1.23	1.13	1.41	1.16
	Dujar (c)	1.29	1.14	1.46	1.13
	Bakolia (b)	1.37	1.19	1.46	1.14
	Bakolia (c)	1.45	1.15	1.51	1.17
	Maximum	1.45	1.19	1.51	1.17
	Minimum	1.23	1.13	1.41	1.13
	Average	1.34	1.15	1.46	1.15
>8.0	Sikarali	1.58	1.13	1.68	1.05
	Malgoan (b)	1.64	1.11	1.71	1.13
	Mangalpura	1.49	1.15	1.59	1.19
	Dujar (b)	1.52	1.18	1.52	1.10
	Maximum	1.64	1.18	1.71	1.19
	Minimum	1.49	1.11	1.52	1.05
	Average	1.56	1.14	1.63	1.12

Table: 4.34 Relationship of fluoride in mustard plant with water and soil

S.No.	Particulars	Equation	r	R ²
1.	Mustard at 30 DAS			
	Relationship of fluoride in mustard stover with water and soil fluoride			
	First year	$Y = 0.790 + 0.0531 \text{ Water (F)} + 0.231 \text{ Soil (F)}$	0.912**	0.831
	Second year	$Y = 0.962 + 0.0562 \text{ Water (F)} + 0.06918 \text{ Soil (F)}$	0.916**	0.838
	Pooled	$Y = 0.906 + 0.0562 \text{ Water (F)} + 0.09423 \text{ Soil (F)}$	0.907**	0.824
2.	Mustard at Harvest			
	Relationship of fluoride in mustard seed with water and soil fluoride			
	First year	$Y = 0.390 + 0.130 \text{ Water (F)} + 0.127 \text{ Soil (F)}$	0.937**	0.878
	Second year	$Y = 0.272 + 0.145 \text{ Water (F)} + 0.06549 \text{ Soil (F)}$	0.959**	0.919
	Pooled	$Y = 0.347 + 0.137 \text{ Water (F)} + 0.07369 \text{ Soil (F)}$	0.942**	0.888
3.	Mustard at Harvest			
	Relationship of plant fluoride with water and soil fluoride			
	First year	$Y = 0.129 + 0.0387 \text{ Water (F)} + 0.115 \text{ Soil (F)}$	0.939**	0.881
	Second year	$Y = 0.0928 + 0.039 \text{ Water (F)} + 0.122 \text{ Soil (F)}$	0.928**	0.861
	Pooled	$Y = 0.117 + 0.039 \text{ Water (F)} + 0.108 \text{ Soil (F)}$	0.926**	0.858

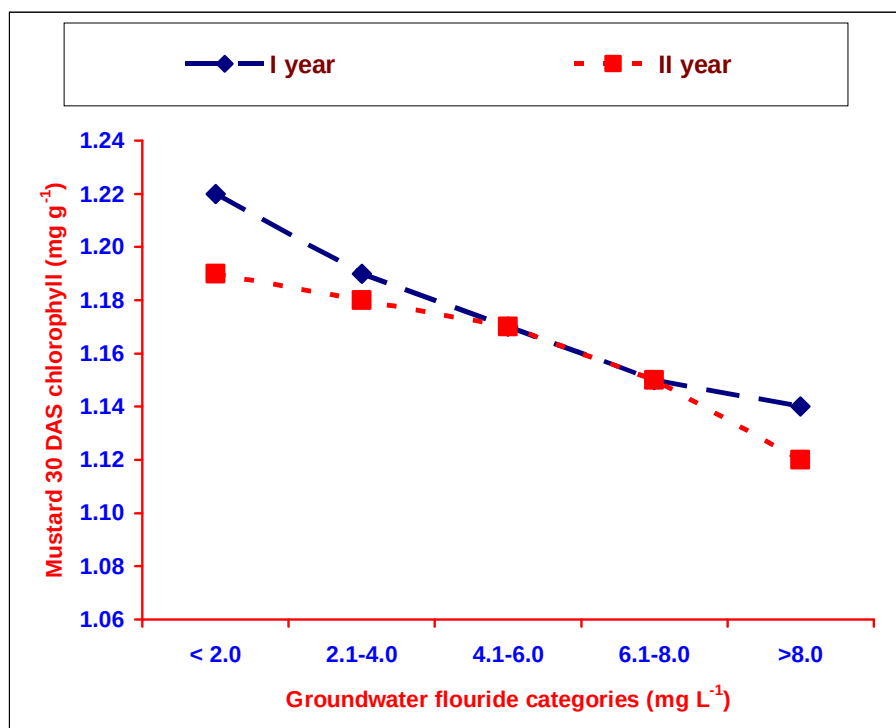
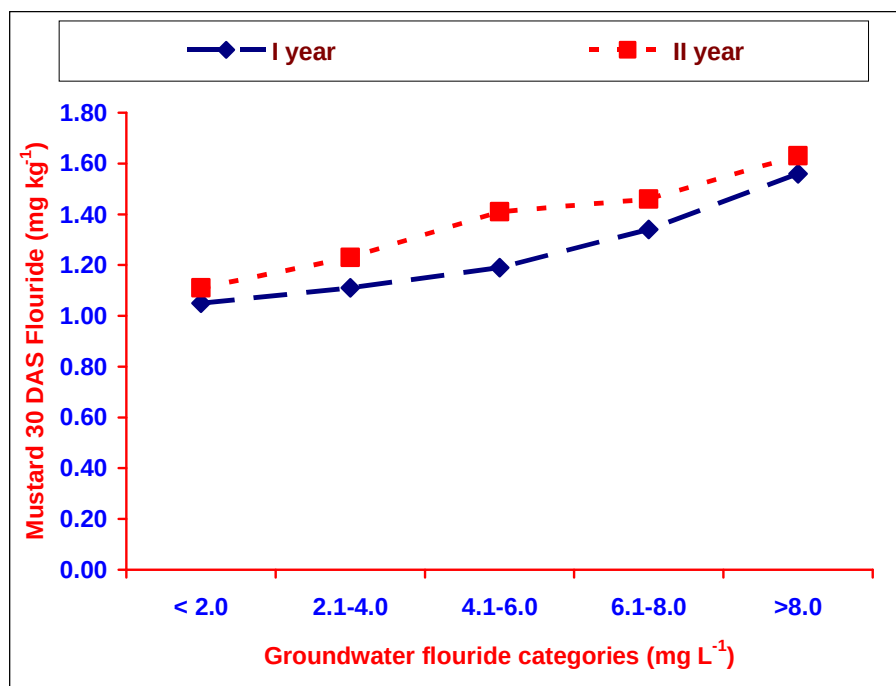


Fig. 4.12 : Fluoride and chlorophyll content of mustard at 30 DAS irrigated with different fluoride waters

phases, possibly due to formation of the mobile fluoro-sodium complexes, thereby higher fluoride content in plants, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Chlorophyll

Data regarding average chlorophyll content of mustard taken at 30 DAS are presented in table 4.33. The average chlorophyll content of mustard at 30 DAS varied from 1.14 to 1.22 mg g⁻¹ and 1.12 to 1.19 mg g⁻¹ during first and second year, respectively, with all categories of groundwater fluoride. Data also revealed that the maximum chlorophyll content of 1.29 mg g⁻¹ was observed at Ratau (c) and 1.22 mg g⁻¹ was recorded at Aundit (c) village in < 2.0 mg L⁻¹ fluoride category during first and second year. The minimum chlorophyll content of 1.11 mg g⁻¹ was observed at Malgoan (b) and 1.05 mg g⁻¹ was recorded at Sikarali village in > 8.0 mg L⁻¹ fluoride category during first and second year.

Further, perusal of data for both the years in table 4.33 and figure 4.12 clearly exhibits that there is decrease in chlorophyll content of plants with increase in groundwater fluoride. Plants sensitivity to fluoride pollution is variable, but certain physiological processes are known to be markedly affected by fluoride, like decreased plant growth, chlorosis and decrease in chlorophyll. Since chloroplasts are the site of most of the fluoride accumulation, hence that might have caused decrease in chlorophyll content with the increase fluoride content of plant. Similar type of observation are also reported by Newman (1961), Chang and Thompson (1966), Holub (1975), Maclean *et al.* (1976), Rathore (1987), Singh *et al.* (2001),

Nitrogen

Data on average nitrogen content of mustard at 30 DAS are presented in table 4.35 showed that nitrogen content varied from 1.11 to 1.23 per cent and 1.17 to 1.26 per cent during first and second year, respectively in all the categories of the groundwater fluoride. Data also evidently show that the maximum nitrogen content of 1.42 per cent was observed at Genana (b) village in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first year and 1.42 per cent was recorded at Lukas (b) village in 2.1 to 4.0 mg L^{-1} fluoride category during second year. The minimum nitrogen content of 1.01 per cent was observed at Natas (b) village in 6.1 to 8.0 mg L^{-1} fluoride category during first year and 1.09 per cent was observed at Genana (b) village in $< 2.0 \text{ mg L}^{-1}$ fluoride category during second year.

Further, critical examination of data for both the years in table 4.35 clearly indicates that there is no definite trend occurred in nitrogen content of plant with the an increase in groundwater fluoride. The published literature suggests that some physiological processes are less susceptible to fluoride concentration and nitrogen metabolism might be one of them. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Phosphorus

Data regarding average phosphorus content of mustard taken at 30 DAS are presented in table 4.35 revealed that average phosphorus content varied from 0.55 to 0.66 per cent and 0.55 to 0.72 per cent during first and second year, respectively in all the categories of groundwater fluoride. The maximum phosphorus content of 0.74 per cent was observed at Ratau (a) village in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first year and 0.86 per cent at Ratau (a) and Lukas (a) villages in $< 2.0 \text{ mg L}^{-1}$ and 2.1 to 4.0 mg L^{-1}

Table 4.35 : Nitrogen, phosphorus and potassium content in mustard at 30 DAS irrigated with different fluoride waters

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		N %	P %	K%	N %	P %	K%
< 2.0	Ratau (a)	1.02	0.74	1.65	1.12	0.86	1.82
	Ratau (c)	1.24	0.66	1.55	1.22	0.64	1.65
	Genana (b)	1.42	0.67	1.69	1.09	0.69	1.45
	Audint (c)	1.23	0.56	1.56	1.24	0.68	1.67
	Maximum	1.42	0.74	1.69	1.24	0.86	1.82
	Minimum	1.02	0.56	1.55	1.09	0.64	1.45
	Average	1.23	0.66	1.61	1.17	0.72	1.65
2.1 – 4.0	Sandas (b)	1.12	0.68	1.61	1.25	0.78	1.58
	Jhardia (c)	1.03	0.66	1.63	1.12	0.82	1.71
	Lukas (a)	1.14	0.63	1.59	1.24	0.86	1.56
	Lukas (b)	1.25	0.59	1.52	1.42	0.34	1.67
	Maximum	1.25	0.68	1.63	1.42	0.86	1.71
	Minimum	1.03	0.59	1.52	1.12	0.34	1.56
	Average	1.14	0.64	1.59	1.26	0.70	1.63
4.1 – 6.0	Baladoo (a)	1.25	0.68	1.53	1.23	0.76	1.57
	Baladoo (b)	1.25	0.58	1.57	1.13	0.61	1.61
	Nimbi Jhodha (a)	1.18	0.62	1.54	1.24	0.66	1.58
	Nimbi Jhodha (b)	1.12	0.56	1.52	1.12	0.63	1.63
	Maximum	1.25	0.68	1.57	1.24	0.76	1.63
	Minimum	1.12	0.56	1.52	1.12	0.61	1.57
	Average	1.20	0.61	1.54	1.18	0.67	1.60
6.1 – 8.0	Natas (b)	1.01	0.63	1.54	1.24	0.59	1.46
	Dujar (c)	1.24	0.59	1.49	1.32	0.61	1.57
	Bakolia (b)	1.25	0.56	1.57	1.23	0.65	1.47
	Bakolia (c)	1.12	0.57	1.48	1.24	0.57	1.59
	Maximum	1.25	0.63	1.57	1.32	0.65	1.59
	Minimum	1.01	0.56	1.48	1.23	0.57	1.46
	Average	1.16	0.59	1.52	1.26	0.61	1.52
>8.0	Sikarali	1.04	0.53	1.48	1.12	0.49	1.45
	Malgoan (b)	1.24	0.56	1.46	1.14	0.51	1.43
	Mangalpura	1.12	0.61	1.55	1.22	0.56	1.54
	Dujar (b)	1.05	0.49	1.44	1.27	0.64	1.49
	Maximum	1.24	0.61	1.55	1.27	0.64	1.54
	Minimum	1.04	0.49	1.44	1.12	0.49	1.43
	Average	1.11	0.55	1.48	1.19	0.55	1.48

fluoride categories during second year. The minimum phosphorus content 0.49 per cent was observed at Dujar (b) village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first year and 0.34 per cent at Lukas (b) village in $2.1 \text{ to } 4.0 \text{ mg L}^{-1}$ fluoride category during second year.

Further, examination data shows that there is continuous decrease in phosphorus content of mustard at 30 DAS with the successive increase in groundwater fluoride. The fluoride content of mustard decreased from 0.66 per cent to 0.64, 0.61, 0.59 and 0.55 per cent during first year and from 0.72 to 0.70, 0.67, 0.61 and 0.55 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1\text{-}4.0$, $4.1\text{-}6.0$, $6.1\text{-}8.0$ and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compared to first year there is decrease in average phosphorus content of mustard during second year in all the categories of groundwater fluoride. Although, no much studies have been done on biochemical aspects of wheat as affected by fluoride content but decrease in phosphorus content of wheat with increase in fluoride content could be ascribed to fluoride induced inhibition of inorganic pyro-phosphatase and oxidation of free acids. Results obtained by Prince *et al.* (1949), Singh *et al.* (1979a), Rathore (1987), Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in line of the present observations.

Potassium

Average potassium content in mustard at 30 DAS during both the years of study under all the categories of groundwater fluoride is given in table 4.35. The average potassium content varied from 1.48 to 1.61 per cent and 1.48 to 1.65 per cent during first and second year, respectively in all the categories of groundwater fluoride. Data further revealed that maximum potassium content of 1.69 per cent was observed at Genana (b) and 1.82 per cent was recorded at Ratau (a)

village in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum potassium content of 1.44 per cent was observed at Dujar (b) and 1.43 per cent was recorded at Malgoan (b) village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year.

Further, perusal of data for both the years in table 4.35 clearly indicates that there is decrease in potassium content with increase in groundwater fluoride categories. The fluoride content of mustard decreased from 1.61 per cent to 1.59, 1.54, 1.52 and 1.48 per cent during first year and from 1.65 to 1.63, 1.60, 1.52 and 1.48 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Decrease in potassium content of mustard with the increase in fluoride, might be related to alteration in permeability of membranes and reduced respiration. Findings of Rathore (1987). Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in accordance with results of present investigation.

4.6.2.2 Mustard quality parameters at harvest

Fluoride in stover

Data on average fluoride content of mustard at harvest are presented in table 4.36. The average fluoride content in mustard at harvest varied from 0.61 to 1.55 mg kg^{-1} and 0.55 to 1.56 mg kg^{-1} during first and second year, respectively. Maximum fluoride content of 1.57 mg kg^{-1} was observed at Sikarali and 1.59 mg kg^{-1} Malgoan (b) village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum fluoride content 0.48 mg kg^{-1} and 0.49 mg kg^{-1} was observed at Ratau (a) and Ratau (c) villages in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. An attempt has also been made to see the relationship of fluoride content in mustard plant with fluoride in water and soil (Table 4.34). From the table 4.34 it is quite clear that

a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Further, perusal of data in table 4.36 and figure 4.13 clearly indicates that there is an increase in the fluoride content of plant from first year to second year in all the categories of groundwater fluoride. Increase in the concentration of cations (Table 4.16) particularly sodium (Table 4.17) from first year to second year, in soil as well as in water might have helped in both fluoride diffusion in early phases, possibly due to formation of the mobile fluoro-sodium complexes, which ultimately resulted in higher fluoride content in plant during second year, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Fluoride in mustard seed

Data on average fluoride content of mustard seed are presented in table 4.36 and figure 4.13. Data revealed that average fluoride content in mustard seed varied from 0.23 to 0.56 mg kg⁻¹ and 0.21 to 0.56 mg kg⁻¹ during first and second year, respectively. The table also revealed that the maximum fluoride content of 0.58 mg kg⁻¹ and 0.59 mg kg⁻¹ was observed at Malgoan (b) village in > 8.0 mg L⁻¹ fluoride category during first and second year. The minimum fluoride content 0.11 mg kg⁻¹ and 0.10 mg kg⁻¹ was observed at Ratau (a) village in < 2.0 mg L⁻¹ fluoride category during first and second year. An attempt has also been made to see the relationship of fluoride content in mustard plant with fluoride in water and soil (Table 4.34). From the table 4.34 it is quite clear that a highly significant relationship of plant fluoride with water and soil fluoride existed during both the years of study.

Table 4.36: Fluoride in seed and stover and Oil per cent in mustard at harvest irrigated with different fluoride waters

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		F (mg kg ⁻¹)		Oil (%)	F (mg kg ⁻¹)		Oil (%)
		Stover	Seed		Stover	Seed	
< 2.0	Ratau (a)	0.48	0.11	36.10	0.49	0.10	32.90
	Ratau (c)	0.48	0.20	32.63	0.50	0.17	39.23
	Genana (b)	0.68	0.30	31.00	0.56	0.27	39.06
	Audint (c)	0.79	0.31	34.24	0.63	0.30	33.82
	Maximum	0.79	0.31	36.10	0.63	0.30	39.23
	Minimum	0.48	0.11	31.00	0.49	0.10	32.90
	Average	0.61	0.23	33.49	0.55	0.21	36.25
2.1 – 4.0	Sandas (b)	0.68	0.31	29.33	0.71	0.31	34.10
	Jhardia (c)	0.98	0.33	32.75	0.89	0.38	34.23
	Lukas (a)	1.00	0.36	31.44	0.98	0.33	37.24
	Lukas (b)	1.10	0.39	36.68	1.03	0.36	37.24
	Maximum	1.10	0.39	36.68	1.03	0.38	37.24
	Minimum	0.68	0.31	29.33	0.71	0.31	34.10
	Average	0.94	0.35	32.55	0.90	0.34	35.71
4.1 – 6.0	Baladoo (a)	1.20	0.42	33.62	1.23	0.40	36.68
	Baladoo (b)	1.30	0.45	31.81	1.29	0.42	37.74
	Nimbi Jhodha (a)	1.35	0.43	31.09	1.31	0.45	31.02
	Nimbi Jhodha (b)	1.45	0.47	28.06	1.39	0.50	34.23
	Maximum	1.45	0.47	33.62	1.39	0.50	37.74
	Minimum	1.20	0.42	28.06	1.23	0.40	31.02
	Average	1.33	0.44	31.14	1.31	0.44	34.92
6.1 – 8.0	Natas (b)	1.41	0.46	32.32	1.43	0.47	33.23
	Dujar (c)	1.43	0.50	31.42	1.48	0.52	35.40
	Bakolia (b)	1.48	0.51	30.02	1.46	0.48	32.46
	Bakolia (c)	1.51	0.54	28.23	1.50	0.56	31.41
	Maximum	1.51	0.54	32.32	1.50	0.56	35.40
	Minimum	1.41	0.46	28.23	1.43	0.47	31.41
	Average	1.46	0.50	30.50	1.47	0.51	33.13
>8.0	Sikarali	1.57	0.57	27.82	1.56	0.58	30.02
	Malgoan (b)	1.56	0.58	28.10	1.59	0.59	31.75
	Mangalpura	1.53	0.54	30.74	1.56	0.52	33.24
	Dujar (b)	1.55	0.55	31.68	1.52	0.54	35.87
	Maximum	1.57	0.58	31.68	1.59	0.59	35.87
	Minimum	1.53	0.54	27.82	1.52	0.52	30.02
	Average	1.55	0.56	29.59	1.56	0.56	32.72

A critical examination of data (Table 4.36) further revealed that with the successive increase in the groundwater fluoride, fluoride content in mustard seed also increased during both the years, but the increase is of higher magnitude during second year. Increase in mustard seed fluoride content could be ascribed to more availability of fluoride from water (Table 4.19) and soil (Table 4.11) possibly due to formation of mobile fluoro-sodium complexes. There by higher fluoride content in plant during second year, especially when waters having more fluoride. The results obtained in the present study are in good agreement with the observations made by Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Oil content

Data (Table 4.34) revealed that average oil content in mustard seed varied from 29.59 to 33.49 per cent and 32.72 to 36.25 per cent during first and second year, respectively. The maximum oil content of 36.68 per cent was observed at Lukas (b) village in 2.1 to 4.0 mg L⁻¹ fluoride category during first year and 39.23 per cent at Ratau (c) village in < 2.0 mg L⁻¹ fluoride category during second year. The minimum oil content of 27.82 per cent and 30.02 per cent was observed at Sikarali village > 8.0 mg L⁻¹ fluoride category during first and second year.

Further, perusal of data for both the years in table 4.36 clearly indicates that there is no definite trend of oil content with respect to increase in groundwater fluoride. This suggests that some physiological processes are less susceptible to fluoride concentration and nitrogen metabolism might be one of them. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

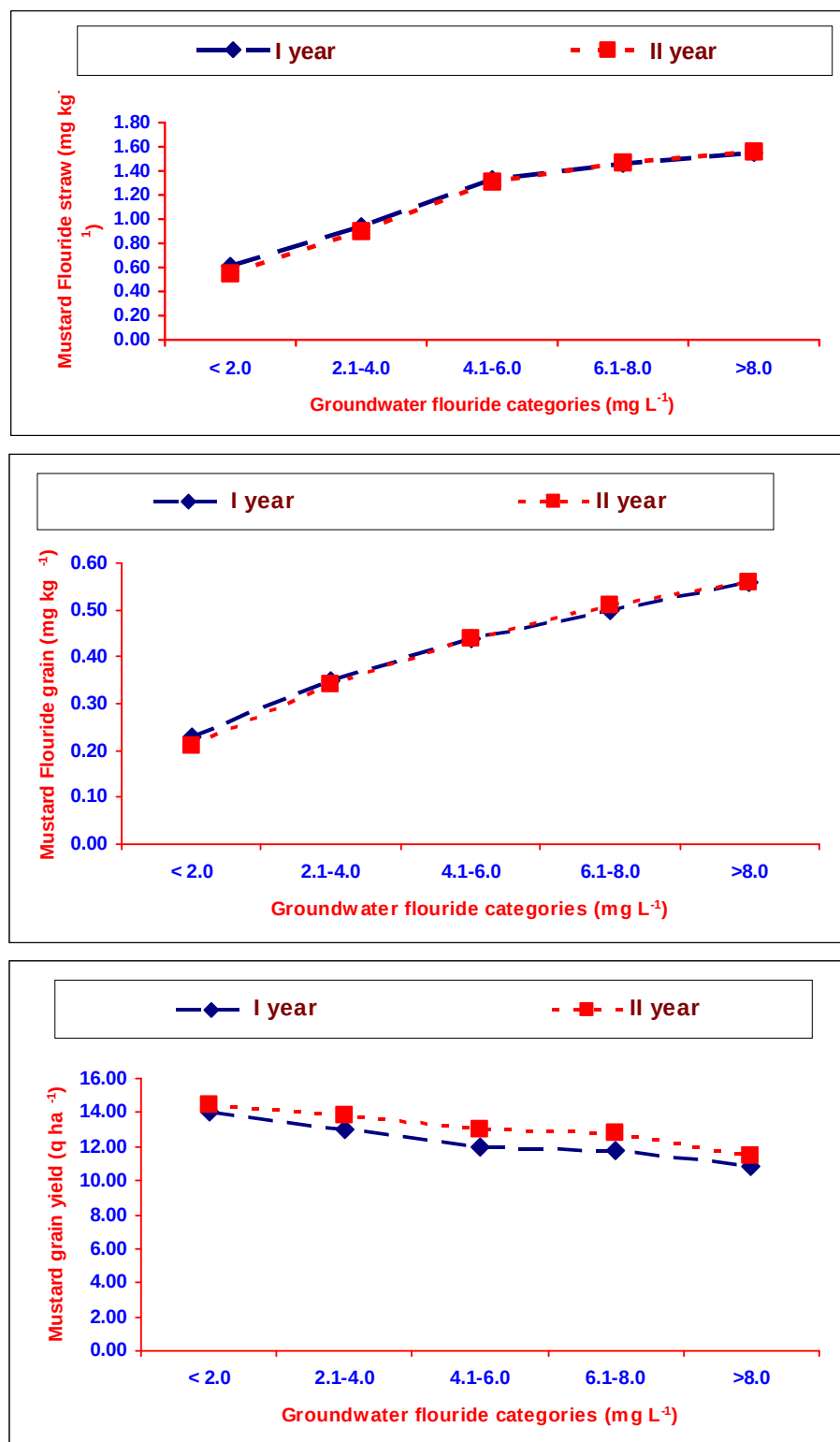


Fig. 4.13 : Fluoride content in mustard straw and grain as well as grain yield of mustard irrigated with different fluoride waters

Nitrogen

Data on average nitrogen content of mustard at harvest for both the years of study are presented in table 4.37. The average nitrogen content in mustard varied from 0.54 to 0.58 per cent and 0.54 to 0.57 per cent during first and second year, respectively. The maximum nitrogen content of 0.61 per cent was observed at Lukas (b) and Dujar (b) villages in 2.1 to 4.0 mg L⁻¹ and > 8.0 mg L⁻¹ fluoride category during first year and 0.61 per cent at Mangalpura village in > 8.0 mg L⁻¹ fluoride category during second year. The minimum nitrogen content 0.51 per cent was observed at Nimbi Jhodha (b) and Sikarali villages in 4.1 to 6.0 mg L⁻¹ and > 8.0 mg L⁻¹ fluoride category during first year and 0.48 per cent at Sikarali village in > 8.0 mg L⁻¹ fluoride category during second year.

Further, perusal of data for both the years presented in table 4.37 clearly indicates that there is no definite trend of nitrogen content with respect to increase in groundwater fluoride. This might be less sensitiveness of nitrogen metabolism to fluoride concentration. The present results are in line with the findings of Rathore (1987). Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012).

Phosphorus

Average phosphorus content in mustard at harvest during both the years of study under all the categories of groundwater fluoride is given in table 4.37. The average phosphorus content in mustard at harvest varied from 0.21 to 0.26 per cent and 0.20 to 0.27 per cent during first and second year, respectively. The maximum phosphorus content of 0.29 per cent was observed at Audint (c) and Genana (b) villages in < 2.0 mg L⁻¹ fluoride category during first and second year. The minimum phosphorus content 0.19 per cent and 0.18 per cent was observed at Sikarali village in > 8.0 mg L⁻¹ fluoride category during first and second year.

Table 4.37: Nitrogen, phosphorus and potassium content in mustard at harvest irrigated with different fluoride waters

Fluoride (mg L ⁻¹) Category	Name of Village	First year			Second year		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
< 2.0	Ratau (a)	0.54	0.29	1.32	0.53	0.26	1.59
	Ratau (c)	0.59	0.24	1.67	0.57	0.27	1.46
	Genana (b)	0.59	0.23	1.59	0.52	0.29	1.45
	Audint (c)	0.57	0.29	1.52	0.54	0.26	1.41
	Maximum	0.59	0.29	1.67	0.57	0.29	1.59
	Minimum	0.54	0.23	1.32	0.52	0.26	1.41
	Average	0.57	0.26	1.53	0.54	0.27	1.48
2.1 – 4.0	Sandas (b)	0.58	0.26	1.42	0.57	0.24	1.35
	Jhardia (c)	0.59	0.24	1.45	0.58	0.25	1.57
	Lukas (a)	0.55	0.27	1.42	0.56	0.24	1.45
	Lukas (b)	0.61	0.23	1.52	0.58	0.27	1.42
	Maximum	0.61	0.27	1.52	0.58	0.27	1.57
	Minimum	0.55	0.23	1.42	0.56	0.24	1.35
	Average	0.58	0.25	1.45	0.57	0.25	1.45
4.1 – 6.0	Baladoo (a)	0.56	0.23	1.21	0.53	0.21	1.45
	Baladoo (b)	0.53	0.26	1.47	0.56	0.23	1.38
	Nimbi Jhodha (a)	0.51	0.22	1.52	0.59	0.26	1.45
	Nimbi Jhodha (b)	0.56	0.25	1.35	0.51	0.22	1.44
	Maximum	0.56	0.26	1.52	0.59	0.26	1.45
	Minimum	0.51	0.22	1.21	0.51	0.21	1.38
	Average	0.54	0.24	1.39	0.55	0.23	1.43
6.1 – 8.0	Natas (b)	0.56	0.23	1.37	0.56	0.24	1.46
	Dujar (c)	0.54	0.21	1.36	0.53	0.23	1.42
	Bakolia (b)	0.58	0.25	1.49	0.57	0.20	1.35
	Bakolia (c)	0.53	0.20	1.12	0.56	0.22	1.34
	Maximum	0.58	0.25	1.49	0.57	0.24	1.46
	Minimum	0.53	0.20	1.12	0.53	0.20	1.34
	Average	0.55	0.22	1.34	0.56	0.22	1.39
>8.0	Sikarali	0.51	0.19	1.34	0.48	0.18	1.31
	Malgoan (b)	0.53	0.21	1.25	0.59	0.20	1.33
	Mangalpura	0.59	0.23	1.25	0.61	0.21	1.35
	Dujar (b)	0.61	0.22	1.41	0.54	0.22	1.42
	Maximum	0.61	0.23	1.41	0.61	0.22	1.42
	Minimum	0.51	0.19	1.25	0.48	0.18	1.31
	Average	0.56	0.21	1.31	0.56	0.20	1.35

Phosphorus

Average phosphorus content in mustard at harvest during both the years of study under all the categories of groundwater fluoride is given in table 4.37. The average phosphorus content in mustard at harvest varied from 0.21 to 0.26 per cent and 0.20 to 0.27 per cent during first and second year, respectively. The maximum phosphorus content of 0.29 per cent was observed at Audint (c) and Genana (b) villages in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum phosphorus content 0.19 per cent and 0.18 per cent was observed at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year.

A critical examination of data in table 4.37 shows that there is continuous decrease in phosphorus content of mustard at harvest with the successive increase in groundwater fluoride. Fluoride content of mustard decreased from 0.26 per cent to 0.25, 0.24, 0.22 and 0.21 per cent during first year and from 0.27 to 0.25, 0.23, 0.22 and 0.20 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compare to first year there is decrease in average phosphorus content of mustard during second year in all the categories of groundwater fluoride. Although, no detail studies have been done on biochemical aspects of wheat as affected by fluoride content but decrease in phosphorus content of wheat with increase in fluoride content could be ascribed to fluoride induced inhibition of inorganic pyro-phosphatase and oxidation of free acids. Results obtained by Prince *et al.* (1949), Singh *et al.* (1979a), Rathore (1987), Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in line of the present observations.

Potassium

Data taken regarding average potassium content of mustard at harvest are presented in table 4.37 revealed that average potassium content varied from 1.31 to 1.53 per cent and 1.35 to 1.48 per cent during first and second year, respectively. The maximum potassium content of 1.67 per cent and 1.59 per cent was observed at Ratau (c) and Ratau (a) villages in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum potassium content of 1.12 per cent was observed at Bakolia (c) village in $6.1 \text{ to } 8.0 \text{ mg L}^{-1}$ fluoride category during first year and 1.31 per cent was observed at Sikarali village in $> 8.0 \text{ mg L}^{-1}$ fluoride category during second year.

Further, perusal of data for both the years, in table 4.37 clearly indicates that there is decrease in potassium content of mustard with increase in groundwater fluoride. The fluoride content of mustard decreased from 1.53 per cent to 1.45, 1.39, 1.34 and 1.31 per cent during first year and from 1.48 to 1.45, 1.43, 1.39 and 1.35 per cent during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to 2.1-4.0, 4.1-6.0, 6.1-8.0 and $> 8.0 \text{ mg L}^{-1}$, respectively. Decrease in potassium content of mustard with the increase in fluoride, might be related to altered membranes permeability and reduced respiration. Findings of Rathore (1987). Elrashidi *et al.* (1998), Kotova *et al.* (2002), Bagoria (2002), Bhardwaj (2006) Nayak *et al.* (2009b) and Yadav *et al.* (2012) are also in accordance with results of present investigation.

Mustard seed yield

Average mustard seed yield of mustard at harvest during both the years of study under all the categories of groundwater fluoride is given in table 4.32. The average mustard seed yield varied from 10.8 to 14.0 and 14.5 to 11.5 q ha^{-1} during first and second year, respectively. The maximum yield of 15.0 q ha^{-1} was observed at Ratau (a) and

Ratau (b) villages in $< 2.0 \text{ mg L}^{-1}$ fluoride category during first and second year. The minimum yield of 10.0 q ha^{-1} was observed at Sikarali and Malgoan (b) villages in $> 8.0 \text{ mg L}^{-1}$ fluoride category during first and second year.

A critical examination of data in table 4.32 and figure 4.10 shows that there is continuous decrease in mustard seed yield with the successive increase in groundwater fluoride. Mustard seed yield of mustard decreased from 14.0 q ha^{-1} to 13.0 , 12.0 , 11.8 and 10.8 q ha^{-1} during first year and 14.5 to 13.8 , 13.0 , 12.8 and 11.5 q ha^{-1} during second year, with the successive increase in groundwater fluoride category from $< 2.0 \text{ mg L}^{-1}$ to $2.1-4.0$, $4.1-6.0$, $6.1-8.0$ and $> 8.0 \text{ mg L}^{-1}$, respectively. Further, it is also clear from the data that as compare to first year there is decrease in average mustard seed yield of mustard during second year in all the categories of groundwater fluoride. Results obtained by Verma (1979), Parmar (1988), Singh *et al.* (2001), Bagoria (2002), Choudhary *et al.* (2004), Bhardwaj (2006) and Yadav *et al.* (2012) are also in line of the present observations.

5. GENERAL DISCUSSION

In the preceding chapter, results on characterization of ground waters especially with respect to fluoride content, interrelationship of soil fluoride with various soil and water parameters, impact of different categories of fluoride water on soil and water parameters, soil fluoride build up and impact of fluoride waters on quality of wheat and mustard, were presented and discussed. In the present chapter an attempt has been made to give a comprehensive discussion of such characterisation.

5.1 Characterization of ground waters and soils

All irrigation waters contain dissolved salts in varying amounts. When salts go into solution they are separated into ions i.e. cations and anions. The principal cations of ground irrigation water are calcium, magnesium, sodium and potassium and the anions are carbonate, bicarbonate, chloride and sulphate. In general, sodium was found dominant cation in all ground irrigation waters of Ladnu tehsil followed by magnesium, calcium and potassium indicating Na-Mg-Ca type waters. Among anions, chloride was observed as dominant anion followed by bicarbonate, sulphate and carbonate. The pH of ground irrigation waters of studied area has clearly indicated that 99 per cent waters belong to marginally alkaline category, which might be due to dominance of sodium as well as carbonate + bicarbonate ions. These results get support from the findings of Sood *et.al.* (1998) and Verma *et.al.* (2003). Similarly, the EC of irrigation waters evidently shows that only 23 per cent waters belong to saline category and rest 67 per cent waters varied from slightly saline to medium salinity which might be due to dominance of salts moderate in solubility in these irrigation waters. Most of the waters have low sodicity to medium sodicity hazard, only 27 per cent irrigation waters have high to very high

sodic hazard. Waters of study area also have non alkali to medium alkali hazard and majority of waters fell in low alkali hazard class. These results get support from the findings of Lal *et.al.*(1998) and Verma *et.al* (2003).

The soil pH of studied area evidently indicated that majority of soils belong to marginally alkaline class, which could be related to dominance of carbonates and bicarbonate of calcium, magnesium and sodium. The soil pH of studied area has clearly indicated that 83 per cent soils belong to marginally alkaline category, which might be due to dominance of sodium as well as carbonate + bicarbonate ions. These results get support from the findings of Sood *et.al.* (1998) and Verma *et.al.* (2003). Similarly, the EC of soil evidently indicated that only 97 per cent soils belong to normal category and rest 3 per cent soils varied from slightly saline to medium salinity. Most of the soils have low sodicity to medium sodicity hazard and only 3 per cent soils had high sodicity hazard. These results get support from the findings of Lal *et.al.*(1998) and Verma *et.al* (2003).

5.2 Categorization of ground water on the basis of fluoride content

Among the water quality parameters, fluoride ion exhibits unique properties as its concentration in optimum dose in drinking water is advantageous to human health and if the concentration exceeds the limit, this affects the health. High fluoride concentration in the ground water of semi-arid and arid part of the Rajasthan is a cause of great concern.

The fluoride content of groundwater in arid aquifers varies from $< 1 \text{ mg L}^{-1}$ to 25 mg L^{-1} . In the studied area, the fluoride content of ground water varied from 1.60 to 8.80 mg L^{-1} , indicating a good degree of variations in fluoride content. Further, most of the waters (69%) of the studied area had fluoride concentration from 2.1 mg L^{-1} to 6.0 mg L^{-1} .

L⁻¹. The concentration of fluoride in groundwater depends on the concentration of fluoride bearing minerals in rock types and their depositional, dissociated and dissolution activities along with residence time of the chemical reaction. Looking to the variations in fluoride content of ground waters even at gram panchayat level, it appears reasonable that dissolution activity of fluoride minerals is more important for fluoride concentration in groundwater rather than fluoride bearing minerals present in rocks. Since alkaline pH is more favourable for fluoride dissolution activity, therefore, in the present case most of the waters being alkaline in nature are enriched with fluoride concentration.

5.3 Interrelationship of soil fluoride with various soil and water parameters

The fluoride concentrations in soils are often inherited from parent material, whereby its distribution in soil profiles is a function of soil forming process, of which the degree of weathering and clay content are the most prominent factors. In general, the lowest fluoride contents are found in sandy soils in humid climate, whereas, higher fluoride concentrations occur in heavy soils and in soils from weathered mafic rocks (Fugs and Andrews, 1988). Fluoride is a mobile ion and its retention in soil depends on the amount and rate of water percolating into the soil zone which depends on the permeability of soil. Generally, fluoride in soil is found to be within the range normally encountered in groundwater of the area. But in the present case, it is less than, what was recorded in groundwater, most probably this is due to very very low clay content and very high permeability of soil, thus causing the fluoride ion to move deeper into the water table.

A correlation analysis made in the present study depicts positive correlations between soil fluoride and soil pH, soil fluoride and EC with $r=+0.243$ and $+0.215$, respectively. This means that the fluoride content increases with soil pH and EC, respectively. These correlations were

all moderate, suggesting that the parameters like pH and EC contribute greatly to the bioavailability of fluoride ion in soil. This is in agreement with what has been observed by Lessern and Widdowson (1971), Perroitt *et al.* (1976); Chhabra *et al.* (1980); Omueti and Jones (1977). Fluoride can also be adsorbed by some cations, radicals and oxides of metals, which have the potential of retaining and releasing it at the appropriate geochemical conditions. In the present investigation, correlation analysis depicts positive but weak relationship between soil fluoride and calcium, soil fluoride and magnesium with $r = +0.074$ and $+0.029$, respectively. Whereas, positive and moderate relationship was observed between soil fluoride and sodium with $r = +0.210$. This means different cations have different retaining and releasing potential for fluoride at different geochemical conditions. These findings are in agreement with the work reported by Kabata-Pendias *et al.* (1992).

Fluoride is dissolved in groundwater mainly from geological sources. Rock-water interaction is the main process in which fluoride-rich minerals are decomposed/dissociated from the source rock and fluoride is dissolved in the groundwater by dissolution (Wenzel and Blum, 1992; Bardum *et al.*, 1976). Most of the fluoride minerals are sparingly soluble in water under normal temperature and pressure conditions. However, under certain physio-chemical conditions, dissolution activity may become faster (Saxena and Ahmed, 2001). In the present case, all the water samples (99%) were found alkaline in nature and their pH values varied from 7.5-8.5. Plots drawn between soil fluoride vs pH of water and soil fluoride vs EC of water have shown positive relationship. This means alkaline medium and certain salts are more favourable for fluoride dissolution. The aqueous ionic concentration of groundwater also influenced the fluoride solubility behaviour, for example, in the present investigation, in the presence of excessive sodium in groundwater, the dissociated activity of fluoride was observed high, as indicated by high positive relationship.

Further, fluoride has shown unique chemical behaviour towards most of the anions, as demonstrated by significant and positive relationship of soil fluoride with all the anions in ground water. Similar type of opinion had also been given by Wenzel and Blum (1992).

5.4 Impact of different categories of fluoride waters on soil and groundwater parameters

No systematic study had been done to observe the changes in soil and water properties, when different concentrations of fluoride enriched groundwaters are used for crop cultivation. Therefore, in the present investigation, an attempt has been made to take care of this part also.

The fluoride enriched groundwaters are invariably observed in all the major hydrogeological formations viz., alluvium, crystallines and sedimentaries. Generally the high fluoride content in water is associated with high alkalinity to calcium ratio, low calcium to fluoride and magnesium to fluoride ratios. In the studied area, it has also been observed that many waters despite low T.D.S. have high fluoride level. Most of the fluoride waters were associated with Cl-HCO₃ type waters. Such waters are normally super saturated with respect to calcite and dolomite (Handa, 1983). Some of the high fluoride bearing waters have high Residual Sodium Carbonate values. The general relationship between fluorides and bicarbonates derived from calcite fluorite chemical equilibrium can be represented as:

$$K_{sp_{cal}} \cdot K_{sp_{flr}} = HCO_3^- / [aH + (aF)^2]$$

Where, K_{sp} refers to the solubility product of respective minerals and activity of ions is expressed by the symbol 'a'. This relationship suggests that activity of fluoride ions is proportional to that of HCO₃⁻ ions and independent of Ca²⁺ ion activity.

Fluoride content in water depends not only on the geochemical background and climate-biological factors, but also on the adsorption

and leaching of fluoride in soil. The adsorption-leaching process directly affects fluoride migration and exchange from soil to water and vice-versa. Increase in fluoride content, sodium content and pH of soil as well as of groundwater itself with the increase in fluoride concentration of irrigation water, indicate that every year enrichment of fluoride is going on. But this enrichment of groundwater is not taking place from the surface soil, because in surface soil, even fluoride concentration is increasing and the increase is more in the soil where more water has been applied i.e. wheat crop. This, further support that though due to release of fluoride from fluoride bearing minerals groundwater fluoride concentration has increased but at the same time fluoride concentration in surface soil has also increased due to increase in sodium content as well as pH of soil and groundwater. This indicate that alkaline pH and sodium ions are the important parameters for maintaining adsorption-release behaviour of fluoride content in soils.

5.5 Evaluation of soil fluoride build-up under wheat and mustard

The ability of different soils to adsorb fluoride can be explained as saturation fluoride adsorbing capacity, which indicate that the adsorption of fluoride in soil decreases from humid areas to arid areas and from acid soils to alkaline soils. The present study area being in semi-arid climate and soils being having alkaline pH have shown less build up or adsorption of fluoride in soil. Further, the fluoride build-up in soil was in accordance to fluoride concentration in irrigation water and the average build up in mustard crop was comparatively less than wheat crop. Owing to application of lesser amount of irrigation water in mustard than wheat crop.

5.6 Impact of different categories of fluoride waters on quality of wheat and mustard

The exact mechanism by which fluoride causes damage to plants is little understood, however, certain plant species have been observed to be injured as a result of accumulation of excessive fluoride from the environment. Certain physiological processes are known to be markedly affected by fluoride concentration. A decrease in chlorophyll content of plant leaves (McNulty and Newman, 1961), a diminished rate of photosynthesis (Thomas and Hendricks, 1956), decreased plant growth (Bonner and Thimann, 1950) and increased respiration in growing plants (McNulty and Newman, 1957) have been reported. In the present investigation also with the increase in fluoride content of water and soil, an increase in fluoride content of plant was observed, which resulted in decreased chlorophyll content in leaves, reduction in some plant nutrients (P & K) and also reduced crop yield. A highly significant relationship of soil fluoride and ground water fluoride with plant fluoride evidently indicated that both soil and water were the cause to fluoride accumulation in plant. However, accumulation of fluoride in plant system varied with plant species i.e. more accumulation in wheat than mustard. Further, as expected much more fluoride content was observed in straw/stover as compared to grain/seed. This implies that the crops grown with fluoride enriched waters can absorb, translocated and accumulated fluoride (Goutam *et al.*, 2010). Thus, after going through all the data, it can be inferred that increase of fluoride content in water as well as in soil results in increase of fluoride content of plants. However, the magnitude of increase varies with the crop. Increased fluoride content of plant might have hampered some of the plant physiological processes, thereby decrease in yield of mustard and wheat crops.

6. SUMMARY AND CONCLUSION

A field survey cum experimentation study entitled “Status of fluoride in underground irrigation water of Ladnu tehsil (Nagaur district) and its effect on wheat and mustard” was undertaken in 31 villages of Ladnu tehsil. Ground water samples were collected from 100 tube wells in the study area. Simultaneously, composite soil samples of 0–15 cm depth were also collected from each site. Thereafter, on the basis of inventory survey of 100 sites at 20 sites i.e. 4 sites for each type of fluoride water, experimentation had been done for two years with wheat and mustard crops. From these 20 sites every year soil, water and plant samples were collected. The collected samples were analysed for different constituents and results are summarized and concluded as under

6.1 Characterization of ground waters and soils of Ladnu tehsil

6.1.1 Quality assessment of ground water

- I. Sodium was found dominant cation in ground irrigation waters of Ladnu tehsil followed by magnesium, calcium and potassium.
- II. Among anions, chloride was observed as dominant anion followed by bicarbonate, sulphate and carbonate.
- III. The pH of ground irrigation waters indicated that 99 per cent waters belong to marginally alkaline category, which might be due to dominance of sodium as well as carbonate + bicarbonate ions.
- IV. The EC of irrigation waters showed that only 23 per cent waters belong to saline category and rest 67 per cent waters varied from slightly saline to medium salinity.

- v. Most of the waters have low sodicity to medium sodicity hazard, only 27 per cent irrigation waters have high to very high sodicity hazard.
- vi. Groundwater samples have shown non alkali to medium alkali hazard but majority of waters belonged to low alkali hazard class.

6.1.2 Characterization of soils

- i. The soil pH indicated that 83 per cent soils belong to marginally alkaline class, which could be due to dominance of carbonates and bicarbonate of calcium, magnesium and sodium.
- ii. The EC of soil showed that 97 per cent soils belong to normal category and only 3 per cent soils varied from slightly saline to medium salinity.
- iii. Most of the soils have low sodicity to medium sodicity hazard, only 3 per cent soils had high sodicity hazard.

6.2 Categorization of ground waters of Ladnu tehsils on the basis of fluoride content

- i. Fluoride content of ground water varied from 1.60 to 8.80 mg L⁻¹, indicating a good degree of variation in fluoride content.
- ii. Most of the groundwaters (69%) had fluoride concentration from 2.1 mg L⁻¹ to 6.0 mg L⁻¹.
- iii. The highest mean fluoride value of 7.80 mg L⁻¹ was recorded in Khamiyad Gram panchayat followed by Mangalpura Gram panchayat (6.07 mg L⁻¹). The lowest mean value (2.05 mg L⁻¹) of fluoride was registered with Ratau Gram panchayat.

6.3 Interrelationships of soil fluoride with various soil and water parameters

6.3.1 Interrelationships of soil fluoride with soil parameters

- i. A correlation analysis depicted positive relationship between soil fluoride and soil pH, soil fluoride and EC with $r=+0.243$ and $+0.215$, respectively. These correlations were all moderate, suggesting that the parameters like pH and EC contribute greatly to the bioavailability of fluoride ion in soil.
- ii. Correlation analysis depicted positive but weak relationship between soil fluoride and calcium, soil fluoride and magnesium with $r= +0.074$ and $+0.029$, respectively. Whereas, positive and moderate relationship was observed between soil fluoride and sodium with $r= +0.210$.
- iii. Available soil nitrogen ($r= -0.036$) and phosphorus ($r= -0.138$) have shown negative and non significant relationship with soil fluoride content, however, in case of available potassium, negative but highly significant ($r= -0.257^{**}$) relationship was observed.
- iv. The correlation coefficient of soil fluoride with $\text{CO}_3^{2-} + \text{HCO}_3^-$ ($r=0.083$), Cl^- ($r=0.208^*$) and SO_4^{2-} ($r=0.175$) indicated positive relationship but significant relationship was found only with chloride ion.
- v. Correlation analysis showed positive and significant relationship between soil fluoride and SAR, soil fluoride and ESP with $r=0.200^*$ and $r=0.202^*$, respectively.

6.3.2 Interrelationships of soil fluoride with water parameters

- i. The correlation coefficient between soil fluoride and EC of water ($r=0.430^*$) showed a significant and positive relationship. The correlation coefficient of soil fluoride with cations, anions, RSC and SAR also showed a positive and significant relationship.
- ii. The correlation coefficient between soil fluoride and fluoride in groundwater has a highly significant positive ($r=0.728^{**}$) relationship.

6.4 Impact of different categories of fluoride waters on soil and ground water quality

6.4.1 Soil parameters

- I. With the successive increase in the groundwater fluoride categories an increase in soil pH was observed during both the years.
- II. No definite trend of soil EC, SAR, ESP, organic carbon, available nitrogen, available phosphorus and available potassium was noted with the successive increase in groundwater fluoride categories during both the years.

6.4.2 Water parameters

- I. With the increase in fluoride content of groundwater, pH, EC, sodium, fluoride, $\text{CO}_3^{2-} + \text{HCO}_3^-$, RSC and SAR of ground water also increased during both the years.
- II. No definite trend of $\text{Ca}^{2+} + \text{Mg}^{2+}$, K^+ , Cl^- , and SO_4^{2-} values of groundwater was observed with respect to groundwater fluoride categories during both the years.

6.5 Evaluation of soil fluoride buildup under wheat and mustard crop

- i. Soils being having alkaline pH have shown low build up or adsorption of fluoride in soil.
- ii. The fluoride build-up in soil was in accordance to fluoride concentration in irrigation water and the average build up under mustard crop was comparatively less than wheat crop. This could be due to application of lesser amount of irrigation water in mustard than wheat crop.

6.6 Impact of different categories of fluoride quality of wheat and mustard

- i. With the increase in fluoride content of groundwater and soil, an increase in fluoride content of plant was observed, which resulted in decreased chlorophyll content in leaves, reduction in plant nutrient content (P & K) and also reduced crop yield.
- ii. A highly significant relationship of soil fluoride and groundwater fluoride with plant fluoride indicated that both soil and groundwater contributed to fluoride accumulation in plant.
- iii. Accumulation of fluoride in plant system varied with plant species i.e. more accumulation in wheat than mustard. Further, as expected much more fluoride content was observed in straw/stover as compared to grain/seed.

CONCLUSION

The majority of groundwaters of the studied area were found in marginally alkaline category. Most of the water samples in the study area evidenced excess fluoride concentrations, mainly due to dissolution from fluoride bearing minerals. The soils of the area had shown slight to moderate sodicity problem. Low fluoride content of soils in comparison to groundwater fluoride at the same sites, revealed minimum sorption of fluoride due to alkaline sandy type soil and most of fluoride leaches into groundwater. Soil fluoride content had positive and significant relation with pH, EC, Na^+ , Cl^- , SAR and ESP while, negative and non-significant relation with organic carbon, available nitrogen and RSC of soil parameters. Further, soil fluoride had positive and significant relation with EC, Fluoride, RSC, SAR, cations and anions of groundwater. Both soil fluoride and groundwater fluoride contributed to accumulation of fluoride in plants. Accumulation of fluoride in plant system varied with plant species i.e. more accumulation in wheat than mustard. Further, increase in the fluoride content of groundwater, resulted in decreased yield of both the crops.

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**Status of Fluoride in under ground irrigation water of Ladnu tehsil
(Nagaur district) and its effect on wheat and mustard**

Rajendra Kumar Jakhar*
(Scholar)

Dr. I.J. Gulati**
(Major Advisor)

ABSTRACT

The present investigation "Status of Fluoride in under ground irrigation water of Ladnu tehsil (Nagaur district) and its effect on wheat and mustard" was undertaken in two phases for two consecutive years 2007-08, 2008-09. In first phase an inventory survey of the area had been done, where in 100 ground water and soil samples were collected from 31 fluoride affected villages of Ladnu tehsil during 2007. During second phase, based on the fluoride content of 100 water samples collected during inventory survey five categories of water were framed, viz. F_1 : < 2.0 mg L⁻¹ fluoride, F_2 : 2.1 – 4.0 mg L⁻¹ fluoride, F_3 : 4.1 – 6.0 mg L⁻¹ fluoride, F_4 : 6.1 – 8.0 mg L⁻¹ fluoride and F_5 : > 8.0 mg L⁻¹ fluoride. Thereafter, for each category of fluoride water four sites were selected for monitoring the changes in the soil and crops *i.e.* mustard and wheat and also in the quality of ground water, as a result of use of fluoride waters.

Ground irrigation waters of Ladnu tehsil indicated that 99 per cent waters belong to marginally alkaline category. 23 per cent waters belong to saline category and rest 67 per cent waters varied from slightly saline to medium salinity. Most of the waters have low sodicity to medium sodicity hazard, only 27 per cent irrigation waters have high to very high sodicity hazard. Waters of study area also have non alkali to medium alkali hazard and majority of waters fell in low alkali hazard class. Majority of soils of Ladnu tehsil belong to marginally alkaline class. Most of the soils have low sodicity to medium sodicity hazard and only 3 per cent soils had high sodicity hazard.

The fluoride content of ground water varied from 1.60 to 8.80 mg L⁻¹, indicating a good degree of variations in fluoride content. Further, most of the waters (69%) of the studied area had fluoride concentration from 2.1 mg L⁻¹ to 6.0 mg L⁻¹.

Positive correlations between soil fluoride and soil pH, soil fluoride and EC was observed, indicated that the fluoride content increases with soil pH and EC, respectively. While, positive and moderate relationship was observed between soil fluoride and sodium.

* Research Scholar , thesis submitted for Ph.D. degree in Department of Soil Science and Agricultural Chemistry; College of Agriculture, SKRAU, Bikaner – 334 006.

** Professor and Dean, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner – 334 006

Soil fluoride vs pH of water and soil fluoride vs EC of water have also shown positive relationship.

The present study area being in semi-arid climate and soils being having alkaline pH have shown less build up or adsorption of fluoride in soil. Further, the fluoride build-up in soil was in accordance to fluoride concentration in irrigation water and the average build up in mustard crop was much less than wheat crop.

In the present investigation, with the increase in fluoride content of water and soil, an increase in fluoride content of plant was also observed, which resulted in decreased chlorophyll content of leaves reduction in some plant nutrients (P & K) and thereby reduced crop yield. A highly significant relationship of soil fluoride and ground water fluoride with plant fluoride evidently indicated that both soil and water were the cause for fluoride accumulation in plant. However, accumulation of fluoride in plant varied with plant species i.e. more accumulation in wheat than mustard. Further, as expected much more fluoride content was observed in straw/stover as compared to grain/seed.

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 $\frac{1}{4}$ * kk/kkFkh $\frac{1}{2}$

Mk- vkb- t- xyVh**
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vu{k i .k

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 8-0 feyhxe ifr yhVj e ckVk x;kA bld i'pkr] iR;d fl_ykjkbM
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 ifr'kr ty U;u yo.kh; l ydj e/e yo.kh; ox l lEcfu/kr ik;
 x;A vf/kdk'k ty e de {kkjh;rk l e/e {kkjh;rk rFkk doy 27
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* 'kk/k Nk=] fo[k okpLifr] enk foKku ,o df"k jlk;u foHkxx] df"k egkfo|ky;] Lokeh
 d'kokun jk t- df"k fo'ofok|ky;] chdkujA

** ikpk; ,o vf/k"Bkrkj df"k egkfo|ky;] Lokeh d'kokun jk t- df"k fo'ofok|ky;] chdkujA

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e/;e {kkj ldV ox l rFkk 3 ifr'kr enk mPp {kkjh; ldV ox l
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ih-,p- vkj fo|r pkydrk c<u l ¶ykbM dh ek=k c<rh gA enk
¶ykbM vkj lkFm;e e /kukRed o e/;e lEcU/k ik;k x;kA enk
¶ykbM vkj ty ih-,p- rFkk enk ¶ykbM vkj ty fo|r pkydrk
d e/; Hkh /kukRed lglEcU/k nf'kr gvKA

oreku v/;;u {k= d v)&'k"d tyok; vkj enk dk ih-,p-
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enk e ¶ykbM LFkkiuk flpkb ty ¶ykbM dh ek=k dh dh vu#irk
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ik/kk e Hkh ¶ykbM dh ek=k c<h ftld dkj.k ifRr;k e gfjr yod
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d QyLo#i Qly mRiknu de gvKA enk ¶ykbM vkj ty ¶ykbM
dk ikni ¶ykbM d lkFk lkFkd lEcU/k ik;k x;k tk bfxr djrk g
fd enk vkj ty nkuk ikni e ¶ykbM lp; dk dkj.k gA gkykfd]
ikni e ¶ykbM lp; fofof/krk ikni itkfr ij Hkh fuHkj djrk g
tl fd xg e ljlk dh vi{kk vf/kd ¶ykbM lp; A bld vfrfjDr
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ek=k cgr vf/kd ikb xBA

Appendix – I

Characteristics of underground irrigation waters of Ladnu tehsil

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	RSC (me L ⁻¹)	SAR
1	Khamiyad	8.20	6.24	1.40	21.05
2	Dhudia	8.10	6.73	3.20	26.29
3	Ratau (a)	7.80	2.97	1.00	10.57
4	Ratau (b)	7.80	4.43	0.40	15.52
5	Ratau (c)	8.00	2.79	0.40	8.49
6	Ratau (d)	8.10	4.43	0.20	14.10
7	Ratau (e)	8.20	4.80	0.20	19.62
8	Ratau (f)	8.20	4.92	2.80	21.29
9	Sikarali	8.10	6.95	0.40	28.87
10	Malgoan (a)	8.20	4.85	4.00	19.16
11	Malgoan (b)	8.30	5.52	0.40	21.04
12	Malgoan (c)	8.00	5.64	0.20	20.68
13	Sandas (a)	8.20	7.12	0.20	26.61
14	Sandas (b)	8.50	3.17	0.40	8.61
15	Sandas (c)	8.10	7.20	3.60	22.83
16	Sandas (d)	8.20	6.52	0.60	26.83
17	Bhakaran ki Dhani (a)	8.10	5.52	0.40	17.80
18	Bhakaran ki Dhani (b)	8.10	5.64	2.00	18.78
19	Bhakaran ki Dhani (c)	8.20	4.95	2.80	19.98
20	Lokat	8.30	5.29	3.20	20.61
21	Genana (a)	8.00	3.96	0.80	18.49
22	Genana (b)	8.30	2.65	1.60	10.89
23	Baladoo (a)	8.50	2.56	0.20	9.16
24	Baladoo (b)	8.30	3.51	2.40	12.22
25	Baladoo (c)	8.40	3.23	2.60	12.58
26	Baladoo (d)	8.40	3.45	1.60	11.96
27	Baladoo (e)	8.30	3.30	2.60	14.47
28	Khokhari (a)	8.20	2.69	2.20	9.86
29	Khokhari (b)	8.00	2.71	3.00	9.96
30	Nimbi Jhodha (a)	8.20	2.95	0.60	9.03
31	Nimbi Jhodha (b)	7.90	2.80	0.60	9.69
32	Beron ki Dhani (a)	8.10	3.10	2.60	10.73
33	Beron ki Dhani (b)	7.90	2.93	0.40	9.31
34	Beron ki Dhani (c)	7.80	2.71	3.60	10.68
35	Jhardia (a)	7.90	2.86	0.60	9.29
36	Jhardia (b)	7.90	2.57	0.20	10.42
37	Jhardia (c)	8.00	2.74	1.20	11.96
38	Jhardia (d)	7.90	2.50	1.80	10.31
39	Jhardia (e)	7.90	4.34	3.80	16.43

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	RSC (me L ⁻¹)	SAR
40	Bharnawa (a)	8.00	5.80	6.20	24.53
41	Bharnawa (b)	7.90	5.61	1.20	18.91
42	Hudas (a)	7.90	5.34	0.60	19.62
43	Hudas (b)	8.10	5.97	3.00	20.98
44	Hudas (c)	7.80	5.28	3.00	21.96
45	Bharnawa (c)	8.00	5.48	3.20	19.14
46	Bharnawa (d)	7.50	4.49	1.80	14.83
47	Bharnawa (e)	7.80	4.52	7.20	19.22
48	Manoo	7.90	3.60	1.20	10.05
49	Chandai (a)	8.10	4.03	0.20	13.02
50	Chandai (b)	7.90	2.95	1.80	11.95
51	Lukas (a)	8.00	3.30	1.60	13.83
52	Lukas (b)	7.80	2.59	3.80	9.79
53	Lukas (c)	8.00	2.92	0.80	11.24
54	Lukas (d)	7.80	2.74	1.00	9.36
55	Lukas (e)	8.00	3.10	0.60	8.92
56	Lukas (f)	8.10	3.67	0.80	12.21
57	Audint (a)	7.90	2.90	1.40	10.15
58	Audint (b)	8.20	3.61	2.20	12.18
59	Audint (c)	8.10	2.72	1.40	9.17
60	Audint (d)	8.00	2.90	1.40	11.82
61	Audint (e)	7.90	2.56	0.80	7.30
62	Audint (f)	8.10	2.95	1.60	8.84
63	Heerawati (a)	7.70	2.39	1.00	6.30
64	Heerawati (b)	7.90	2.91	0.40	9.38
65	Heerawati (c)	8.10	4.69	2.20	13.94
66	Sonari (a)	8.00	2.57	1.40	9.92
67	Sonari (b)	8.00	2.72	0.60	8.52
68	Sonari (c)	8.20	2.32	0.80	7.91
69	Sonari (d)	8.10	3.98	2.60	14.18
70	Sonari (e)	8.40	4.24	0.40	11.62
71	Ladnu	8.20	4.13	3.20	12.42
72	Mangalpura	8.10	2.90	1.20	10.68
73	Natas (a)	8.20	2.60	0.20	7.81
74	Natas (b)	8.10	7.26	0.60	26.18
75	Dujar (a)	8.20	3.35	2.40	10.07
76	Dujar (b)	8.00	6.48	0.20	23.19
77	Dujar (c)	8.10	5.37	0.80	20.38
78	Bakolia (a)	8.20	2.62	1.80	8.42
79	Bakolia (b)	8.10	2.23	0.80	7.49
80	Bakolia (c)	8.20	2.86	0.80	8.78
81	Bakolia (d)	8.00	4.42	2.00	14.95

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	RSC (me L ⁻¹)	SAR
82	Bakolia (e)	8.10	4.48	0.40	13.90
83	Baded (a)	8.20	2.98	3.60	10.60
84	Baded (b)	7.90	2.53	3.40	10.22
85	Baded (c)	8.10	2.90	1.20	8.76
86	Baded (d)	7.80	2.55	0.60	7.01
87	Bheid (a)	8.10	2.30	0.80	6.87
88	Bheid (b)	8.00	2.78	6.20	10.26
89	Bheid (c)	7.80	2.36	1.20	8.37
90	Bheid (d)	8.00	8.05	1.40	31.03
91	Bheid (e)	8.20	8.10	1.20	33.84
92	Koyal (a)	8.10	2.78	5.20	11.83
93	Koyal (b)	7.90	2.38	2.80	8.50
94	Koyal (c)	8.20	2.80	5.00	10.43
95	Koyal (d)	8.00	2.65	1.80	8.59
96	Dhuria (a)	8.30	2.96	4.00	10.99
97	Dhuria (b)	8.00	2.78	2.00	9.21
98	Dhuria (c)	8.40	3.12	1.60	10.81
99	Khangar (a)	7.90	3.18	2.80	10.07
100	Khangar (b)	8.20	2.73	3.00	11.57
	Maximum	8.50	8.10	7.20	33.84
	Minimum	7.50	2.23	0.20	6.30
	Average	8.06	3.87	1.79	13.90

Appendix – II

Cationic composition of underground irrigation waters of Ladnu tehsil.

S. No.	Name of Villages	Cationic composition (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
1	Khamiyad	3.60	8.00	50.69	0.11
2	Dhudia	3.20	6.40	57.60	0.10
3	Ratau (a)	3.20	5.00	21.41	0.09
4	Ratau (b)	3.60	6.20	34.36	0.15
5	Ratau (c)	3.80	5.60	18.40	0.10
6	Ratau (d)	5.80	5.20	33.07	0.23
7	Ratau (e)	3.20	5.00	39.72	0.08
8	Ratau (f)	2.40	5.20	41.50	0.10
9	Sikarali	5.20	3.60	60.56	0.14
10	Malgoan (a)	3.20	5.40	39.74	0.16
11	Malgoan (b)	3.60	5.80	45.62	0.18
12	Malgoan (c)	3.80	6.20	46.25	0.15
13	Sandas (a)	5.00	5.40	60.67	0.13
14	Sandas (b)	3.60	7.60	20.38	0.13
15	Sandas (c)	5.80	7.40	58.66	0.14
16	Sandas (d)	2.60	6.20	56.29	0.12
17	Bhakaran ki Dhani (a)	3.20	8.60	43.25	0.15
18	Bhakaran ki Dhani (b)	2.40	9.00	44.84	0.16
19	Bhakaran ki Dhani (c)	3.20	5.20	40.95	0.15
20	Lokat	2.80	6.20	43.73	0.17
21	Genana (a)	1.60	4.80	33.07	0.13
22	Genana (b)	2.40	4.20	19.78	0.13
23	Baladoo (a)	3.20	4.40	17.86	0.14
24	Baladoo (b)	3.60	5.40	25.93	0.17
25	Baladoo (c)	2.60	5.00	24.53	0.17
26	Baladoo (d)	2.80	6.20	25.37	0.13
27	Baladoo (e)	2.20	4.40	26.28	0.12
28	Khokhari (a)	2.20	5.40	19.22	0.08
29	Khokhari (b)	3.40	4.20	19.41	0.09
30	Nimbi Jhodha (a)	2.60	7.00	19.79	0.11
31	Nimbi Jhodha (b)	3.20	5.00	19.63	0.18
32	Beron ki Dhani (a)	4.00	4.60	22.25	0.15
33	Beron ki Dhani (b)	2.60	6.60	19.97	0.13
34	Beron ki Dhani (c)	3.00	4.00	19.98	0.12
35	Jhardia (a)	3.20	5.40	19.26	0.14
36	Jhardia (b)	1.80	4.80	18.93	0.17

S. No.	Name of Villages	Cationic composition (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
37	Jhardia (c)	2.20	4.00	21.06	0.15
38	Jhardia (d)	1.60	4.80	18.45	0.15
39	Jhardia (e)	3.60	5.20	34.47	0.14
40	Bharnawa (a)	2.40	5.80	49.66	0.14
41	Bharnawa (b)	5.40	5.80	44.75	0.15
43	Hudas (b)	3.80	7.00	48.75	0.15
44	Hudas (c)	3.00	5.20	44.46	0.14
45	Bharnawa (c)	3.60	7.00	44.06	0.14
46	Bharnawa (d)	5.20	5.40	34.15	0.16
47	Bharnawa (e)	3.20	4.40	37.46	0.14
48	Manoo	5.60	6.00	24.21	0.19
49	Chandai (a)	4.60	5.80	29.69	0.21
50	Chandai (b)	3.40	3.60	22.35	0.15
51	Lukas (a)	3.20	3.80	25.87	0.13
52	Lukas (b)	3.60	3.60	18.58	0.12
53	Lukas (c)	2.40	5.00	21.62	0.18
54	Lukas (d)	2.60	5.60	18.96	0.24
55	Lukas (e)	2.60	7.80	20.34	0.27
56	Lukas (f)	4.60	5.00	26.75	0.35
57	Audint (a)	2.80	5.40	20.56	0.25
58	Audint (b)	4.20	5.20	26.40	0.30
59	Audint (c)	3.60	4.60	18.57	0.43
60	Audint (d)	2.20	4.60	21.80	0.40
61	Audint (e)	3.40	6.00	15.84	0.37
62	Audint (f)	3.20	6.60	19.57	0.13
63	Heerawati (a)	3.40	6.40	13.94	0.17
64	Heerawati (b)	3.60	5.40	19.89	0.21
65	Heerawati (c)	4.40	7.80	34.43	0.28
66	Sonari (a)	3.00	4.00	18.56	0.14
67	Sonari (b)	3.60	5.40	18.07	0.13
68	Sonari (c)	4.20	3.40	15.43	0.18
69	Sonari (d)	4.20	5.00	30.41	0.20
70	Sonari (e)	5.40	7.40	29.41	0.19
71	Ladnu	5.20	6.20	29.65	0.25
72	Mangalpura	2.00	5.80	21.10	0.11
73	Natas (a)	3.80	5.40	16.75	0.05
74	Natas (b)	3.40	7.60	61.39	0.21
75	Dujar (a)	4.60	5.80	22.97	0.13
76	Dujar (b)	4.00	6.80	53.88	0.12
77	Dujar (c)	3.80	5.60	44.18	0.12
78	Bakolia (a)	4.20	4.40	17.45	0.15
79	Bakolia (b)	2.00	5.60	14.60	0.10

S. No.	Name of Villages	Cationic composition (me L ⁻¹)			
		Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺
80	Bakolia (c)	3.40	6.00	19.03	0.17
81	Bakolia (d)	4.40	5.80	33.77	0.24
82	Bakolia (e)	4.80	6.60	33.18	0.22
83	Baded (a)	2.80	5.40	21.46	0.14
84	Baded (b)	2.00	4.60	18.57	0.13
85	Baded (c)	3.20	6.40	19.19	0.21
86	Baded (d)	4.60	5.20	15.53	0.18
87	Bheid (a)	2.80	5.80	14.24	0.16
89	Bheid (c)	2.60	4.80	16.11	0.10
90	Bheid (d)	4.60	5.60	70.08	0.22
91	Bheid (e)	4.40	4.60	71.79	0.21
92	Koyal (a)	2.60	3.80	21.17	0.23
93	Koyal (b)	2.80	4.60	16.35	0.05
94	Koyal (c)	2.80	4.80	20.33	0.08
95	Koyal (d)	4.20	4.40	17.82	0.08
96	Dhuria (a)	3.60	4.20	21.71	0.09
97	Dhuria (b)	3.80	4.80	19.10	0.10
98	Dhuria (c)	4.20	4.40	22.42	0.18
99	Khangar (a)	3.80	5.80	22.06	0.14
100	Khangar (b)	1.80	4.60	20.71	0.20
	Maximum	5.80	9.00	71.79	0.43
	Minimum	1.60	3.40	13.94	0.05
	Average	3.43	5.50	29.57	0.16

Appendix- III

Anionic composition of underground irrigation waters of Ladnu tehsil.

S.No.	Name of Villages	Anionic composition (me L ⁻¹)			
		F (mg L ⁻¹)	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
1	Khamiyad	7.80	13.00	43.80	5.60
2	Dhudia	5.60	12.80	36.80	17.70
3	Ratau (a)	1.60	9.20	17.20	3.30
4	Ratau (b)	2.70	10.20	34.00	0.10
5	Ratau (c)	1.60	9.80	18.00	0.10
6	Ratau (d)	1.60	11.20	31.80	1.30
7	Ratau (e)	2.40	8.40	37.00	2.60
8	Ratau (f)	2.90	10.40	35.00	3.80
9	Sikarali	8.80	9.20	57.00	3.30
10	Malgoan (a)	7.50	12.60	34.80	1.10
11	Malgoan (b)	8.70	9.80	39.60	5.80
12	Malgoan (c)	5.10	10.20	45.00	1.20
13	Sandas (a)	4.90	10.60	46.80	13.80
14	Sandas (b)	3.60	11.60	16.60	3.50
15	Sandas (c)	7.80	16.80	40.60	14.60
16	Sandas (d)	5.20	9.40	53.60	2.20
17	Bhakaran ki Dhani (a)	4.40	12.20	36.20	6.80
18	Bhakaran ki Dhani (b)	4.20	13.40	37.80	5.20
19	Bhakaran ki Dhani (c)	5.40	11.20	37.20	1.10
20	Lokat	4.40	12.20	40.00	0.70
21	Genana (a)	2.30	7.20	32.20	0.20
22	Genana (b)	1.60	8.20	17.60	0.70
23	Baladoo (a)	4.80	7.80	17.40	0.40
24	Baladoo (b)	5.20	11.40	21.80	1.90
25	Baladoo (c)	4.30	10.20	21.00	1.10
26	Baladoo (d)	4.10	10.60	19.40	4.50
27	Baladoo (e)	4.90	9.20	20.40	3.40
28	Khokhari (a)	4.20	9.80	16.60	0.50
29	Khokhari (b)	5.40	10.60	16.40	0.10
30	Nimbi Jhodha (a)	5.90	10.20	16.80	2.50
31	Nimbi Jhodha (b)	5.70	8.80	18.60	0.60
32	Beron ki Dhani (a)	4.50	11.20	18.80	1.00
33	Beron ki Dhani (b)	3.40	9.60	19.60	0.10
34	Beron ki Dhani (c)	4.80	10.60	13.60	2.90
35	Jhardia (a)	3.10	9.80	14.40	4.40
36	Jhardia (b)	3.20	6.80	18.80	0.10

S.No.	Name of Villages	Anionic composition (me L ⁻¹)			
		F (mg L ⁻¹)	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
37	Jhardia (c)	3.60	7.40	16.40	3.60
38	Jhardia (d)	1.60	8.20	15.20	1.60
39	Jhardia (e)	6.60	12.60	29.20	1.60
40	Bharnawa (a)	6.10	14.40	37.00	6.60
41	Bharnawa (b)	5.20	12.40	37.60	6.10
42	Hudas (a)	3.30	10.40	35.60	7.40
44	Hudas (c)	4.50	11.20	37.20	4.40
45	Bharnawa (c)	5.10	13.80	39.60	1.40
46	Bharnawa (d)	4.20	12.40	23.00	9.50
47	Bharnawa (e)	5.80	14.80	25.60	4.80
48	Manoo	3.20	12.80	21.00	2.20
49	Chandai (a)	5.80	10.60	27.20	2.50
50	Chandai (b)	3.50	8.80	20.00	0.70
51	Lukas (a)	3.30	8.60	19.20	5.20
52	Lukas (b)	3.10	11.00	14.40	0.50
53	Lukas (c)	3.50	8.20	19.00	2.00
54	Lukas (d)	3.20	9.20	17.20	1.00
55	Lukas (e)	2.90	11.00	19.00	1.00
56	Lukas (f)	4.40	10.40	22.60	3.70
57	Audint (a)	1.60	9.60	18.20	1.20
58	Audint (b)	4.20	11.60	24.40	0.10
59	Audint (c)	1.60	9.60	16.60	1.00
60	Audint (d)	1.60	8.20	20.40	0.40
61	Audint (e)	1.60	10.20	14.80	0.60
62	Audint (f)	1.60	11.40	17.60	0.50
63	Heerawati (a)	1.60	10.80	12.80	0.30
64	Heerawati (b)	1.60	9.40	19.40	0.30
65	Heerawati (c)	4.50	14.40	22.40	10.10
66	Sonari (a)	3.60	8.40	16.60	0.70
67	Sonari (b)	1.60	9.60	15.20	2.40
68	Sonari (c)	1.60	8.40	12.80	2.00
69	Sonari (d)	4.40	11.80	25.20	2.80
70	Sonari (e)	4.10	13.20	24.80	4.40
71	Ladnu	5.10	14.60	18.80	7.90
72	Mangalpura	8.20	9.00	18.20	1.80
73	Natas (a)	3.70	9.40	14.60	2.00
74	Natas (b)	6.30	11.60	51.80	9.20
75	Dujar (a)	6.80	12.80	20.20	0.50
76	Dujar (b)	8.10	11.00	48.80	5.00
77	Dujar (c)	7.50	10.20	42.80	0.70
78	Bakolia (a)	3.70	10.40	15.20	0.60

S.No.	Name of Villages	Anionic composition (me L ⁻¹)			
		F (mg L ⁻¹)	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
79	Bakolia (b)	6.30	8.40	13.80	0.10
80	Bakolia (c)	7.30	10.20	17.40	1.00
81	Bakolia (d)	6.70	12.20	29.80	2.20
82	Bakolia (e)	4.70	11.80	25.00	8.00
83	Baded (a)	5.00	11.80	17.20	0.80
84	Baded (b)	4.80	10.00	12.80	2.50
85	Baded (c)	4.40	10.80	17.20	1.00
86	Baded (d)	3.70	10.40	14.40	0.70
87	Bheid (a)	4.30	9.40	13.00	0.60
88	Bheid (b)	7.60	13.80	13.20	0.80
90	Bheid (d)	5.70	11.60	27.80	41.10
91	Bheid (e)	4.10	10.20	32.40	38.40
92	Koyal (a)	5.10	11.60	15.20	1.00
93	Koyal (b)	4.20	10.20	12.60	1.00
94	Koyal (c)	5.60	12.60	13.80	1.60
95	Koyal (d)	5.50	10.40	13.40	2.70
96	Dhuria (a)	5.60	11.80	16.20	1.60
97	Dhuria (b)	5.20	10.60	15.40	1.80
98	Dhuria (c)	5.90	10.20	20.40	0.60
99	Khangar (a)	6.10	12.40	15.00	4.40
100	Khangar (b)	3.80	9.40	16.80	1.10
	Maximum	8.80	16.80	57.00	41.10
	Minimum	1.60	6.80	10.60	0.10
	Average	4.47	10.72	24.33	3.62

Appendix – IV

Characteristics of soil of selected villages of Ladnu tehsil

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	O.C. %	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)
1	Khamiyad	8.50	2.93	0.11	106.20	13.78	134.40
2	Dhudia	8.70	0.50	0.18	173.78	14.67	122.45
3	Ratau (a)	8.60	0.69	0.14	132.86	14.83	140.37
4	Ratau (b)	8.30	0.59	0.10	93.00	11.91	173.23
5	Ratau (c)	8.60	0.47	0.12	119.57	14.68	140.37
6	Ratau (d)	8.40	0.42	0.15	146.14	14.65	188.16
7	Ratau (e)	8.50	0.34	0.19	186.00	15.75	152.32
8	Ratau (f)	8.40	0.66	0.15	146.14	15.22	146.35
9	Sikarali	8.40	0.79	0.18	172.72	14.51	167.25
10	Malgoan (a)	8.30	0.65	0.11	106.29	12.00	191.15
11	Malgoan (b)	8.50	0.54	0.14	132.86	14.36	215.04
12	Malgoan (c)	8.30	0.62	0.15	146.14	14.48	182.19
13	Sandas (a)	8.20	0.79	0.10	96.54	11.80	155.31
14	Sandas (b)	8.60	0.52	0.15	146.14	14.30	188.16
15	Sandas (c)	8.40	0.77	0.22	212.57	10.10	167.25
16	Sandas (d)	8.40	1.02	0.15	146.14	13.33	170.24
17	Bhakaran ki Dhani(a)	8.30	0.61	0.12	119.57	12.70	182.19
18	Bhakaran ki Dhani(b)	8.10	0.56	0.18	172.72	15.65	194.13
19	Bhakaran ki Dhani(c)	8.30	0.37	0.21	199.29	18.60	179.20
20	Lokat	8.10	1.68	0.17	159.43	14.10	206.08
21	Genana (a)	8.30	0.49	0.21	199.29	15.80	152.32
22	Genana (b)	7.90	0.52	0.18	172.72	15.52	149.33
23	Baladoo (a)	8.10	0.43	0.17	159.43	15.88	170.24
24	Baladoo (b)	8.00	0.48	0.12	119.57	13.60	200.11
25	Baladoo (c)	8.30	0.62	0.18	172.72	15.34	203.09
26	Baladoo (d)	8.50	0.49	0.15	146.14	14.70	152.32
27	Baladoo (e)	8.00	0.52	0.11	109.83	12.40	161.28
28	Khokhari (a)	8.50	0.49	0.21	199.29	15.28	125.44
29	Khokhari (b)	7.70	0.43	0.18	173.78	13.70	134.40
30	Nimbi Jhodha (a)	8.10	0.39	0.14	132.86	15.25	221.01
31	Nimbi Jhodha (b)	7.90	0.34	0.15	146.14	13.10	209.07
32	Beron ki Dhani (a)	8.50	0.37	0.19	186.00	14.70	176.21
33	Beron ki Dhani (b)	8.40	0.45	0.15	146.14	10.80	155.31
34	Beron ki Dhani (c)	8.70	0.54	0.21	199.29	17.07	146.35
35	Jhardia (a)	8.10	0.64	0.10	93.00	15.68	167.25
36	Jhardia (b)	8.30	0.43	0.15	146.14	16.80	206.08
37	Jhardia (c)	7.50	0.39	0.21	199.29	14.00	173.23

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	O.C. %	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)
38	Jhardia (d)	7.30	0.52	0.14	132.86	16.33	179.20
39	Jhardia (e)	7.70	0.46	0.11	106.29	15.67	161.28
40	Bharnawa (a)	7.90	0.59	0.10	93.00	15.17	167.25
41	Bharnawa (b)	7.90	0.51	0.12	119.57	15.58	179.20
42	Hudas (a)	7.80	0.62	0.11	106.20	15.71	209.07
43	Hudas (b)	8.00	0.45	0.17	159.43	13.04	179.20
44	Hudas (c)	7.70	0.34	0.15	146.14	15.51	188.16
45	Bharnawa (c)	7.80	0.45	0.12	119.57	15.61	167.25
46	Bharnawa (d)	7.50	0.58	0.12	115.85	16.95	185.17
47	Bharnawa (e)	7.30	0.41	0.08	94.06	16.30	170.24
48	Manoo	7.50	0.38	0.12	119.57	16.45	224.00
49	Chandai (a)	7.80	0.63	0.17	159.43	16.42	253.87
50	Chandai (b)	7.40	0.48	0.10	93.00	16.86	238.93
51	Lukas (a)	7.30	0.39	0.21	202.74	16.89	241.92
52	Lukas (b)	7.50	0.55	0.08	100.44	16.38	229.97
53	Lukas (c)	7.70	0.47	0.15	146.14	16.76	218.03
54	Lukas (d)	7.60	0.52	0.16	154.47	16.47	283.73
55	Lukas (e)	7.30	0.41	0.17	159.43	16.10	286.72
56	Lukas (f)	7.70	0.39	0.14	132.86	16.49	271.79
57	Audint (a)	7.60	0.33	0.17	159.43	16.17	292.69
58	Audint (b)	7.80	0.49	0.12	119.57	16.04	271.79
59	Audint (c)	7.40	0.55	0.17	159.43	16.47	277.76
60	Audint (d)	7.60	0.31	0.16	154.47	16.08	265.81
61	Audint (e)	7.70	0.36	0.25	239.15	14.09	256.85
62	Audint (f)	7.50	0.48	0.19	186.00	15.82	271.79
63	Heerawati (a)	7.80	0.52	0.14	132.86	15.04	215.04
64	Heerawati (b)	7.40	0.35	0.18	176.26	15.84	250.88
65	Heerawati (c)	7.50	0.41	0.22	212.57	15.26	238.93
66	Sonari (a)	7.80	0.32	0.19	186.00	15.25	197.12
67	Sonari (b)	7.90	0.26	0.12	119.57	15.28	188.16
68	Sonari (c)	7.70	0.37	0.15	146.14	15.11	209.07
69	Sonari (d)	8.00	0.42	0.11	106.29	15.11	232.96
70	Sonari (e)	7.90	0.39	0.10	93.00	14.24	229.97
71	Ladnu	8.10	0.33	0.14	132.86	15.49	295.68
72	Mangalpura	7.80	0.52	0.15	146.14	14.68	125.44
73	Natas (a)	8.40	0.61	0.10	93.00	14.09	131.41
74	Natas (b)	8.30	0.49	0.17	159.43	14.86	149.33
75	Dujar (a)	8.20	0.51	0.19	186.00	17.86	158.29
76	Dujar (b)	8.10	0.75	0.17	159.43	15.51	167.25
77	Dujar (c)	8.30	0.46	0.15	146.14	16.37	182.19
78	Bakolia (a)	7.90	0.48	0.08	98.85	16.28	176.21
79	Bakolia (b)	8.10	0.41	0.17	159.43	15.73	182.19
80	Bakolia (c)	8.00	0.57	0.14	132.86	14.24	203.09

S. No.	Name of Villages	pH	EC (dS m ⁻¹)	O.C. %	N (kg ha ⁻¹)	P ₂ O ₅ (kg ha ⁻¹)	K ₂ O (kg ha ⁻¹)
81	Bakolia (d)	7.60	0.66	0.12	119.57	15.37	191.15
82	Bakolia (e)	8.30	0.44	0.15	146.14	15.61	200.11
83	Baded (a)	7.60	0.76	0.10	93.00	14.09	226.99
84	Baded (b)	8.70	0.49	0.14	132.86	15.37	212.05
85	Baded (c)	8.00	0.41	0.18	172.72	15.43	247.89
86	Baded (d)	8.10	0.52	0.22	212.57	13.92	209.07
87	Bheid (a)	7.80	0.49	0.15	146.14	15.18	188.16
88	Bheid (b)	7.90	0.43	0.17	159.43	15.37	229.97
89	Bheid (c)	8.00	0.39	0.21	199.29	16.90	203.09
90	Bheid (d)	7.90	0.56	0.17	159.43	15.09	259.84
91	Bheid (e)	7.80	0.60	0.14	132.86	16.04	250.88
92	Koyal (a)	8.30	0.49	0.11	106.29	16.47	277.76
93	Koyal (b)	8.20	0.50	0.12	119.57	13.08	212.05
94	Koyal (c)	8.00	0.58	0.10	93.00	14.09	238.93
95	Koyal (d)	8.30	0.61	0.17	159.43	15.82	215.04
96	Dhuria (a)	8.10	0.49	0.14	132.86	15.04	226.99
97	Dhuria (b)	7.80	0.53	0.07	85.03	15.84	238.93
98	Dhuria (c)	8.40	0.44	0.15	146.14	15.26	215.04
99	Khangar (a)	8.20	0.47	0.14	132.86	13.79	224.00
100	Khangar (b)	8.50	0.62	0.08	102.04	13.07	232.96
	Maximum	8.70	2.93	0.25	239.15	18.60	295.68
	Minimum	7.30	0.26	0.07	85.03	10.10	122.45
	Average	8.02	0.54	0.15	144.33	15.07	200.05

Appendix – V

Characteristics of soil of selected villages of Ladnu tehsil

S.No.	Name of Villages	F (mg kg ⁻¹)	SAR	ESP
1	Khamiyad	2.22	19.63	21.69
2	Dhudia	1.87	1.35	0.73
3	Ratau (a)	0.80	2.00	1.67
4	Ratau (b)	1.10	2.32	2.12
5	Ratau (c)	0.80	1.77	1.34
6	Ratau (d)	0.70	1.72	1.26
7	Ratau (e)	1.20	1.08	0.32
8	Ratau (f)	0.90	2.69	2.63
9	Sikarali	2.80	3.38	3.59
10	Malgoan (a)	2.60	3.28	3.45
11	Malgoan (b)	2.60	2.26	2.04
12	Malgoan (c)	1.70	2.83	2.83
13	Sandas (a)	1.40	3.94	4.35
14	Sandas (b)	0.90	1.69	1.22
15	Sandas (c)	1.20	1.81	1.38
16	Sandas (d)	0.80	5.69	6.66
17	Bhakaran ki Dhani (a)	0.70	2.42	2.26
18	Bhakaran ki Dhani (b)	0.60	1.59	1.07
19	Bhakaran ki Dhani (c)	0.90	2.88	2.90
20	Lokat	0.50	8.15	9.72
21	Genana (a)	0.80	2.19	1.93
22	Genana (b)	0.50	1.24	0.56
23	Baladoo (a)	0.60	1.90	1.52
24	Baladoo (b)	0.70	1.10	0.36
25	Baladoo (c)	0.50	2.02	1.69
26	Baladoo (d)	0.40	1.94	1.57
27	Baladoo (e)	0.70	2.90	2.93
28	Khokhari (a)	0.60	1.08	0.33
29	Khokhari (b)	0.85	0.99	0.20
30	Nimbi Jhodha (a)	0.80	2.06	1.75
31	Nimbi Jhodha (b)	1.10	1.90	1.52
32	Beron ki Dhani (a)	0.90	1.87	1.48
33	Beron ki Dhani (b)	1.72	1.59	1.07
34	Beron ki Dhani (c)	0.80	1.06	0.30
35	Jhardia (a)	0.80	2.84	2.85
36	Jhardia (b)	0.90	1.66	1.18
37	Jhardia (c)	0.85	1.10	0.36
38	Jhardia (d)	0.61	1.02	0.25
39	Jhardia (e)	2.05	1.43	0.84

S.No.	Name of Villages	F (mg kg ⁻¹)	SAR	ESP
40	Bharnawa (a)	1.90	1.38	0.77
41	Bharnawa (b)	1.53	1.06	0.31
42	Hudas (a)	0.80	2.02	1.69
43	Hudas (b)	0.90	1.53	0.98
44	Hudas (c)	0.90	1.54	1.00
45	Bharnawa (c)	0.80	1.17	0.46
46	Bharnawa (d)	0.90	2.19	1.94
47	Bharnawa (e)	0.80	1.43	0.85
48	Manoo	0.70	1.61	1.10
49	Chandai (a)	0.60	2.82	2.81
50	Chandai (b)	0.90	3.12	3.23
51	Lukas (a)	0.70	1.02	0.24
52	Lukas (b)	0.60	2.10	1.81
53	Lukas (c)	0.70	1.33	0.70
54	Lukas (d)	0.60	1.75	1.30
55	Lukas (e)	0.48	1.21	0.52
56	Lukas (f)	0.80	2.12	1.83
57	Audint (a)	0.70	1.92	1.55
58	Audint (b)	1.10	1.55	1.02
59	Audint (c)	0.63	2.43	2.26
60	Audint (d)	0.50	1.13	0.41
61	Audint (e)	0.57	1.14	0.42
62	Audint (f)	0.60	2.38	2.20
63	Heerawati (a)	0.50	4.30	4.84
64	Heerawati (b)	0.60	1.65	1.16
65	Heerawati (c)	0.70	2.13	1.85
66	Sonari (a)	0.80	1.00	0.21
67	Sonari (b)	0.51	2.86	2.87
68	Sonari (c)	0.58	1.10	0.36
69	Sonari (d)	0.52	0.95	0.14
70	Sonari (e)	0.90	1.00	0.22
71	Ladnu	0.51	1.90	1.52
72	Mangalpura	2.40	2.20	1.94
73	Natas (a)	0.90	2.58	2.49
74	Natas (b)	2.32	1.37	0.76
75	Dujar (a)	2.20	1.21	0.52
76	Dujar (b)	2.50	2.96	3.02
77	Dujar (c)	2.30	1.44	0.86
78	Bakolia (a)	0.90	1.72	1.26
79	Bakolia (b)	2.10	1.09	0.34
80	Bakolia (c)	2.20	2.23	1.99
81	Bakolia (d)	2.30	2.81	2.80
82	Bakolia (e)	0.90	1.44	0.86

S.No.	Name of Villages	F (mg kg ⁻¹)	SAR	ESP
83	Baded (a)	1.00	2.63	2.55
84	Baded (b)	1.30	2.20	1.95
85	Baded (c)	1.80	1.67	1.19
86	Baded (d)	1.20	2.29	2.08
87	Bheid (a)	0.54	1.02	0.24
88	Bheid (b)	2.10	1.52	0.98
89	Bheid (c)	1.90	1.35	0.72
90	Bheid (d)	2.20	2.48	2.34
91	Bheid (e)	1.70	2.04	1.72
92	Koyal (a)	0.65	2.03	1.70
93	Koyal (b)	0.80	2.16	1.88
94	Koyal (c)	0.70	1.63	1.13
95	Koyal (d)	0.80	2.71	2.67
96	Dhuria (a)	1.30	1.77	1.33
97	Dhuria (b)	1.30	2.61	2.52
98	Dhuria (c)	1.20	1.09	0.34
99	Khangar (a)	1.50	1.79	1.37
100	Khangar (b)	0.90	3.11	3.22
	Maximum	2.80	19.63	21.69
	Minimum	0.40	0.95	0.14
	Average	1.11	2.18	1.85

Appendix – VI

Characteristics of soil of selected villages of Ladnu tehsil

S. No.	Name of Villages	Ionic compustion (me L ⁻¹)					
		Ca ²⁺	Mg ²⁺	Na ⁺	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
1	Khamiyad	2.20	1.20	25.90	3.60	1.60	24.10
2	Dhudia	2.60	0.60	1.80	3.40	1.40	0.20
3	Ratau (a)	3.20	0.80	2.90	4.20	1.80	0.90
4	Ratau (b)	2.40	0.60	2.90	3.20	2.40	0.30
5	Ratau (c)	2.20	0.40	2.10	2.80	1.60	0.30
6	Ratau (d)	1.80	0.40	2.00	2.80	1.20	0.20
7	Ratau (e)	1.60	0.60	1.20	2.40	0.80	0.20
8	Ratau (f)	2.60	0.40	3.60	3.00	1.80	1.80
9	Sikarali	2.20	1.20	4.50	4.20	1.00	2.70
10	Malgoan (a)	2.00	0.60	3.90	2.80	3.20	0.50
11	Malgoan (b)	1.60	1.00	2.80	3.20	2.00	0.20
12	Malgoan (c)	1.80	1.00	3.40	3.00	2.60	0.60
13	Sandas (a)	1.80	1.20	4.90	3.80	1.80	2.30
14	Sandas (b)	2.20	0.80	2.20	3.60	1.40	0.20
15	Sandas (c)	3.40	1.40	2.90	5.20	1.80	0.70
16	Sandas (d)	2.00	1.00	7.20	4.20	1.20	4.80
17	Bhakaran ki Dhani(a)	2.20	0.80	3.10	3.40	2.20	0.50
18	Bhakaran ki Dhani(b)	2.20	1.20	2.20	3.60	1.60	0.40
19	Bhakaran ki Dhani(c)	1.60	1.00	1.10	3.00	0.60	0.10
20	Lokat	2.60	1.60	12.60	4.40	1.80	10.60
21	Genana (a)	1.60	0.80	2.50	2.80	1.60	0.50
22	Genana (b)	2.00	1.40	1.80	3.80	1.20	0.20
23	Baladoo (a)	2.00	1.20	1.10	3.40	0.80	0.10
24	Baladoo (b)	2.20	1.60	1.00	4.00	0.60	0.20
25	Baladoo (c)	2.60	0.80	2.80	3.80	1.40	1.00
26	Baladoo (d)	1.60	1.00	2.30	3.00	1.80	0.10
27	Baladoo (e)	2.60	1.80	0.80	4.60	0.40	0.20
28	Khokhari (a)	3.20	0.20	1.50	3.80	1.00	0.10
29	Khokhari (b)	2.20	0.40	1.70	3.20	0.80	0.30
30	Nimbi Jhodha (a)	1.60	1.00	1.30	3.00	0.80	0.10
31	Nimbi Jhodha (b)	1.80	0.60	1.00	2.60	0.60	0.20
32	Beron ki Dhani (a)	1.80	0.80	1.10	2.80	0.80	0.10
33	Beron ki Dhani (b)	2.20	0.40	1.90	3.00	1.40	0.10
34	Beron ki Dhani (c)	3.00	0.80	1.60	4.20	1.00	0.20
35	Jhardia (a)	2.20	0.60	3.60	3.80	2.20	0.40
36	Jhardia (b)	1.60	0.80	1.90	2.80	1.40	0.10
37	Jhardia (c)	1.80	1.00	1.10	3.20	0.60	0.10
38	Jhardia (d)	2.20	1.40	1.60	3.80	1.00	0.40

S. No.	Name of Villages	Ionic compustion (me L ⁻¹)					
		Ca ²⁺	Mg ²⁺	Na ⁺	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
39	Jhardia (e)	2.20	0.60	1.80	3.40	0.80	0.40
40	Bharnawa (a)	3.00	0.60	2.30	3.80	1.20	0.90
41	Bharnawa (b)	2.60	0.80	1.70	3.60	1.00	0.50
42	Hudas (a)	2.00	1.40	2.80	3.80	1.80	0.60
44	Hudas (c)	1.20	0.60	1.60	2.20	0.80	0.40
45	Bharnawa (c)	1.40	1.40	1.70	3.20	1.20	0.10
46	Bharnawa (d)	1.80	1.20	2.80	3.69	1.60	0.51
47	Bharnawa (e)	1.20	1.20	1.70	2.80	1.00	0.30
48	Manoo	0.40	1.60	1.80	2.20	1.40	0.20
49	Chandai (a)	1.60	1.20	3.50	3.40	1.80	1.10
50	Chandai (b)	1.20	0.60	3.00	2.40	2.20	0.20
51	Lukas (a)	1.80	0.80	1.30	2.80	1.00	0.10
52	Lukas (b)	1.40	1.40	2.70	3.60	1.80	0.10
53	Lukas (c)	1.80	1.20	1.70	3.20	1.20	0.30
54	Lukas (d)	2.20	0.80	2.20	3.40	1.60	0.20
55	Lukas (e)	1.60	0.80	1.70	2.80	0.80	0.50
56	Lukas (f)	1.20	0.60	2.10	2.40	1.00	0.50
57	Audint (a)	0.80	1.40	1.10	2.40	0.60	0.30
58	Audint (b)	2.20	0.60	2.10	3.60	1.20	0.10
59	Audint (c)	1.60	1.00	2.90	2.80	0.60	2.10
60	Audint (d)	1.20	0.60	1.30	2.20	0.80	0.10
61	Audint (e)	1.20	1.00	1.40	3.00	0.40	0.20
62	Audint (f)	1.80	0.40	2.60	2.60	1.60	0.60
63	Heerawati (a)	0.60	0.80	3.80	2.40	1.20	1.60
64	Heerawati (b)	1.40	0.40	1.70	2.60	0.80	0.10
65	Heerawati (c)	1.60	1.00	1.50	2.80	1.20	0.10
66	Sonari (a)	1.40	0.80	1.00	2.40	0.40	0.40
67	Sonari (b)	0.80	0.80	1.00	1.80	0.60	0.20
68	Sonari (c)	1.60	1.00	1.10	2.80	0.80	0.10
69	Sonari (d)	2.20	0.80	1.20	3.40	0.60	0.20
70	Sonari (e)	2.20	0.20	1.50	2.60	0.80	0.50
71	Ladnu	1.80	0.80	0.70	2.80	0.40	0.10
72	Mangalpura	2.40	0.00	2.80	3.00	1.40	0.80
73	Natas (a)	1.80	1.00	3.30	3.20	2.40	0.50
74	Natas (b)	1.80	0.80	2.30	2.80	1.80	0.30
75	Dujar (a)	2.20	1.00	1.90	3.60	0.60	0.90
76	Dujar (b)	1.80	1.60	4.10	4.00	1.80	1.70
77	Dujar (c)	1.40	1.20	2.00	3.00	1.20	0.40
78	Bakolia (a)	2.20	0.40	2.20	2.80	1.60	0.40
79	Bakolia (b)	1.00	1.20	1.90	2.40	1.00	0.70
80	Bakolia (c)	1.80	1.00	2.90	3.00	1.20	1.50
81	Bakolia (d)	1.20	1.80	3.60	3.40	2.20	1.00

S. No.	Name of Villages	Ionic compustion (me L ⁻¹)					
		Ca ²⁺	Mg ²⁺	Na ⁺	CO ₃ ²⁻ + HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
82	Bakolia (e)	1.80	0.60	2.00	2.80	1.40	0.20
83	Baded (a)	0.60	2.80	4.20	4.60	2.60	0.40
84	Baded (b)	1.60	0.60	2.70	3.00	1.60	0.30
85	Baded (c)	2.60	0.40	1.10	3.20	0.80	0.10
86	Baded (d)	1.80	0.60	2.80	2.60	1.80	0.80
87	Bheid (a)	2.60	0.80	1.50	3.80	0.80	0.30
88	Bheid (b)	1.80	1.60	0.90	3.60	0.60	0.10
89	Bheid (c)	1.00	1.20	1.70	2.60	1.20	0.10
91	Bheid (e)	1.60	1.60	2.80	3.80	1.10	1.10
92	Koyal (a)	0.80	1.60	2.50	2.60	1.80	0.50
93	Koyal (b)	1.80	0.60	2.60	3.20	1.60	0.20
94	Koyal (c)	2.20	1.20	2.40	3.80	1.60	0.40
95	Koyal (d)	1.40	1.20	3.50	4.20	0.60	1.30
96	Dhuria (a)	1.40	1.20	2.30	3.00	1.80	0.10
97	Dhuria (b)	1.20	1.00	3.10	2.40	2.40	0.50
98	Dhuria (c)	1.60	1.20	1.60	3.20	0.60	0.60
99	Khangar (a)	1.80	0.60	2.30	3.80	0.60	0.30
100	Khangar (b)	2.20	0.20	3.80	2.80	1.80	1.60
	Maximum	3.40	2.80	25.90	5.20	3.20	24.10
	Minimum	0.40	0.00	0.70	1.80	0.40	0.10
	Average	1.84	0.93	2.61	3.20	1.30	0.88

Appendix-VII

Mustard crop details sown to first year

S. No.	Sowing Date	Seed Rate (kg ha ⁻¹)	Variety	Seed Treatment	FYM (tones ha ⁻¹)	Fertilizer (kg ha ⁻¹)	Irrigation	Harvesting Date
1	18 Oct, 2007	4	Pusa Bold	Captan	4-5	Urea-80, DAP-25	3	10 March, 2008
2	14 Oct, 2007	3	Pusa Bold	-----	3-4	Urea-70, DAP-40	2	16 March, 2008
3	9 Oct, 2007	4	Pusa Bold	-----	4-5	Urea-90 ,DAP-30	4	20 March, 2008
4	15 Oct, 2007	4	Pusa Bold	Captan	1-2	Urea-80, DAP-40	4	18 March, 2008
5	21 Oct, 2007	4	Pusa Bold	-----	3-4	Urea-90, DAP-60	2	17 March, 2008
6	14 Oct, 2007	3.5	Pusa Bold	Captan	3-4	Urea-85, DAP-50	3	21 March, 2008
7	18 Oct, 2007	4	Pusa Bold	Captan	4-5	Urea-90, DAP-60	3	18 March, 2008
8	15 Oct, 2007	3	Pusa Bold	-----	2-3	Urea-85 ,DAP-60	3	19 March, 2008
9	13 Oct, 2007	4	Pusa Bold	-----	3-4	Urea-70 ,DAP-60	4	18 March, 2008
10	20 Oct, 2007	4	Pusa Bold	-----	1-2	Urea-85, DAP-70	3	23 March, 2008
11	12 Oct, 2007	3.5	Pusa Bold	Captan	3-4	Urea-90,DAP-60	2	18 March, 2008
12	15 Oct, 2007	4	Pusa Bold	Captan	2-3	Urea-85, DAP-50	3	22 March, 2008
13	18 Oct, 2007	4	Pusa Bold	-----	1-2	Urea-80,DAP-70	2	26 March, 2008
14	14 Oct, 2007	4	Pusa Bold	-----	3-4	Urea-90, DAP-60	4	23 March, 2008
15	16 Oct, 2007	3	Pusa Bold	-----	2-3	Urea-70, DAP-50	2	23 March, 2008
16	19 Oct, 2007	4	Pusa Bold	-----	3-4	Urea-80,DAP-60	3	25 March, 2008
17	12 Oct, 2007	3.5	Bio-902	Captan	2-3	Urea-90 ,DAP-50	4	26 March, 2008
18	8 Oct, 2007	3.5	Pusa Bold	-----	3-4	Urea-80, DAP-60	4	15 March, 2008
19	14 Oct, 2007	3	T-59	-----	3-4	Urea-80, DAP-50	3	18 March, 2008
20	14 Oct, 2007	3	T-59	-----	2-3	Urea-70, DAP-50	4	23 March, 2008

Appendix-VIII

Wheat crop details sown to first year

S. No.	Sowing Date	Seed Rate (kg ha ⁻¹)	Variety	Seed Treatment	FYM (tones ha ⁻¹)	Fertilizer (kg ha ⁻¹)	Irrigation	Weed Control	Harvesting Date
1	24,Nov.2007	110	Raj-3077	Thiram	6-8	Urea-80,DAP-25	8-9	2,4-D	28,April 2008
2	27,Nov.2007	115	Raj-3077	Chloropyriphos	5-6	Urea-70,DAP-20	8-9	Metoxuron	30,April 2008
3	20,Nov.2007	110	Raj-3077	Thiram	7-8	Urea-100,DAP-30	9-10	2,4-D	20,April 2008
4	15,Nov.2007	100	Raj-3077	Chloropyriphos	8-9	Urea-100,DAP-40	8-9	Metoxuron	18,April 2008
5	18,Nov.2007	105	Raj-3077	Thiram	7-8	Urea-100,DAP-25	8-9	2,4-D	20,April 2008
6	10,Nov.2007	105	Raj-3077	Thiram	8-9	Urea-100,DAP-30	9-10	2,4-D	16,April 2008
7	12,Nov.2007	100	Raj-3077	Chloropyriphos	7-8	Urea-90,DAP-30	9-10	Metoxuron	17,April 2008
8	05,Nov.2007	100	Raj-3077	Agrosan G.N.	8-10	Urea-100,DAP-40	8-9	Metoxuron	15,April 2008
9	05,Nov.2007	100	Raj-3077	Chloropyriphos	8-10	Urea-100,DAP-40	8-9	Metoxuron	15,April 2008
10	12,Nov.2007	110	Raj-3077	Bavistin	7-8	Urea-100,DAP-30	9-10	2,4-D	20,April 2008
11	15,Nov.2007	110	Raj-3077	Bavistin	7-8	Urea-90,DAP-32	9-10	2,4-D	22,April 2008
12	08,Nov.2007	100	Raj-3077	Chloropyriphos	8-9	Urea-110,DAP-40	9-10	Metoxuron	16,April 2008
13	12,Nov.2007	110	Raj-3077	Agrosan G.N.	7-8	Urea-80,DAP-30	8-9	2,4-D	20,April 2008
14	17,Nov.2007	120	Raj-3077	Bavistin	5-6	Urea-100,DAP-30	8-9	Metoxuron	25,April 2008
15	14,Nov.2007	120	Raj-3077	Thiram	6-7	Urea-100,DAP-30	9-10	Metoxuron	24,April 2008
16	20,Nov.2007	115	Raj-3077	Agrosan G.N.	6-7	Urea-100,DAP-30	10-11	2,4-D	28,April 2008
17	10,Nov.2007	105	Raj-3077	Thiram	7-8	Urea-100,DAP-35	10-11	2,4-D	20,April 2008
18	13,Nov.2007	110	Raj-3077	Bavistin	8-9	Urea-80,DAP-30	9-10	Metoxuron	22,April 2008
19	18,Nov.2007	115	Raj-3077	Bavistin	6-7	Urea-80,DAP-40	9-10	2,4-D	25,April 2008
20	15,Nov.2007	110	Raj-3077	Chloropyriphos	6-7	Urea-80,DAP-40	8-9	2,4-D	25,April 2008

Appendix-IX

Mustard crop details sown to second year

S. No.	Sowing Date	Seed Rate (kg/ha)	Variety	Seed Treatment	FYM (tones ha ⁻¹)	Fertilizer (kg ha ⁻¹)	Irrigation	Harvesting Date
1	18 Oct, 2008	4	Pusa Bold	Thiram	4-5	Urea-80, DAP-45	3	10 March, 2009
2	14 Oct, 2008	3	Pusa Bold	Thiram	3-4	Urea-90, DAP-40	2	16 March, 2009
3	9 Oct, 2008	3.5	Pusa Bold	Captan	4-5	Urea-90, DAP-30	2	20 March, 2009
4	17 Oct, 2008	3.5	Pusa Bold	Captan	2-3	Urea-80, DAP-40	3	26 March, 2009
5	11 Oct, 2008	4	Pusa Bold	Captan	3-4	Urea-85, DAP-50	3	21 March, 2009
6	14 Oct, 2008	4	Pusa Bold	Captan	2-3	Urea-90, DAP-60	2	17 March, 2009
7	12 Oct, 2008	4	Pusa Bold	Thiram	1-2	Urea-80, DAP-50	2	18 March, 2009
8	15 Oct, 2008	3.5	Pusa Bold	Thiram	2-3	Urea-80, DAP-50	3	22 March, 2009
9	10 Oct, 2008	4	Pusa Bold	Captan	3-4	Urea-90, DAP-50	3	21 March, 2009
10	12 Oct, 2008	4	Pusa Bold	Thiram	1-2	Urea-85, DAP-50	2	17 March, 2009
11	14 Oct, 2008	4	Pusa Bold	Captan	3-4	Urea-80, DAP-60	3	25 March, 2009
12	8 Oct, 2008	3.5	Pusa Bold	Captan	2-3	Urea-80, DAP-60	2	14 March, 2009
13	12 Oct, 2008	3.5	Pusa Bold	Captan	1-2	Urea-85, DAP-60	2	19 March, 2009
14	14 Oct, 2008	4	Pusa Bold	Captan	3-4	Urea-90, DAP-60	4	25 March, 2009
15	10 Oct, 2008	4	Pusa Bold	Captan	2-3	Urea-80, DAP-50	3	17 March, 2009
16	8 Oct, 2008	3.5	Pusa Bold	Thiram	2-3	Urea-80, DAP-50	4	26 March, 2009
17	12 Oct, 2008	4	Pusa Bold	Thiram	1-2	Urea-85, DAP-40	3	21 March, 2009
18	8 Oct, 2008	3.5	Pusa Bold	Thiram	2-3	Urea-70, DAP-40	2	16 March, 2009
19	13 Oct, 2008	4	Pusa Bold	Captan	3-4	Urea-90, DAP-60	4	15 March, 2009
20	11 Oct, 2008	3.5	Pusa Bold	Thiram	2-3	Urea-80, DAP-50	2	20 March, 2009

Appendix-X

Wheat crop details sown to second year

S. No.	Sowing Date	Seed Rate (kg ha ⁻¹)	Variety	Seed Treatment	FYM (tones ha ⁻¹)	Fertilizer (kg ha ⁻¹)	Irrigation	Weed Control	Harvesting Date
1	20,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	7-8	Urea-100, DAP-40	8-9	2,4-D	24, April 2009
2	24,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	6-8	Urea-80, DAP-25	8-9	2,4-D	28, April 2009
3	22,Nov., 2008	115	Raj-3077	Bavistin, Chloropyriphos	5-6	Urea-90, DAP-50	9-10	Metoxuron	30, April 2009
4	23,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	7-8	Urea-100, DAP-50	8-9	2,4-D	21, April 2009
5	24,Nov., 2008	105	Raj-3077	Bavistin, Chloropyriphos	6-7	Urea-100, DAP-60	8-9	2,4-D	28, April 2009
6	23,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	6-7	Urea-90, DAP-40	7-8	2,4-D	27, April 2009
7	20,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	8-10	Urea-120, DAP-35	8-9	2,4-D	21, April 2009
8	20,Nov., 2008	100	Raj-3077	Bavistin, Chloropyriphos	6-7	Urea-100, DAP-35	7-8	Metoxuron	30, April 2009
9	21,Nov., 2008	100	Raj-3077	Bavistin, Chloropyriphos	7-8	Urea-110, DAP-45	9-10	2,4-D	28, April 2009
10	21,Nov., 2008	105	Raj-3077	Bavistin, Chloropyriphos	8-9	Urea-100, DAP-60	9-10	2,4-D	28, April 2009
11	20,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	7-8	Urea-100, DAP-40	8-9	Metoxuron	23, April 2009
12	20,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	7-8	Urea-110, DAP-35	9-10	2,4-D	25, April 2009
13	20,Nov., 2008	105	Raj-3077	Bavistin, Chloropyriphos	6-7	Urea-100, DAP-35	9-10	2,4-D	22, April 2009
14	23,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	5-6	Urea-90, DAP-40	9-10	2,4-D	30, April 2009
15	20,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	4-5	Urea-80, DAP-35	8-9	2,4-D	25, April 2009
16	20,Nov., 2008	120	Raj-3077	Bavistin, Chloropyriphos	4-5	Urea-90, DAP-40	8-9	2,4-D	25, April 2009
17	21,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	5-6	Urea-100, DAP-50	10-11	2,4-D	27, April 2009
18	20,Nov., 2008	100	Raj-3077	Bavistin, Chloropyriphos	4-5	Urea-80, DAP-40	9-10	2,4-D	20, April 2009
19	20,Nov., 2008	120	Raj-3077	Bavistin, Chloropyriphos	5-6	Urea-90, DAP-40	9-10	2,4-D	25, April 2009
20	21,Nov., 2008	110	Raj-3077	Bavistin, Chloropyriphos	5-6	Urea-100, DAP-60	8-9	2,4-D	27, April 2009

