

**IMPACT OF INDUSTRIALIZATION ON  
WATER QUALITY AND SOIL HEALTH IN  
BADDI-BAROTIWALA-NALAGARH  
INDUSTRIAL HUBS OF  
HIMACHAL PRADESH**

*Thesis*

*by*

**NEETAN KHAJURIA**

*Submitted in partial fulfilment of the requirements  
of the degree of*

**DOCTOR OF PHILOSOPHY**

*in*

**SOIL SCIENCE AND WATER MANAGEMENT**



**COLLEGE OF FORESTRY  
Dr Yashwant Singh Parmar University of  
Horticulture and Forestry, Nauri,  
Solan – 173230 (H.P.), INDIA  
2010**

***Dr D.Tripathi***  
***Professor***

**Department of Soil Science and Water management**  
College of forestry  
Dr. Y S Parmar University of Horticulture  
and Forestry, Nauni-173 230, Solan (HP)

## **CERTIFICATE-I**

This is to certify that the thesis entitled, “**Impact of industrialization on water quality and soil health in Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh**” submitted in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND WATER MANAGEMENT** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Mr. Neetan Khajuria (F-2006-07-D)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

**Place:** Nauni-Solan  
**Dated:** 31st July, 2010

**(Dr. D. Tripathi)**  
**Chairman**  
**Advisory Committee**

## **CERTIFICATE-II**

This is to certify that the thesis entitled, “**Impact of industrialization on water quality and soil health in Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh**” submitted by **Mr. Neetan Khajuria (F-2006-07-D)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY in SOIL SCIENCE AND WATER MANAGEMENT** has been approved by the Student’s Advisory Committee after an oral examination of the same in collaboration with the external examiner.

\_\_\_\_\_  
**Dean’s Nominee**

\_\_\_\_\_  
**External Examiner**

\_\_\_\_\_  
**(Dr. D. Tripathi)**  
**Chairman**  
**Advisory Committee**

**Members, Advisory Committee**

\_\_\_\_\_  
**(Dr. J.N. Raina)**

\_\_\_\_\_  
**(Dr. P.K. Mahajan)**

\_\_\_\_\_  
**(Dr. Veena Sharma.)**

\_\_\_\_\_  
**(Dr. R. Kaushal)**

\_\_\_\_\_  
**(Dr. D.P. Sharma)**

\_\_\_\_\_  
**Professor and Head**  
**Department of Soil Science and Water Management**  
**Dr. Y. S. Parmar, UHF, Nauni-173 230, Solan (HP)**

\_\_\_\_\_  
**Dean**  
**College of Forestry**  
**Dr. Y. S. Parmar University of Horticulture & Forestry,**  
**Nauni-Solan (HP)**

## **CERTIFICATE-III**

This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, **“Impact of industrialization on water quality and soil health in Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh”** submitted to Dr Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (HP) by **Mr. Neetan Khajuria (F-2006-07-D)** in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND WATER MANAGEMENT**.

---

**(Dr. D.Tripathi)**  
**Chairman, Advisory Committee**

---

**Professor and Head**  
**Department of Soil Science and Water Management**  
**Dr. Y S Parmar, UHF, Nauni-173 230, Solan (HP)**

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**Place: Nauri, Solan**  
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**(Neetan Khajuria)**

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## ABBREVIATIONS USED

$\text{g kg}^{-1}$	Gram per kilogram
N	Nitrogen
OC	Organic carbon
P	Phosphorus
%	Per cent
BOD	Biological oxygen demand
COD	Chemical oxygen demand
$\text{Ca}^{++}$	Calcium
$\text{Mg}^{++}$	Magnesium
$\text{Na}^{+}$	Sodium
$\text{Cd}^{+}$	Cadmium
$\text{K}^{+}$	Potassium
$\text{Mn}^{++}$	Manganese
$\text{Cu}^{++}$	Copper
$\text{cfu g}^{-1}$	Colony forming unit per gram
$\text{cfu ml}^{-1}$	Colony forming unit per milliliter
$\text{dSm}^{-1}$	Deci-siemens per meter
$\text{Fe}^{++}$	Iron
$\text{Zn}^{++}$	Zinc
$\text{Pb}^{++}$	Lead
Ni	Nickel
EC	Electrical Conductivity
$\text{CaCO}_3$	Calcium Carbonate
WHO	World Health Organization
$\text{Cl}^{\square}$	Chloride
$\text{CO}_3^{\square}$	Carbonate
$\text{HCO}_3^{\square}$	Bicarbonate
TSS	Total Suspended Solids
FAI	Fertilizer Association of India

# ***CHAPTER-1***

## ***INTRODUCTION***

---

Earth originated about five hundred million years ago (Chadha and Swaminathan, 2006). To sustain life on earth, natural ecosystems developed in such a way that every form of life was dependent and complementary to each other. Exploitation of the environment in terms of fast development and changing life style has resulted in various life threatening problems related to environment. Environmental pollution is the most rapidly growing hazard of the modern technological society inspite of the diligent efforts of environmental engineers, scientists, enlightened legislators and an aroused public, our environmental problems remain. The advanced technology in agricultural industry and scientific endeavours coupled with changed human life style has resulted in massive deterioration of the environment and ecosystems. The industrial pollution has spoiled the three most important components of life viz., water, air and soil. The industrial pollution has caused havoc for all. Infact, rapid industrialization has left us with polluted rivers, contaminated soil, and depleted wild life and exhausted natural resources. We stand at a critical moment in Earth's history, a time when humanity must choose its future. As the world becomes increasingly interdependent and fragile, the future at once holds great peril and great promise. To move forward we must recognize that in the midst of a magnificent diversity of cultures and life forms we are one human family and one earth community with a common destiny. We must join together to bring forth a sustainable global society founded on respect for nature. The resilience of the community of life and the well being of humanity depends upon preserving a healthy biosphere with all its ecological systems, a rich variety of plants and animals, fertile soils and pure waters and clean air.

The fast increasing trends of urbanization and industrialization in India are having a pronounced detrimental impact on the water quality and soil health. Mismanagement of huge quantities of city garbage, sewage sludge, sewage water, industrial effluents, agricultural chemicals etc. is leading to water and soil contamination. Most of the industries are located in

and around cities. Very few industries produced treated effluents as per the statutory standards. The highly polluting industries are related to primary metallurgy, paper pulps, and news print, pesticides, insecticides, refineries, fertilizers, paint, dyes, leather tanning, basic drugs, foundry, lead type storage batteries, acids, plastics, rubber, cement, asbestos, electroplating, textile etc. The composition and volume of waste water discharged vary from industry to industry, but broadly the effluent is reported to contain toxic elements as Cd, Cr, Cu, Fe, Mn, Pb and Zn. Accumulation of the heavy metals beyond the permissible limit adversely affect the water quality and soil health in turn, human and animal health.

Industrial waste, which contain toxic components such as heavy metal ions are of great concern, as it poses not only health risks to humans but also potentially unacceptable ecological risks to plants, animals and microorganisms. Disposal of sewage water and industrial wastes is a great problem. Often it drained to the agricultural lands where it is used for growing crops including vegetables. These sewage effluents are considered not only a rich source of organic matter and other nutrients but also elevate the level of heavy metals like Fe, Mn, Cu, Zn, Pb, Cr, Ni, Cd and Co in receiving soils (Singh *et al.*, 2004). As a result, it leads to contamination of the food chain, because vegetables absorb heavy metals from the soil, polluted air and water. One important dietary uptake pathway could be through crops irrigated with contaminated wastewater. Heavy metals are not easily biodegradable and consequently can be accumulated in human vital organs. This situation causes varying degrees of illness based on acute and chronic exposures (Demirezen & Ahmet, 2006). Vegetables are an important part of human diet. In addition to a potential source of important nutrients, vegetables constitute important functional food components by contributing protein, vitamins, iron and calcium which have marked health effects (Arai, 2002). Vegetables, especially those of leafy nature grown in heavy metals contaminated soils, accumulate higher amounts of metals than those grown in uncontaminated soils because of the fact that they absorb these metals through their leaves.

Water, next to oxygen is the most important substance for human existence and it is essential for living being on our planet to grow and prosper. Freshwater rivers, lakes and ground water are used to irrigate crops, provide drinking water and act as a sanitation system. Although we as human being recognize this fact, we disregard it by polluting our rivers, lakes, and oceans. Most of our water resources are gradually becoming contaminated due to

the addition of foreign materials from the surroundings. These include organic matter of plant and animal origin, land surface washing and industrial and sewage effluents. Rapid urbanization and industrialization with improper environmental planning often lead to discharge of industrial and sewage effluents into rivers. In addition to the process of desertification, pollution is also reducing the volume of safe fishing, irrigation and drinking water. The problem of water pollution due to toxic metals has begun to cause concern now in most metropolitan cities. The toxic heavy metals entering the ecosystem may lead to geoaccumulation, bioaccumulation and biomagnifications. Heavy metals like Fe, Cu, Zn, Ni and other trace elements are important for proper functioning of biological systems and their deficiency or excess could lead to a number of disorders. Food chain contamination by heavy metals has become a burning issue in recent years because of their potential accumulation in biosystems through contaminated water, soil and air.

Wastewater irrigation is known to contribute significantly to the heavy metal contents of soil and plants (Mapanda *et al.*, 2005). The plants die and decay, heavy metals taken into them are redistributed, so the soil is enriched with the pollutants. Uptake and accumulation of elements by plants may follow two different paths i.e., through the roots and foliar surface (Sawidis *et al.*, 2001). The uptake of metals from the soil depends on different factors such as their soluble content in it, soil pH, plant growth stages, types of species, fertilizers and soil (Ismail *et al.*, 2005; Sharma *et al.*, 2006). Plant species have a variety of capacities in removing and accumulating heavy metals, it has been documented that some species may accumulate specific heavy metals, causing a serious health risk to human health when such plants based food stuffs are consumed (Wenzel & Jackwer, 1999).

During the last five years, the industrialization in the hill state of Himachal Pradesh has made a significant progress. The share of industry and services sectors to the state GDP has increased from 1.1 & 5.9 % in 1950-51 to 15.9 & 7.3 %, respectively during 2004-05 (<http://www.bbni.com>). The share of Industry sector was 17.1 % during 2005-06 (<http://www.bbni.com>). The rich natural resources of the state are ideally suited for investments in three major sectors namely industries, hydroelectric power and tourism. The grant of special package of incentives by the central government has acted as a catalyst in boosting the industrial development in the state. Today, the state has about 33618 small scale and 356 medium and large scale units with an investment of about Rs. 5243.39 crores

generating employment for more than 2.0 lakh (<http://www.bbnia.com>). The Solan district has about 3444 industrial units and most of the units are situated in Baddi, Barotiwala and Nalagarh (<http://www.bbnia.com>). The major industries in these areas include pharmaceutical, chemicals, ghee industry, food industry etc. These industries, although developed with proper planning, are discharging their effluents in the nearby natural drains and are being ultimately collected in big drains known as Sandhouli nullha, Balad nadi and Sirsa river. Increasing industrialization and urbanization in these areas are resulting in the degradation of natural resources. The disposal of effluents generated by the industries into nearby water bodies or cultivable agricultural lands is likely to cause excess accumulation of metals thereby resulting in poor soil health, disturbance in microbial population and phytotoxicity.

Therefore, a better understanding of heavy metal sources, their accumulation in the soil and the effect of their presence in water, soil and plant systems seem to be particularly important issues of present day research. Since, no attempt has so far been made to study the impact of industrialization on soil quality, water quality and vegetation, the present investigation was, therefore, undertaken by selecting Baddi, Barotiwala and Nalagarh industrial hubs of Solan district, which are likely to have excess accumulation of metals, with following objectives :-

- ▶ To study the effluent quality of selected industries.
- ▶ To determine the impact of pollution with effluents on water quality, soil characteristics, microbial activity and bio-mass of soil.

## **CHAPTER-2**

### **REVIEW OF LITERATURE**

---

India's environment is becoming fragile and environmental pollution is one of the undesirable side effects of industrialization, urbanization, population growth and unconscious attitude towards the environment. At present environmental protection is the main need of the society. Though industrialization and development in agriculture are necessary to meet the basic requirements of people, at the same time it is necessary to preserve the environment. In India, due to lack of sewage treatment plants, generally untreated effluents are released either on agricultural lands for irrigation or disposed of in nearby water bodies. These practices deteriorate the soil health and water quality, which is the basic need of agricultural crops. The pertinent literature from the sources available has been reviewed under the following heads:

#### **2.1 Quality characteristics of industrial effluents**

#### **2.2 Impact of industries on:**

##### **2.2.1 Water characteristics**

##### **2.2.2 Soil characteristics and microbial properties**

##### **2.2.3 Plant nutrient contents**

#### **2.1 Quality characteristics of industrial effluents**

There is large variability in the quality of industrial effluents which varies with industrial processes. The effluents discharged by different industries contain a high range of physico-chemical parameters like pH, conductivity, COD, TSS, cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$ ) and anions ( $\text{Cl}^-$ ,  $\text{CO}_3^-$  and  $\text{HCO}_3^-$  etc.). These effluents from different industries also contain heavy metals and trace elements (Ali *et al.*, 1996).

Basu (1966) analyzed pulp and paper mill effluents at several discharge points in the Hooghly River estuary. His results indicated that the population load was  $4 \times 10^4$  lbs of lignin per day. Malkee and Wolt (1963) reported the presence of toxic compounds like sodium carbonate, sodium sulphite, methyl mercaptans,  $H_2S$  and formaldehyde in the kraft pulp mill waste water.

Dhaneshwar *et al.* (1970) analysed waste water from Titaghur paper mill and found the BOD and COD values of the effluent water to range from 136 to 165 and 268 to 480 mg/l, respectively.

Subbarao (1971) reported that pH of distillery effluents ranged from 8.0 to 8.4. The total solids, volatile solids, BOD and COD were found to be 10,000 to 86,000 mg/l, 5000 to 13000 mg/l, 2,000 to 45,000 mg/l and 8,000 to 95,000 mg/l, respectively.

Verma and Mathur (1971) reported lethal effects of colloidal particles of cellulose and lignin in mixed pulp and paper mill effluent. They found that distillery wastes were more toxic than mixed pulp and paper mill waste water.

Jadhav and Savant (1975) reported that pH and electrical conductivity of undiluted spent wash were 8.0 and  $31.0 \text{ dSm}^{-1}$  in undiluted effluent, respectively. The chemical oxygen demand, total dissolved solids and mineral matter were found to be 13000 mg/l, 45000 mg/l and 26000 mg/l, respectively. The total content of calcium, magnesium, potassium, nitrogen, and phosphorus were found to be 100.0, 1700.0, 13600.0, 1400.0 and 1225 mg/l, respectively. Bicarbonate and chloride contents were 10,000.0 and 5500.0 mg/l, respectively, in the undiluted spent wash. They concluded that spent wash may have some manurial value provided it is used without causing deleterious effects due to accumulation of salts and organic matter.

Saxena (1978) studied the characteristics of waste water from an integrated pulp and paper mill and found that the pulp washing possessed maximum suspended solids (900 mg/l), whereas in paper processing and combined waste, it was found to be 300 mg/l and 503 mg/l, respectively. The soluble solids concentrations in these three types of effluents were 30, 50 and 29 mg/l, respectively.

Saxena *et al.* (1979) reported that in small paper mills using rice straw and waste paper as raw material, the combined waste water was found to have 1500 and 710 mg/l of suspended solids and BOD, respectively. Mudri *et al.* (1984) reported the physico-chemical characteristics of Bengal pulp and paper mills. The pollution load of different drains with respect to BOD, COD, TSS was reported to be 10.9 mg/l, 38.4 mg/l and 59.1 kg/day.

Somashekar *et al.* (1984) analyzed the physico-chemical characteristics of effluent streams of a paper factory a food and paper industry, a textile factory and an automobile industry, all situated close to Mysore (Karnataka). The results of physico-chemical analysis revealed that the effluent had objectionable levels of BOD, COD, dissolved solids, suspended solids and residual chlorine as compared to ISI standards. The pH of all the effluents was on alkaline side; being highest (10.5) in paper mill effluent.

Ajmal *et al.* (1984) analyzed the effluents discharged by Glaxo Laboratory and reported that the values of pH, BOD, COD, Ca<sup>++</sup>, Cl<sup>-</sup>, Mg<sup>++</sup>, N and P was 7.90, 698, 1128, 134, 101, 0.30 and 1.25 mg/l, respectively.

Vijayram *et al.* (1988) assessed the effect of paper mill on water quality of Pagalur high-level channel, a tributary of river Cauvery. The results revealed that both raw and treated effluents possessed high value of total solids, BOD, COD, chlorides etc. and these contributed to toxicity of the effluent.

Several workers have studied the composition of the spent-wash and reported that being of organic origin, the effluent has as high as 50,000 mg/l of BOD and low pH (Patil and Shinde, 1995). When the effluents with high BOD values are discharged in agricultural fields, it creates problems for some soil processes. Apart from BOD, spent wash contains more soluble salts and many plant nutrients (Jadhav and Savant, 1975; Zalawadia and Raman, 1994)

Chakravorty *et al.* (1996) reported that BOD of the pulp and paper mill effluent varied between 1286 to 1769 mg/l. They further, reveal that the total solids in pulp and paper mill effluent range from 3200-6940 mg/l, which is well above the minimum national standards. The high suspended solids impart high BOD, COD and turbidity to the effluent. This figure

still seems an average compared to the report of Singh *et al.* (1996). High BOD is mainly due to the suspended low molecular weight solids.

Naidu and Raman (1995) reported that pH of distillery effluent was 7.6 and colour was dark brown. Dissolved oxygen was absent in the distillery effluent, however, biochemical oxygen demand (BOD) was 38,000 ppm. Total solids, dissolved solids, and undissolved solids were found 40,000, 34,650, and 5,350 ppm, respectively, in the distillery effluent. The electrical conductivity was found 1,221  $\mu$  mho /cm in the effluent. Chloride and oil contents were 4,600 and 60 ppm in the distillery effluent, respectively.

Vaidhyathan *et al.* (1995) studied the physicochemical characteristics of distillery effluent and observed the pH of the distillery spent wash was in the range of 4.0 - 4.2. Total dissolved solids and total solids were found in the range of 90,000 - 1,11,000 mg/l and 86,000 - 1,10,000 mg/l, respectively. COD and BOD were found in the range of 1,15,000 - 1,20,000 mg/l and 42,000 - 50,000 mg/l, respectively. Total nitrogen, phosphates and chlorides were found in the range of 1800 - 2000 mg/l, 30000 - 34,000 mg/l, 2000 - 2100 mg/l and 7000 - 8000 mg/l, respectively.

Raman *et al.* (1996) while studying the chemical composition of press mud reported that pH and EC were found to be 6.05 and 3.90  $\text{dSm}^{-1}$ , respectively. The total content of the N,  $\text{P}_2\text{O}_5$ ,  $\text{K}_2\text{O}$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and S were 1.28, 2.25, 0.68, 2.00, 0.27 and 0.39 percent, respectively. They also reported that the concentration of Fe, Mn, Zn, and Cu were 8000, 280, 155 and 90 ppm, respectively.

Bajpai and Bajpai (1997) identified about 300 different chlorinated organic compound in bleached pulp and paper mill effluents. Out of these, 200 include chlorinated resin acids, chlorinated phenolics and dioxin (Sordergren *et al.* 1989; Kringstad and Makaque, 1988; Suntio *et al.* 1988). These compounds were classified as acidic, phenolic and neutral and may be partly responsible for the BOD and COD, effluent colour, toxicity, mutagenicity and carcinogenicity (Walden and Howard, 1977; Dence *et al.* 1980).

Lignin imparts colour and odour to the waste and increases its BOD and COD. Typically a pulp and paper mill waste may contain 750 mg/l of lignin exerting a COD of

1650 mg/l, BOD of 325 mg/l and causing colour of the order of 8000 units (Subrahmanyam and Hanumanulu, 1976) at pH 7.0. The dark colour of the effluent is mainly due to the raw material used in the manufacturing process and its treatment with chemicals which releases sizable amount of lignin and its chlorinated derivatives in the process (Bajpai and Bajpai, 1997).

Patil (1998) reported that the pH and EC of the spent wash were 4.42 and  $21.56 \text{ dSm}^{-1}$ , respectively. The colour of spent wash was dark brown. BOD and COD contents of spent wash were 30450 and 73600 mg/l, respectively. The calcium, magnesium, sodium, potassium, nitrate, sulphate and chloride contents were 1603, 730, 3575, 7115, 4216, 3819, and 14250 mg/l, respectively.

Subramani *et al.* (1999) determined the physico-chemical properties of Pod; cherry distilleries and reported that colour of effluent was deep red and pH was 5.0. Suspended solids and dissolved solids were found 12,212 and 24,814 mg/l, respectively, in the distillery effluent. BOD and COD contents were 16,500 and 81,800 mg/l, respectively. Analysis of inorganic components in the effluents showed that chloride, phosphate, sulphate, calcium and potassium were 3114, 85, 2516, 421 and 5234 mg/l, respectively.

Chhonkar *et al.* (2000) studied the impact of industrial effluents on soil properties and reported that the spent wash had high organic load (50,000 mg/l BOD and 95,000 mg/l COD). The spent wash contained 1,000 mg/l nitrogen, 40 mg/l phosphorus, 11,000 mg/l potassium and 1,500 mg/l sulphate with  $15 \text{ dSm}^{-1}$  electrical conductivity and 4.5 pH. Metals like Fe (34.8), Mn (12.7), Zn (4.61), Cu (3.65), Cr (0.64) Cd (0.48) and Co (0.08 mg/l) were also found in spent wash.

Tannery waste contains high concentration of salts and chromium and these wastes had resulted in severe pollution in Vellore and Dindigul district of Tamil Nadu (Mahimairaja *et al.* 2000). Bachewar and Mehta (2001) analyzed the physico-chemical characteristics of the effluents from Godavari Drug Industry from the Nanded district of Maharashtra. The toxic effect of waste effluent was evaluated with respect to soil quality. SAR value of the soil was very high and cannot be recommended for any agricultural use.

Patel *et al.* (2004) reported that the COD values (12810 mg/l) of effluents from industries were extremely high, while BOD values (560 mg/l) were within the safe limit at Ankleshwar, Gujrat. The effluents from Ankleshwar were the most polluted with respect to different elements viz. Fe (25.5 mg/l), Cu (0.70 mg/l), Mn (4.83 mg/l), Cd (0.10 mg/l), Ni (0.73 mg/l), Co (0.56 mg/l) and Cr (2.76 mg/l).

Singh and Singh (2005) reported that effluent from paper mill had pH 7.9, electrical conductivity  $2.19 \text{ dSm}^{-1}$ , organic carbon 5.7 g/kg and N, P and K contents 2.0, 5.2 and 157.5 mg/l, respectively. The microbial load in effluent was: bacteria  $8.3 \times 10^6$ , fungi  $4.5 \times 10^4$  and actinomycetes  $8.1 \times 10^2 \text{ cfu ml}^{-1}$ .

Hazarika *et al.* (2007) reported that pulp and paper mill effluent was alkaline in reaction (pH 7.6 and EC  $2.5 \text{ dSm}^{-1}$ ) and contained high levels of dissolved salts, bases and chloride.

Babushakila and Usha (2009) analyzed the tannery effluents of leather processing industry in Dindigul of Tamil Nadu and reported the concentrations of BOD, COD, dissolved solids and suspended solids in the tune of 35, 318, 17150 and 258 mg/l, respectively. The concentration of  $\text{Na}^+$ ,  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  was recorded to be 600, 432 and 5100 mg/l.

## **2.2 Impact of industries on:**

### **2.2.1 Water characteristics**

The continuous release of waste water in the water bodies not only cause asthetic water pollution but also has been reported to be hazardous for aquatic flora and fauna (Nampoothery and Sahidharan, 1976; Roald, 1977 and Mcleay, 1979).

Pande *et al.* (2000) studied the pollution of the Ramganga river in a stretch about 25 km around Moradabad. The pollution is caused by effluent wastes produced by nearly 450 electroplating units and entire brass and stainless steel industry, apart from the domestic wastewaters. The river at Moradabad manifests severe organic pollution and build-up of toxicants (heavy metals) particularly, the iron which has well exceeded its permissible limit.

Bhattacharyya *et al.* (2001) studied the monthly variations of dissolved Zn, Cu and Pb in the southwestern sector of Sagar island. The concentrations of heavy metals in the ambient aquatic phase exhibited a sharp seasonal oscillation with the highest value during monsoon and lowest during pre-monsoon. The concentrations of dissolved heavy metals seem to be controlled by the ambient aquatic salinity and pH.

Bandela *et al.* (2002) investigated the polluting strength of sewage in terms of oxygen that will require its discharge into Barul dam water in which aerobic condition exists. The values of B.O.D. were maximum (11.1 ppm) in the monsoon and minimum (3.2 ppm) in the winter season. The B.O.D. test may be considered as wet oxidation procedure in which the living organisms serve as the medium for oxidation of the organic matter into carbon-dioxide and water.

Dinesh *et al.* (2001) studied the probable movement and mixing of contaminants within and through the Kundalika river estuary along the west coast of India. Neutrally buoyant biplane drogues, floats and dyes were tracked at different stages of the tide to assess the behaviour of the contaminants released in the estuary. The studies have shown that contaminants if released in the inner estuary tend to accumulate in the upstream regions and would not be flushed out effectively.

Sarma and Bhattacharyya (2001) analyzed the quality of tube well water and reported that the potassium concentrations were relatively lower than the sodium concentration. Similarly  $Mg^{++}$  concentrations were lower than the  $Ca^{++}$  concentrations. Iron concentration was above the permissible limit. However it was observed that the iron content of the water samples of Mangaldai sub division was slightly higher than those of Udalguri sub division.

Latha *et al.* (2002) analyzed 133 water samples from Avinashi, Pollachi and Palladam areas of Coimbatore district, Tamil Nadu, India, for water quality parameters. The electrical conductivity (EC) of water samples from these areas ranged from 0.45- 4.50, 2.27-9.95 and 0.2-2.7  $dSm^{-1}$ , respectively. The highest Sodium Adsorption Ratio (SAR) of 34.20 was observed in Palladam samples.

Kathikeyani *et al.* (2002) studied the water quality of the river Shanmuganadhi. The main source of pollution in the river water is the dispersal of sewage water from the surrounding area in and around. The hydrological parameters were analyzed and all the parameters studied are in high level. The biological pollution indicators are also dominant. Results show that the water is unsuitable for drinking and irrigation purposes.

Srinivas *et al.* (2002) analyzed the physico-chemical characteristics of bore wells of industrial areas of Visakhapatnam. The results of physico-chemical characteristics of bore wells revealed that the water quality index calculated from ten physico-chemical parameters taken together varied as 50.0-97.41 ppm indicating level of nutrient load and pollution in the bore waters. The water was not conforming to drinking standards.

Singh and Singh (2005) reported that soil pH, EC and organic carbon increased with increasing level of paper mill effluent. However, available nitrogen decreases which could be attributed to its depletion by increasing microbial population.

Tripathi *et al.* (2006) studied the impact of polluted underground water from seepage of industrial effluents on soil properties and growth of *Acacia senegal*. The study indicated that the use of contaminated well water significantly increased the soil pH and EC and there was reduction in organic matter content, available N and P. The higher pH and EC values were attributed to the higher concentration of Na and Residual Sodium Carbonate values of the contaminated well water.

Hazarika *et al.* (2007) reported that pH of the effluent (pulp and paper mill) irrigated soil was observed to be 1.3 units higher. The EC was increased by more than three times. Chloride concentration of the effluent irrigated soil was 197 mg/kg against 43 mg/kg observed in shallow tube well irrigation.

A total of 1.057 Tm<sup>3</sup> of waste water was produced from industries during 1997 in India. The fraction of waste water that was treated anaerobically for the different industries has been considered as 20% except for distilleries, where 57% of water is treated in India. These industrial waters are potential source of irrigation and nutrients (Parma and Biswas, 2009)

### 2.2.2 Soil characteristics and microbial properties

The use of land as receptor of waste water has been practiced for hundreds of years throughout the world. History records that irrigation with waste water was practiced in Athens before the birth of Christ (Metcalf and Eddy, 1972). Sewage farming was used in Germany as early as the sixteenth century and was common in England until the late 1800 (Wolman, 1977). The farmers use such effluents for irrigation with a view that it is rich in minerals and organic matter, but the toxic heavy metals present in such effluent is a major concern for fertility of soil and accumulation of heavy metals in soils and ultimately their way into crops which in turn effect the physiological, reproductive and other metabolic activities of man (Mittar *et al.* 1992; Medhappan, 1993; Rao *et al.* 1993). Due to the disposal of industrial effluent on land, the physico-chemical properties of soil are greatly influenced and that also brings about change in composition of micro-organisms in soil (Alexander, 1978).

Bajpai and Dua (1972) reported that pH values are not affected by distillery effluent application. Total-N contents were observed to increase by application of spent wash. From the data on available N contents, it was observed that its contents were increased by the application of spent wash at the dose of 100 kg N ha<sup>-1</sup> and 220 kg N ha<sup>-1</sup> but reverse was the case when spent wash was applied at rate of 300 kg N ha<sup>-1</sup>. It might be due to adverse effect of higher quantities of decomposable matter because of which nitrogen being temporarily locked up in microbial cells. Organic carbon content was decreased in all the treatments when compared with control.

Nashikar (1985) reported that irrigation with high BOD waste waters did not adversely affect the nitrification activity in soil. Adhikari and Sahu (1985) reported that the distillery effluent at low concentration (1-10 % V/V) and at proper pH levels (7.0 - 8.0) increased the growth and nitrogen fixing abilities of blue green algae. Purushottam *et al.* (1986) reported the absence of nitrogen fixing bacteria from the soil treated with distillery effluent. Illyaltadinov *et al.* (1990) reported that the application of decomposed paper mill wastes at the rate of 10 - 22 t/ha improved biological activity.

Sivaswamy (1990) reported decreased pH and increased concentration of Zn, Cu, Fe and Mn in soils affected by tannery effluent. Behera (1986) observed an increase in pH, electrical conductivity, K<sup>+</sup>, Na<sup>+</sup>, organic matter and total nitrogen content of soil with increase in concentration of paper mill waste water. Mishra and Sahoo (1989) also observed similar results.

Paper mill effluent greatly affects soil physical properties. There are reports that paper mill contains high amount of metal ions like sodium and potassium. Due to high concentration of these ions in soil, particles are dispersed resulting in poor soil structure and reduced infiltration rates. Not only this, these metal ions also form complex organic compounds which are highly resistant against any microbial degradation (Agarwal *et al.*, 1982). Due to use of paper mill effluent, the textural characteristics of soil at various depths were modified (Rao and Shantaram, 1996).

Due to irrigation with paper mill effluent, the soil available nitrogen decreased significantly which may be due to utilization of nitrogen by increasing microbial population and loss through denitrification (Mukherjee *et al.* 1990; Saha *et al.* 1995). At later stages, the rate of denitrification loss exceeds the rate of mineralization of organic nitrogen and thus results in lower values (Smith and Douglas, 1970).

Ajmal and Khan (1985) observed tremendous increase in sodium content in soils irrigated with industrial effluents. Sharma *et al.* (2000) reported that organic carbon content was found to be significantly lower in textile mill effluent affected soil as compared to normal rainfed soils. There was a sharp depletion in the content of available nutrients in effluent affected soils.

Irrigation with sewage and paper/pulp mills effluent had enriched the soil mainly with respect to N, P, K and it enhanced crop yields considerably (Neelay and Dhondiyal, 1985). Enrichment of soil with organic carbon due to addition of industrial effluent was also reported by Jadhav and Savant (1975) and Joshi *et al.* (1994). Moura (1987) reported that the irrigation with the card board factory effluent resulted in improved soil fertility.

Tripathi *et al.* (1990) reported that a 40 times higher concentration of Na<sup>+</sup> was observed in the industrial effluent than in the nearby well water used for irrigation. These concentrations showed a significantly positive correlation with the Na<sup>+</sup> in the soil.

Bansal *et al.* (1992) reported lower pH and higher organic carbon in soils receiving industrial effluent near Ludhiana. In another study, conducted by Dhevagi *et al.* (2000) observed that the plots receiving treated paper mill effluent recorded an increase in soil pH, which might be due to continuous irrigation with the effluent having alkaline nature thereby salt causes accumulation in the soil. This was in line with the findings of Rajannan and Oblisami (1979); Narasimha and Narasimharao (1992) and Sandana (1995).

Bansal *et al.* (1992) studied the accumulation and bioavailability of Zn, Cu, Mn and Fe in soils irrigated with industrial waste water. Observations made at the interval of 0, 2 and 5 years of application showed decrease in wheat yield and soil pH and increase in available heavy metal content in soil and their concentrations in grain and straw. This underlines the need for monitoring the pH of the soil and consequent changes in bioavailability of heavy metals in soil. Mobility of Pb down the profile was very slow or negligible but that of Cd was slightly more.

Abasheeva and Revenski (1992) reported that irrigation with sewage water did not increase accumulation of heavy metals (Mn, Mo, Cu, Co, Zn, Pb) in plants and soil. It slightly increased the soil exchangeable Na<sup>+</sup> content and pH. Mishra *et al.* (1992) reported that continuous irrigation with distillery waste water decreased the pH, N, P and K, however, organic carbon content increased substantially.

Adhikari *et al.* (1993) reported more accumulation of heavy metals in surface soils (0-15 cm) than in subsurface soils. Their findings were also supported by Kuhad *et al.* (1989). It has been widely reported that effluent irrigation adversely affected the soil system and thereby crop growth (Anand *et al.* 1969; Karande *et al.* 1993; Madhappan, 1993; Rao *et al.* 1993 and Vijaykumari *et al.* 1993).

Agrawal *et al.* (1994) reported that irrigation with effluent water had increased the pH of soil about 0.3 unit up to the depth of 0-45 cm and SAR increased to 74.3 from 6.19 in 0-15

cms. In an another study, Naidu and Raman (1995) reported that irrigation with distillery water slightly increased the pH, organic matter and conductivity of the soils. Flisberjak *et al.* (1996) reported that fertilizing proportion occurred in the following order: manure > municipal waste > industrial waste. Raman *et al.* (1996) reported that the application of fly ash and pressmud did not change the pH of soil. Organic carbon content increased substantially due to pressmud application either alone or in combination with rice straw.

Mahakur and Mishra, (1995) reported a significant increase in pH with increase in the concentration of effluent in the soil. The electrical conductivity, organic matter, total nitrogen, sodium and potassium content also showed similar increase with increase in textile waste water concentration in soil.

Raman *et al.* (1996) studied the use of industrial effluents and byproducts in agriculture. The waste water of paper mill, sugar factory and vegetable ghee were found less hazardous and could be used for irrigation with appropriate precautions. Among the solid wastes, pressmud was found to be most useful. Use of pressmud, flyash and coir pith tended to improve the physical conditions of the soil.

Rani and Singeram (1996) conducted a study to determine the effect of tannery effluent on physical parameters of soil. They concluded that the bulk density value increased progressively from 1.35 g/cc in check (water alone) to 1.51 g/cc in treatment with two times dilution with water and then subsequently remained at par with a value of 1.54 g/cc in undiluted effluent. Applications of undiluted effluent reduced the hydraulic conductivity from 7.48 to 3.35 cm/hr and the porosity from 41.2 to 37.6 percent and increased the bulk density from 1.40 to 1.54 g/cc. The findings indicated that the physical properties of soil are going to be damaged severely in the long run. Dilution of the tannery effluent may be beneficial for saving the soil physical properties.

Nemade and Shrivastava (1997) concluded from their experiment that paper mill effluents are highly contaminated with metal pollutants. The maximum concentration of the metals were observed in following order:  $Ca^{++} > Mg^{++} > Na^{+} > K > Fe > Ni > Pb > Zn > Hg = Cd > Cu$ . The movement of these pollutants through soil beds enhances the contamination of ground water resources. After proper treatment and dilution, it could be used for irrigation.

Pathak *et al.* (1998) reported that application of distillery effluent increased the EC in post-harvest soil after wheat crop. This increase in EC was due to the higher EC of the effluent. Higher EC was recorded at higher levels of effluent application. There was not significant change in soil pH. An increase in organic carbon content was observed with effluent irrigation. Appreciable increase in available K status in soil after wheat crop was observed in effluent treated plots. The available K status was the highest (2365 kg ha<sup>-1</sup>) in the treatment that received effluent with 2000 mg/l BOD. The increase in K status could be attributed to the high K content (6000 mg/l) of the effluent.

Babar and Tariq (1998) analyzed physical and chemical parameters of drainage Channel-1 of Faisalabad city. Due to discharge of effluents of textile processing units into the channel, high values of EC, pH, sodium adsorption ratio (SAR) and total suspended solids (TSS) were found.

Achari *et al.* (1999) reported an increase in the available N and K status with various paper mill effluent irrigation treatments. Undiluted effluent irrigation registered lower P values, over the control. Dhevagi *et al.* (2000) reported that the available nitrogen, phosphorus and potassium status were higher in the paper mill effluent irrigated plots than the well water irrigated plots.

Udayasoorian *et al.* (1999) in Tamil Nadu showed that continuous irrigation with treated paper mills waste water increased the soil pH, EC, organic carbon, N, P, K<sup>+</sup>, Na<sup>+</sup> and Ca<sup>++</sup>. Similarly, irrigation with tannery effluent increased the pH, EC and ESP.

Thawalo *et al.* (1999) reported that irrigation with wastewater to soil increased in their WHC, pH, EC, ESP, OC and available nutrient (NPK) contents; however, there was a decrease in their bulk density. Chhonkar *et al.* (2000) reported that the distillery effluent irrigation increased the pH, EC, OC, SAR, PAR, exchangeable Na<sup>+</sup>, and exchangeable K<sup>+</sup> and available nutrient content i.e. NPK of the soils under sugarcane than the normal water at the same level of fertilizer application.

Paper mill effluent increased the pH of the soil, indicating the increase in alkaline nature of soil (Behra, 1986; Mishra and Sahoo 1989; Nemade and Srivastava, 1997). There

was increase in the electrical conductivity of the soil which clearly indicated the contamination of the ionic pollutants in amended soil. Mill effluent also increased the organic matter and organic carbon status of the soil (Behra, 1986; Mishra and Sahoo, 1989; Kannan and Oblisami, 1990; Chhonkar *et al.* 2000). The importance of organic matter in complexing heavy metals in polluted environment is being increasingly recognized. Paper mill effluent amended soils were found to have increased concentration of N, P and K (Kannan and Oblisami, 1990; Nemade and Shrivastava, 1997; Achari *et al.* 1999; Chhonkar *et al.* 2000; Dhevagi *et al.* 2000).

Tannery and Textile industrial waste contains appreciable amounts of plant nutrients such as N, P, K<sup>+</sup>, Ca<sup>++</sup>, Mg<sup>++</sup> and S, these nutrients can be used for plant growth after proper treatment. Enrichment of organic carbon in soil due to addition of industrial waste water was reported by Chhonkar *et al.* (2000).

The use of paper mill waste water favorably influenced crop production, and its continuous application for a number of years may result in enrichment of heavy metals in the top layers of soil (Gupta *et al.* 1990). Untreated industrial effluents contain higher amounts of Cd, Pb, Zn, Cu, Mn and Fe and enhance the concentration of heavy metals at surface in irrigated soils (Xiong *et al.* 2001).

Higher amount of heavy metals like Cu, Zn, Fe and Mn is recorded in irrigated soil near industrial complex (Barman *et al.* 2001). Long term and indiscriminate application of raw sewage effluent resulted in accumulation of heavy metals in surface and subsurface soils (Datta *et al.* 2000). Excessive accumulation of heavy metals such as Cd, Pb, Cr and Ni in the soil and the resultant phytotoxicity was reported by Peralta *et al.* (2001).

Chandio *et al.* (2001) concluded that quality of soil was changed and the use of untreated waste water for irrigation was unsafe for food production. Generally, the waste water contains higher amount of total dissolved solids which contaminates the soil matrix and affects crop production.

Impact of bicycle manufacturing industry effluent on soils was studied by Sastry *et al.* (2001). The study revealed that the effluents altered soil colour, moisture content, electrical

conductivity, organic carbon percentage and available potassium and phosphorus. Concentration of chromium and nickel exceeded permissible limits and was many fold higher in affected soils than effluents. Presence of cyanide was also recorded in effluent affected soils. The chemical changes decreased the microbial population in the affected soil.

Irrigation with sewage and paper mill effluent had enriched the soil mainly with respect to N, P, K and enhanced the crop yields considerably (Nan and Chung, 2001). Waste water application for crop irrigation increased the Zn concentration in soil (Terres *et al.* 2002).

Thangavel (2002) reported that irrigation with tannery effluent not only increased the fertility of the soil but also absorption ratio. While, organic amendments enhanced the availability of nutrients, unlike gypsum incorporation, they are not effective in decreasing sodium adsorption ratio of the soil.

Patel *et al.* (2004) reported that Cu, Pb, Zn and Cd were the most available elements in different soils treated with effluents of industries. However the soils continuously irrigated with effluents of industries showed the highest Cu availability and Mn, Cd, and Ni moderately available, while Fe and Cr indicated low availability. They also reported that effluents from fertilizer and refinery industry at Vadodara and chemical industry at Bharuch and Ankleshwar had shown high content of micronutrients and heavy metals as compared to well water irrigated soils which indicated that these polluting metals had accumulated due to use of effluents/waste water.

Microbial biomass comprises 1-3% of total soil organic carbon (Anderson and Domsch, 1978). Microbial biomass which is sum total of all microorganisms in the soil, often serves as a temporary sink for nutrients including N (Jenkinson and Ladd, 1981). Microbial biomass and microbial activity are often closely related because biomass plays an important role in the transformation of organic elements (C, N and S). Microbial biomass behaves as a small but labile reservoir of these elements (Frankenberger and Dick, 1983).

The decrease in CO<sub>2</sub> evolution/release was observed due to addition of the chemical fertilizers (Schinner *et al.* 1980 and Jakubczyk *et al.* 1976).

Adhikari and Sahu (1985) reported that the distillery effluent at low concentration (1-10% v/v) and at proper pH levels (7.0-8.0) increased the growth and nitrogen fixing abilities of blue green algae.

Purushottam *et al.* (1986) reported the absence of nitrogen fixing bacteria in the soil treated with distillery effluent. Dhevagi *et al.* (2000) observed that the paper mill effluent irrigated plots exhibited higher bacterial population than well irrigated plots. Saxena *et al.* (1979) reported that irrigation with pulp and paper mill effluent tends to decrease the microbial biomass, carbon and nitrogen in the soil samples.

Nowak and Nowak (1990) reported that effluent irrigation for several years adversely affected the microbial biomass carbon in soils and a higher amount of non – microbial carbon was accumulated in the organic fraction of the clayey soils which was due to decreased decomposition and greater stabilization of organic carbon in soils with higher clay content. Pankhurst *et al.* (2001) reported that the salinity of effluent affected soil increased several fold and high salinity reduces microbial biomass carbon in soils.

Rao *et al.* (1993) observed that the populations of different microorganisms in soil irrigated with polluted water were significantly lower as compared to those of the soils irrigated with ordinary water. Once the microbial population is affected, the soil productivity is decreased resulting in the reduced nutrient availability and plant production.

Chauhan and Kaur (1993) reported that number of bacteria, fungi and N<sub>2</sub> fixing bacteria were reduced with undiluted effluent by 23, 36 and 17.6%, respectively, whereas diluted effluent only slightly decreased numbers of bacteria whilst increasing number of fungi and N<sub>2</sub> fixing bacteria. Undiluted effluent was therefore considered unsuitable for direct application to soil whereas diluted effluent could be used to increase soil fertility.

Iqbal and Mehta (1996) studied the microbial dynamics of an effluent affected soil and reported that the maximum number of bacteria per gram of dry soil recorded in November was  $14.76 \times 10^5$  cfu g<sup>-1</sup> soil, however, the minimum number of bacterial counts was found in the month of March in surface as well as at 15 cm depth. They recorded that the bacterial and fungi populations varied from  $0.78 \times 10^5$  to  $14.76 \times 10^5$  and  $0.523 \times 10^5$  to 1.536

$\times 10^5$  and 0.4 to  $9.86 \times 10^5$  and 0.035 to  $0.244 \times 10^5$  cfu  $g^{-1}$  soil in surface and subsurface soils, respectively.

Gowrisankar *et al.* (1997) reported the inhibitory effect of textile mill effluent on rhizospheric microflora with the increase in the effluent concentration. Gupta (1997) reported that the population of *Rhizobium*, *Azotobacter*, bacteria, fungi and actinomycetes varied from  $21 \times 10^2$  to  $43 \times 10^2$ ,  $27 \times 10^2$  to  $37 \times 10^2$ ,  $131 \times 10^4$  to  $241 \times 10^4$ ,  $23 \times 10^2$  to  $61 \times 10^2$  and  $46 \times 10^2$  to  $73 \times 10^2$  cfu  $g^{-1}$  soil, respectively. She concluded that values of different microbial groups and their number in soils changes due to the presence of the extraneous pollutant. The increased number of different groups in paper mill effluent irrigated field indicates that it may not have any adverse effect on the soil microflora, but in the long run its impact needed to be seen in the light of accumulation of pollutant in soil.

Narasimha *et al.* (1999) reported that the direct discharge of industrial effluents especially without treatments to soil alter biological properties of soil. Bacterial populations with  $131 \times 10^4$  cfu  $g^{-1}$  soil were recorded in respect of soil with effluent discharges as against  $310 \times 10^4$  in control soil. There was increase in fungal population from  $3.33 \times 10^4$  cfu  $g^{-1}$  soil in control to  $9.6 \times 10^4$  cfu  $g^{-1}$  soil in polluted soil. The increase in the fungal population in a polluted soil could probably be due to the presence of high organic matter and low pH in soil as a result of release of acidic effluent rich in organic matter.

The C-mineralization can be useful tool for quantifying the impact of various organic and inorganic amendments on soil functions. It is generally determined by monitoring  $CO_2$  fluxes from moist soil samples (50% field capacity) and subsequently incubated in the laboratory for various periods of time (Haney *et al.* 2004). Uckan and Okur (2000) recorded higher rates of mineralizable-C under vegetables.

Tripathi *et al.* (2006) reported that use of ground water polluted through seepage of textile industrial effluents reduced the activities of dehydrogenase, alkaline and acid phosphatase in soil. High salt build up in soil resulted in significant reduction of N fixing bacteria, nitrifying bacteria and AM-fungal root infection.

Hazarika *et al.* (2007) reported that the content of microbial biomass carbon in shallow tube-well irrigated soil was 1.8 times greater than that in effluent irrigated soil and this difference was statically significant. He further concluded that chloride and water soluble  $\text{Na}^+$  content of soil did not show any significant correlation with microbial biomass carbon and this could be the result of low microbial activity in effluent irrigated soil.

### 2.2.3 Plant nutrient contents

The study conducted by Tripathi (1978) revealed that sodium concentration of effluent was positively correlated with that of plant nutrient content, whereas calcium concentration of the effluents exhibited a reverse trend.

Vegetables can absorb metals from the soil as well as from deposits on parts of the vegetables exposed to the air from polluted environments (Haiyan & Stuanes, 2003). The extent of absorption of the elements by the plant depends on, among other things, the nature of the plant, chemical constitution of the pollutant, concentration of the element in the soil, pH and the interaction with other metals (Zurera *et al.* 1989).

Wastewater, especially if it contains industrial effluent, can contain levels of nutrients, metals and other constituents that are toxic for plant growth. Nitrogen, although essential for growth and reproduction will, in cases of over application, lead to a prolonged vegetative stage, making the crop more susceptible to pests and diseases eventually resulting in lower yields (Morishita, 1988).

Sharma and Naik (1991) studied the effect of a steel mill effluent on agricultural soil and vegetable crop. The study showed that the concentration of  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{PO}_4^{-3}$  decreased, but Fe concentration increased in *Abelmoschus esculentus* (Bhindi).

Ramasubramanian *et al.* (1993) observed that germination percentage and seedling length of *Phaseolus mungo* grown in sand culture decreased with an increase in the concentration of effluents obtained from match and dye industries. They also observed that decrease in plant's fresh and dry weight paralleled a decrease in leaf pigment (chlorophyll a and b carotenoids). They attributed this to the degradation of chlorophyll caused by increased peroxidase activity.

Wong *et al.* (1996) and Sukreeyapongse *et al.* (2002) reported that copper release rates from contaminated soils are comparatively lower than those for lead and some other heavy metals. This high tendency of added copper to remain in the soil could be the main controlling factor for its uptake rates by plants.

Malathi (2001) found that the germination percent alongwith root and shoot growth of vegetables like ladyfinger, brinjal, chilli, tomato and bitter gourd was better with treated waste water as compared to untreated waste water. Plant growth characteristics of these vegetables were better with waste water irrigation than well water irrigation and further increase in growth was observed with higher proportion of well water.

Fytianos *et al.* (2001) analyzed different vegetables from industrial and rural areas of Greece and reported no significant differences in the concentration of metals in most of the vegetables analyzed except a significant uptake of Zn in spinach. Research work conducted by Itanna (2002) in Addis Ababa revealed that cabbage was the least accumulator of chromium among the different vegetable crops.

Lark *et al.* (2002) drew soil and vegetable samples from the fields being irrigated by the city sewage were analysed for some toxic metals namely copper, iron, cadmium, lead and chromium using atomic absorption spectrometry and anodic stripping voltammetry. It has been found that these vegetables contain an appreciable amount of these metals per unit dry mass, which the general public is ingesting everyday.

Midio and Satake (2003) reported that Cabbage was generally the least accumulator of metals as compared to other vegetables. Cu, Mn and Ni content in all vegetables were found to be less than the maximum limit. Cd accumulation was more in leafy vegetables viz., lettuce, swiss chard, spinach and radish. The reason for the accumulation of more Cd is because of relatively easily taken up by leafy vegetables and also due to the foliar absorption of atmospheric deposits on plant leaves. The iron content was found to be very high in different crops, irrespective of the type of effluent used for irrigation purpose (Patel *et al.* 2004).

Patel *et al.* (2004) studied the heavy metal content of different vegetable crops irrigated with effluent water around industrial cities of Gujrat. They reported that the content of Cr in different crops was very high in spite of its level in soils. Fe content was found to invariably very high in different crops irrespective of the types of effluents. However, brinjal crop irrigated with fertilizer industry effluent showed exceptionally high amounts of Fe and Mn. The cauliflower crop grown had shown the lowest level of Cu, while tobacco plant irrigated with refinery effluent contained the lowest Fe content.

Vegetables, especially those of leafy nature grown in heavy metals contaminated soils, accumulate higher amounts of metals than those grown in uncontaminated soils because of the fact that they absorb these metals through their leaves (Al Jassir *et al.* 2005).

Demirezen and Ahmet (2006) analyzed different samples of vegetables and reported a high concentration (3.0-10.7 mg kg<sup>-1</sup>) of Pb which poses health risks to human life. They also reported that the levels of Cu (22.19-76.50 mg kg<sup>-1</sup>) were higher in leafy species than non leafy vegetable species in Turkey and this may be related to the richness in chlorophyll. Sharma *et al.* (2006) reported that the concentration of Pb ranged from 17.54-25.00 mg kg<sup>-1</sup> in vegetables grown in waste water irrigated areas of Varanasi. The concentration was found to be above the safer limit (2.5 mg kg<sup>-1</sup>), whereas concentration of Cu (2.25-5.42 mg kg<sup>-1</sup>) in vegetables was within the safe limit.

Chove *et al.* (2006) studied the concentration of copper and lead in vegetable crops and reported that the level of copper and lead ranged from 0.88 to 1.39 and 0.05 to 0.32 mg/100g dry weight in vegetable crops. They also concluded that the level of both lead and copper in vegetable crops was found to be below the maximum permissible levels recommended by FAO/WHO in vegetables.

In general, there are two mechanism viz., 'adsorption' which refers to binding of material onto the surface and 'absorption' which implies penetration of metals into the inner matrix. Either one of these or both the mechanisms might take place in the transportation of metals into the plant body. Vegetables take up metals by absorbing them from contaminated soils, as well as from deposits on different parts of the vegetables exposed to the air from polluted environments (Ejaz *et al.* 2007 and Michio, 2005).

Farooq *et al.* (2008) assessed the concentration of lead, copper, chromium, zinc and cadmium in various leafy vegetables grown in an effluent irrigated field in the vicinity of Faisalabad industrial area, Pakistan. They reported that the leaves of spinach, cabbage, cauliflower, radish and coriander contained higher concentrations of Cu ( $0.923 \text{ mg kg}^{-1}$ ), Cd ( $0.073 \text{ mg kg}^{-1}$ ), Cr ( $0.546 \text{ mg kg}^{-1}$ ), Zn ( $1.893 \text{ mg kg}^{-1}$ ) and Pb ( $2.652 \text{ mg kg}^{-1}$ ) as compared to other parts of each vegetable.

Prabu (2009) conducted a study to assess the extent of heavy metal contamination of vegetables due to irrigation with polluted river water and he reported that heavy metals content in soil was higher than vegetable samples and the reason might be their strong adsorptive nature in soil. The concentration of Cr in all vegetables was more than the maximum limit. The Cd accumulation was more in leafy vegetables than other vegetables under study. Metal transfer factors from soil to vegetables were significant for Zn, Mn, Cu, Fe and Cd and accumulation of Cr and Ni was comparatively less while that of Zn, Fe, Cu and Mn was more in vegetable plants.

## Chapter-3

# MATERIAL AND METHODS

The present investigation entitled “Impact of industrialization on water quality and soil health in Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh” was aimed at determining the impact of industrialization on the water quality, soil characteristics and microbial activity and biomass of the soil as no attempt has earlier been made on these aspects in the Himachal Pradesh. The details of material used and methodologies employed are presented in this chapter.

### 3.1 General description of the study area and selection of sites

#### 3.1.1 General description of study area.

Baddi, Barotiwala, Nalagarh (BBN) area is a fast upcoming industrial township which has emerged as a major industrial hub in Himachal Pradesh. The BBN area has large tracts of plain land suitable for industrial activity spread over 318.74 square km ([www.bbnia.com](http://www.bbnia.com)). It is located in District Solan of Himachal Pradesh. Main area of the BBN jurisdiction falls in Nalagarh tehsil though the part of it fall in Kasauli tehsil. BBN Region is well connected by national and state highways. It is mainly accessible through NH21 and NH22 which connect Chandigarh to Manali and Shimla, respectively.

**Table 3.1 Details of the industrial estates in BBN region.**

No	Name of Industrial area	Total area in Bighas (1 Bigha = 752 sq mts.)
1	DIC Industrial Area, Baddi	369
2	HPSIDC Industrial Area, Baddi	910
3	Industrial Area, Barotiwala	303
4	Export Promotion Industrial Park (EPIP) Phase 1, Jharmajri	995
5	Export Promotion Industrial Park (EPIP) Phase 2, Thana	1178
6	HIMUDA Industrial Area, Bhataulikalan	340
7	Industrial Area, Katha	376

There is a presence of large as well as small industrial units in BBN region like Cipla, Colgate, Palmolive and TVS Motors. These industries are located in the above mentioned Industrial Estates (Table 3.1), as well as outside, spatially scattered across the BBN region.

### 3.1.2 Location and climate

The experimental area is located at a distance of 45 km from Chandigarh in the foothills of Kasauli hills, situated at an altitude of about 460 metres in district Solan. The area lies between 30°-55' North latitude and 76°-50' East longitude. Geological structure of the region comprises shiwalik formations. The soils of hilly terrain are formed on soft sandstone, poorly sorted/bedded conglomerate, brownish clays and boulder beds. Baddi, Barotiwala, Nalagarh (BBN) area has moderate and salubrious climate. Average yearly rainfall is about 143cm with occasionally foggy weather, temperature varies from 8° to 42°C. Most of the rainfall occurs in the months of July-September. However, sufficient rainfall is received in winter also. The locations and sites of the study - area are presented in Fig 3.1.

### 3.1.3 Selection of study area

The Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh is set up in three different locations, viz Baddi, Barotiwala and Nalagarh area of Nalagrah tehsil of district Solan of Himachal Pradesh. In the present investigation ten sites were selected from each location and the names of selected sites and locations are given in Table 3.2.

**Table 3.2 Location and sites of sampled area**

Locations Sites	BADDI	BAROTIWALA	NALAGARH
1	SAIRAJMAJRA GUJRA	JHARMAJRI	KISHANPURA
2	SAIRAJMAJRA LABANA	BATED	MANPUR
3	BILLAWALI GUJRA	BAURAWALA	KHERA
4	BILLAWALI LABANA	PLANKWALA	KHRONI
5	KANTHA	SAINSIWALA	DHATOWAL
6	JUDDI KALAN	BROTIWALA	RAJPURA
7	JUDDI KHURD	SATTIWALA	CHOWKIWALA
8	BADDI	PANGA	SALEWAL

9	MALPUR	KURANWALA	DHBOTA
10	GULARWALA	KUNJHAL	BHATIYAN

### 3.2 Survey of study area

A detailed survey of the selected area was conducted in order to collect information on the soil, water, vegetation, industrial setup, effluents discharged by selected industries, irrigation water used for agriculture, drainage system near study area, sources of drinking water and other practices being followed in the selected area. People of study area procure drinking water from the water taps. Industries are situated near the agricultural fields and lot of pollutant material gets settled down on the surface of the leaves of crops growing in the area. A blackish layer was examined on the leaves of the vegetable crops in the study area. The main source of irrigation water was borewell. However, during the monsoon season, water of *nullhas* and *khuds* were also used for irrigation. Different industries discharge their effluents in the Sandhouli *nullha* and Balad *khud* and this practice is more during the monsoon season. The most important point was found to be that the effluents which were discharged in the Sandhouli *nullha* and Balad *khud* were finally merged with the Sirsa river which flows from Pinjore (Haryana) towards Baddi, Braotiwal, Nalagarh and finally to Ropar district of Punjab and ultimately enters into Sutlej river which is the main source of irrigation in different states. Several reports appeared in the print and electronic media regarding the dying of fish in the Sirsa River due to the pollution.

### 3.3 Collection and preparation of samples

#### 3.3.1 Soil samples

Soil samples were collected in two seasons i.e., pre-monsoon (May-June) and post-monsoon (Sept-Oct) and from two depths viz. surface (0-20 cm) and sub- surface (20-40 cm) from each site at three different locations. The soil samples were dried in shade and then crushed in a wooden pestle and mortar, passed through 2 mm sieve and stored in glass bottles for subsequent analysis.

#### 3.3.2 Plant samples

Leaf samples from two vegetable crops viz. brinjal and cauliflower growing in the study area were collected in pre-monsoon (May-June) and post-monsoon (Sept-Oct) seasons, respectively, from each location as per procedure suggested by Bhargava and Raghupathi (1993). The leaf samples were washed with ordinary water and then with 0.1 N HCl followed by washing with distilled water. These samples were dried in oven at 70<sup>0</sup>C, ground in stainless steel grinder to facilitate proper mixing of plant material and stored in paper bags for subsequent analysis.

### **3.3.3 Collection and preparation of water and industrial effluent samples**

Water and industrial effluent samples were collected in two seasons: pre-monsoon (May-June) and post-monsoon (Sept-Oct). Water samples of different sources viz. Borewell and tap were collected and preserved for quality analysis from each location. The water samples were preserved by adding 1.5 ml of Conc. HNO<sub>3</sub> to each one liter of sample. Similarly, water samples from Sandhouli *nullah*, Balad *khud* and Sirsa river were also collected and preserved for quality analysis. Industrial effluent samples from discharge outlet points of selected industries (Pharmaceutical, chemical, ghee and paper and textile industry) were collected and preserved for quality analysis of effluents. Water and industrial effluent samples were filtered by using Whatman No. 41 (0.45 µm pore size) filter paper for estimation of dissolved metal content.

## **3.4 Soil analysis**

### **a) Soil pH and electrical conductivity (EC)**

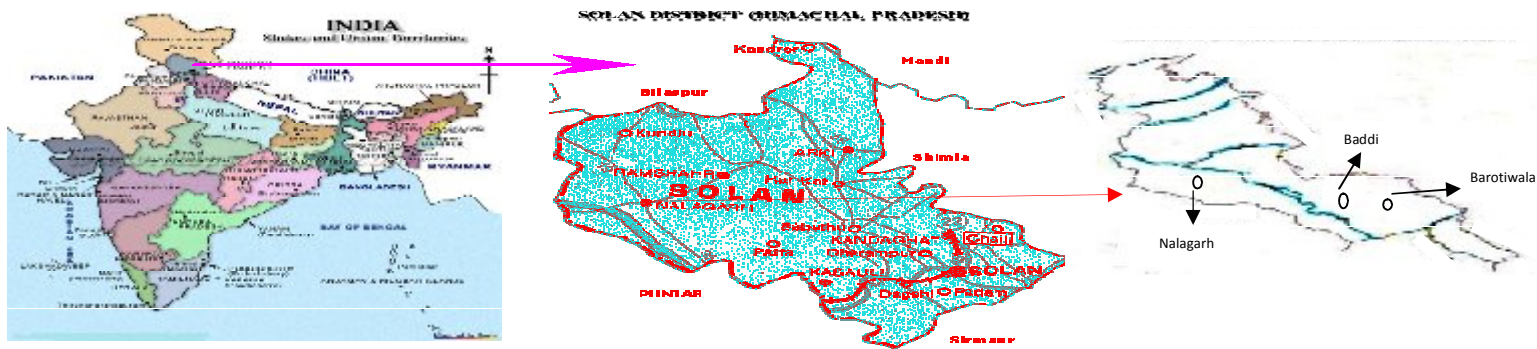
Soil pH and EC were determined in 1:2 soil: water suspension (Jackson, 1973).

### **b) Organic carbon**

Organic carbon was determined by rapid titration method (Walkley and Black, 1934).

### **c) Calcium carbonate**

Calcium carbonate content of soil was determined by the rapid titration method (Puri, 1930).



*Fig 3.1. Location Map of Baddi-Barotiwala-Nalagarh industrial area*

Source : [www.bbniia.com](http://www.bbniia.com)

Source : [www.MapsofIndia.com](http://www.MapsofIndia.com)

Fig. 3.2 Direction of Sirsa river flowing from Pinjore towards Ropar with adjoining nullhas and nadi of Baddi, Barotiwala and Nalagarh industrial area

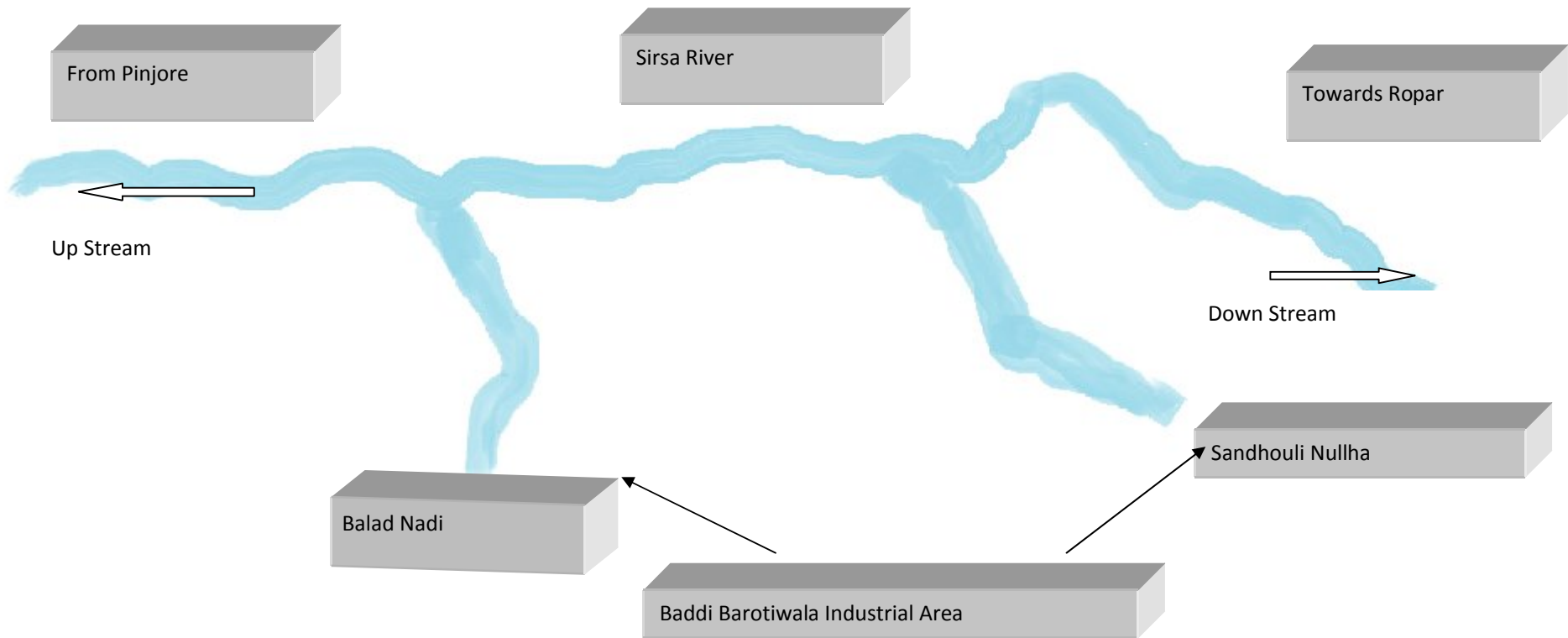




Plate 5: Effluents discharged from industry to nearby *khud*



Plate 6: Sirsa river surrounded by industries



Plate 7: Effluents collected in nearby agricultural field



Plate 3



Plate 4

Plate 3 & 4 : Effluents collected in nearby agricultural land



Plate 1



Plate 2

Plate 1 & 2 Effluents discharge from industries

**d) Available nitrogen**

Available nitrogen was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956).

**e) Available phosphorus**

Available phosphorus in soil was extracted by using 0.5 M NaHCO<sub>3</sub> at pH 8.5 (Olsen *et al.*, 1954) and determined by SnCl<sub>2</sub> reduced molybdate phosphoric acid blue colour method as described by Jackson (1973).

**f) Available potassium**

Available potassium in soil was extracted with neutral N. NH<sub>4</sub>OAC as described by Merwin and Peech (1951) and K was determined on flame photometer (Singh *et al.*, 1999).

**g) Micronutrients and Heavy metals (Zn, Mn, Cu, Fe, Cd, Pb and Ni)**

These were estimated following the method as described by Lindsay and Norvell (1978), where soil was extracted with DTPA extractant and Zn, Mn, Cu, Fe, Cd, Pb and Ni were determined with atomic absorption spectrophotometer (Jackson, 1973).

**g) Critical limits**

The critical limits followed for categorizing available nutrient status of soils are presented in Table 3.3

**Table 3.3 Critical limits of available nutrient status in soils**

Nutrient elements	Soil fertility classes			References
	Low	Medium	High	
Organic carbon (g kg <sup>-1</sup> )	< 5.0	5.0 - 10.0	> 10.0	Bhandari and Tripathi (1979)
N (kg ha <sup>-1</sup> )	< 280.0	280.0 - 560.0	> 560.0	FAI (1977)
P (kg ha <sup>-1</sup> )	< 10.0	10.0 - 24.6	> 24.6	FAI (1977)
K (kg ha <sup>-1</sup> )	< 98.6	98.6 - 280.0	> 280.0	FAI (1977)
Zn (mg kg <sup>-1</sup> )	< 0.9	1.0 - 1.5	> 1.5	Singh (2007)
Cu (mg kg <sup>-1</sup> )	< 0.5	-	> 0.5	Singh (2007)
Fe (mg kg <sup>-1</sup> )	< 2.0	2.1- 4.0	> 4.0	Singh (2007)

Mn (mg kg <sup>-1</sup> )	< 1.8	-	> 1.8	Singh (2007)
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The permissible limits followed for categorizing heavy metals in soils are presented in Table 3.4

**Table 3.4 Maximum permissible levels for heavy metals in soils**

Heavy metals	Permissible level	Source
Pb (mg kg <sup>-1</sup> )	5.00	Chapman (1975)
Cd (mg kg <sup>-1</sup> )	0.50	Chapman (1975)
Ni (mg kg <sup>-1</sup> )	2.00	Chapman (1975)

### 3.5 Plant analysis

#### a) Nitrogen

It was determined by Kjeldahl method as described by Jackson (1973).

#### b) Phosphorus and potassium

The samples were digested in HNO<sub>3</sub>:HClO<sub>4</sub> mixture (4:1) and phosphorus was determined by Vanadomolybdate yellow colour method (Jackson, 1973) and potassium was estimated on flame photometer (Jackson, 1973).

#### c) Micronutrients and Heavy metals (Zn, Mn, Cu, Fe, Cd, Pb and Ni)

The samples were digested in di-acid (HNO<sub>3</sub> + HClO<sub>4</sub>) mixture and micronutrients and heavy metals (Zn, Mn, Cu, Fe, Cd, Pb and Ni) were estimated with atomic absorption spectrophotometer as given by Jackson (1973).

#### d) Permissible limits

The permissible limits followed for categorizing macro and micronutrients and heavy metal elements of plants are presented in Table 3.5

**Table 3.5 Maximum permissible levels of macro and micronutrients and heavy metals present in vegetables crops**

Parameters	Max. Level	Parameters	Max. Level
N (g/kg)	10-50	Mn (mg/kg)	500
P (g/kg)	10-40	Cu (mg/kg)	73.30
K (g/kg)	10-40	Pb (mg/kg)	0.30
Fe (mg/kg)	425.50	Ni (mg/kg)	67.90
Zn (mg/kg)	99.40	Cd (mg/kg)	0.20

Source : FAO/WHO (2001)

### 3.6 Water and industrial effluents analysis

- a) The electrical conductivity, pH, chloride ( $\text{Cl}^-$ ), bicarbonate ( $\text{HCO}_3^-$ ) and carbonate ( $\text{CO}_3^{2-}$ ) contents were analyzed by volumetric titration method as described by Richard (1954).
- b) For the TSS test; the settleable solids were removed first and the TSS test conducted. 100ml of the supernatant liquid was passed through a  $0.45\mu\text{m}$  pore preweighed filter paper and the final mass of the filter paper after oven drying at temperature of  $103^\circ\text{C}$ - $105^\circ\text{C}$  was measured and the TSS (mg/l) was calculated as per the method given by American Public Health Association (APHA, 2005).
- c) Chemical oxygen demand (COD), Biological oxygen demand (BOD), Total Nitrogen (N), Phosphorus (P) and Potassium (K) were analyzed as per the method given by American Public Health Association (APHA, 2005).
- d) Micronutrients and Heavy metals (Zn, Mn, Cu, Fe, Cd, Pb and Ni)

The water and industrial effluent samples were digested in nitric acid. The micronutrients and heavy metals were estimated with Atomic Absorption Spectrophotometer using standard methods given by American Public Health Association (APHA, 2005).

#### e) Permissible limits

The permissible limits followed for categorizing different parameters of effluents and irrigation water are presented in Table 3.6 and 3.7.

**Table 3.6 Permissible limit of parameters of different industrial effluents**

Parameters	Permissible limit	Source
pH	5.5-9.0	*BIS, 2003
EC (dSm <sup>-1</sup> )	NA	**NA
TSS (mg/l)	100	BIS, 2003
Cl <sup>-</sup> (mg/l)	600	BIS, 2003
HCO <sub>3</sub> <sup>-</sup> (mg/l)	NA	NA
CO <sub>3</sub> <sup>-</sup> (mg/l)	NA	NA
BOD (mg/l)	30	BIS, 2003
COD (mg/l)	250	BIS, 2003
Zn (mg/l)	5.0	BIS, 2003
Mn (mg/l)	1.5	***UNESCAP, 2000
Cd (mg/l)	2.0	BIS, 2003
Pb (mg/l)	0.1	BIS, 2003
Ni (mg/l)	3.0	BIS, 2003
Cu (mg/l)	3.0	BIS, 2003
Fe (mg/l)	15	****FAO/WHO, 2001

\* Bureau of Indian Standards

\*\* Not Available

\*\*\* United Nations Economic and Social Commission for Asia and the Pacific

\*\*\*\* Food and Agriculture Organisation/World Health Organisation

**Table 3.7 Permissible limit of irrigation water parameters**

Parameters	Permissible limit	Source
pH	6.5 - 8.4	*FAO/WHO, 2001
EC (μSiemens cm <sup>-1</sup> )	700	FAO/WHO, 2001
TSS (mg/l)	NA	NA
Cl <sup>-</sup> (mg/l)	1050	FAO/WHO, 2001
HCO <sub>3</sub> <sup>-</sup> (mg/l)	400	FAO/WHO, 2001
CO <sub>3</sub> <sup>-</sup> (mg/l)	NA	NA
Ca <sup>++</sup> (mg/l)	400	FAO/WHO, 2001
Mg <sup>++</sup> (mg/l)	0- 60	FAO/WHO, 2001
Na <sup>+</sup> (mg/l)	920	FAO/WHO, 2001
BOD (mg/l)	NA	NA
COD (mg/l)	NA	NA
Zn (mg/l)	5.0	FAO/WHO, 2001
Mn (mg/l)	0.1	** ISI, 1977
Cd (mg/l)	0.01	*** BIS, 2003
Pb (mg/l)	5.0	FAO/WHO, 2001
Ni (mg/l)	0.1	ISI, 1977
Cu (mg/l)	0.05	ISI, 1977
Fe (mg/l)	0.3	ISI, 1977

- \* Food and Agriculture Organisation/World Health Organisation
- \*\* Indian Standards Institute
- \*\*\* Bureau of Indian Standards

### 3.7 Microbial properties

#### 3.7.1 Microbial biomass (Soil Fumigation-Extraction Method)

Soil microbial biomass carbon was determined by soil fumigation-extraction method as detailed by Vance *et al.* (1987). In this method, 10 g of soil was fumigated with 20 ml of CHCl<sub>3</sub> in vacuum desiccator for 24 hr in dark and other 10 g of same soil sample was refrigerated, then both the samples (fumigated and unfumigated) were extracted with 0.5 M K<sub>2</sub>SO<sub>4</sub> for half an hour and then treated with H<sub>2</sub>SO<sub>4</sub> and orthophosphoric acid and heated on hot plate at 120<sup>0</sup>C for 30 minutes. After that diluted to 250 ml with distilled water and 2-3 drops of ferroin indicator was added and titrated against 0.005 N. Ferrous ammonium sulphate and was calculated by following formula:

$$\text{MB-C } (\mu\text{g/g soil}) = \frac{\text{OC}_F - \text{OC}_{UF}}{K}$$

OC<sub>F</sub> = Total amount of extractable carbon in fumigated soil

OC<sub>UF</sub> = Total amount of extractable carbon in unfumigated soil

K = Factor (0.45)

#### 3.7.2 Microbial activity (CO<sub>2</sub> evolution method)

Soil microbial activity was determined by the CO<sub>2</sub> evolution method (Pramer and Schmidt, 1964). One hundred gram of soil was taken in one litre flask, sufficient water was added to bring it to field capacity. Fifteen ml of N. NaOH was taken in 50 ml test tube and the test tube was suspended inside the flask with the help of thread. The mouth of flask was closed tightly with the help of rubber cork and wax to avoid any leakage of carbon dioxide. The CO<sub>2</sub> released was quantified at periodic interval

(12hr, 24hr, 36hr and 48hr) by acid titration in the presence of phenolphthalein indicator. The results were expressed as mg CO<sub>2</sub>/g soil.

$$\begin{array}{l} \text{CO}_2 \text{ evolution} \\ \text{(mg CO}_2\text{/g soil)} \end{array} = (\text{B-V}) \text{NE}$$

Where,

- B = Volume of HCl used for blank
- V = Volume of HCl used for sample
- N = Normality of acid
- E = 22 (equivalent weight of CO<sub>2</sub>)

### 3.8 Statistical analysis

The observations recorded on various parameters of soil, plant and water were subjected to analysis of variance (**ANOVA**) using completely randomized design (Factorial) and randomized block design (Factorial) at five percent level of significance (Gomez and Gomez, 1984). Variability analysis was computed as given by Gupta and Kapoor (1996).

## **CHAPTER-4**

# **EXPERIMENTAL RESULTS**

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The results emerging out of the present investigation are presented in this chapter under the following headings:

- 4.1 Chemical characteristics of industrial effluents**
- 4.2 Water characteristics**
- 4.3 Physico - chemical properties of the soils**
- 4.4 Available nutrient status of soils**
- 4.5 Microbial properties**
- 4.6 Macro and micronutrients concentration in plants**
- 4.7 Variability analysis**

### **4.1 Chemical characteristics of industrial effluents**

#### **4.1.1 Chemical characteristics of industrial effluents during pre-monsoon season**

The data in Table 4.1a represented the chemical analysis of effluents of paper, pharmaceutical, textile, ghee and chemical industries during pre-monsoon season. The pH ranged from 7.89 to 8.65 and highest was recorded in textile industry effluent and lowest in paper industry effluent. The EC ranged from 1.49 to 4.34 dS m<sup>-1</sup> and highest was found in textile industry and lowest in pharmaceutical industry effluent. Total Suspended Solids ranged from 169 to 2538 mg/l and highest was found in chemical industry effluent and lowest in paper industry effluents. The Cl<sup>-</sup> ranged from 496 to 624 mg/l and highest was noticed in pharmaceutical industry and lowest in ghee industry effluent samples. The HCO<sub>3</sub><sup>-</sup> content ranged from 181 to 286 mg/l and highest value was found in the effluents of chemical

industry and lowest in ghee industry.  $\text{CO}_3^{2-}$  concentration was found to be in the range of 57 to 87 mg/l and highest was recorded in chemical industry and lowest in ghee industry effluents. The BOD ranged from 1.88 to 2.35 mg/l and highest BOD was observed in the effluent of paper industry and lowest in ghee industry.

**Table 4.1a. Chemical characteristics of industrial effluents during pre-monsoon season**

Industry Parameters	Paper	Pharmaceutical	Textile	Ghee	Chemical
pH	7.89	8.08	8.65	7.94	8.38
EC ( $\text{dSm}^{-1}$ )	2.74	1.49	4.34	2.05	1.65
TSS (mg/l)	169.00	427.00	1722.00	823.00	2538.00
$\text{Cl}^{-}$ (mg/l)	517.00	624.00	604.00	496.00	582.00
$\text{HCO}_3^{-}$ (mg/l)	283.00	258.00	230.00	181.00	286.00
$\text{CO}_3^{2-}$ (mg/l)	85.00	75.00	66.00	57.00	87.00
BOD (mg/l)	2.35	2.14	2.15	1.88	2.05
COD (mg/l)	427.00	375.00	303.00	455.00	1403.00
Zn (mg/l)	0.22	0.38	0.65	0.19	1.77
Mn (mg/l)	1.10	1.01	1.37	0.97	1.74
Cu (mg/l)	6.61	1.10	0.90	1.27	6.08
Fe (mg/l)	1.20	2.27	1.96	0.98	3.13
Cd (mg/l)	0.015	0.019	0.024	0.00	0.026
Pb (mg/l)	0.027	0.162	0.029	0.022	0.108
Ni (mg/l)	0.019	0.026	0.037	0.015	0.056
N (mg/l)	3.10	0.39	0.28	6.00	3.00
P (mg/l)	3.02	5.14	13.89	3.71	14.65
K (mg/l)	44.00	43.00	42.00	35.00	48.00

The values of COD ranged from 303 mg/l (Textile) to 1403 mg/l (chemical). The content of Zn and Mn ranged from 0.19 to 1.77 mg/l and 0.97 to 1.74 mg/l and highest value was recorded in chemical industry. The content of Cu varied from 0.90 to 6.61 mg/l and highest content was recorded in paper industry and lowest in textile industry. The content of Fe ranged from 0.98 to 3.13 mg/l and highest was recorded in chemical industry and lowest was recorded in ghee industry. Cd ranged from 0.00 to 0.026 mg/l and highest content was observed in chemical industry and lowest in ghee industry. Pb ranged from 0.022 to 0.162

mg/l and highest was recorded in pharmaceutical industry and lowest was observed in ghee industry. The content of Ni varied from 0.015 to 0.056 mg/l and highest was recorded in chemical industry and lowest in ghee industry. Total nitrogen content ranged from 0.28 to 6.0 mg/l and highest was found in ghee industry and lowest was recorded in textile industry. Likewise, P ranged from 3.02 to 14.65 mg/l and highest content was recorded in chemical industry and lowest in paper industry. The potassium ranged from 35.00 to 48.00 mg/l and highest was noticed in chemical industry and lowest in ghee industry effluents.

#### 4.1.2 Chemical characteristics of industrial effluents during post-monsoon season

The data presented in Table 4.1b represented the chemical analysis of different effluents of paper, pharmaceutical, textile, ghee and chemical industries during post-monsoon

**Table 4.1b. Chemical characteristics of industrial effluents during post-monsoon season**

<b>Industry Parameters</b>	<b>Paper</b>	<b>Pharmaceutical</b>	<b>Textile</b>	<b>Ghee</b>	<b>Chemical</b>
pH	7.99	8.15	8.94	7.97	8.41
EC (dSm <sup>-1</sup> )	2.79	1.54	4.49	2.19	1.74
TSS (mg/l)	181.00	445.00	1754.00	841.00	2599.00
Cl <sup>-</sup> (mg/l)	538.00	645.00	631.00	519.00	604.00
HCO <sub>3</sub> <sup>-</sup> (mg/l)	286.00	264.00	239.00	187.00	293.00
CO <sub>3</sub> <sup>-</sup> (mg/l)	92.00	82.00	73.00	61.00	93.00
BOD (mg/l)	2.41	2.22	2.21	1.94	2.14
COD (mg/l)	444.00	399.00	313.00	474.00	1425.00
Zn (mg/l)	0.26	0.41	0.69	0.21	1.96
Mn (mg/l)	1.14	1.04	1.43	0.99	1.95
Cu (mg/l)	6.68	1.13	0.95	1.32	6.12
Fe (mg/l)	1.24	8.15	2.09	1.01	3.54
Cd (mg/l)	0.017	0.022	0.028	0.00	0.026
Pb (mg/l)	0.031	0.178	0.034	0.023	0.114
Ni (mg/l)	0.023	0.026	0.039	0.018	0.059
N (mg/l)	3.32	0.400	0.34	8.00	8.00
P (mg/l)	3.97	6.99	15.87	5.56	16.45
K (mg/l)	48.00	42.00	45.00	38.00	49.80

season. The pH ranged from 7.97 to 8.94 and highest was recorded in textile industry effluent and lowest in ghee industry effluent. The EC ranged from 1.54 to 4.49 dS m<sup>-1</sup> and highest was found in textile industry and lowest in pharmaceutical industry effluent. Total Suspended Solids ranged from 181 to 2599 mg/l and highest was found in chemical industry effluent and lowest in paper industry effluents. The Cl<sup>-</sup> ranged from 519 to 645 mg/l and highest was noticed in pharmaceutical industry and lowest in ghee industry effluent samples. The HCO<sub>3</sub><sup>-</sup> content ranged from 187 to 293 mg/l and highest value was found in the effluents of chemical industry and lowest in ghee industry. CO<sub>3</sub><sup>-</sup> concentration was found to be in the range of 61 to 93 mg/l and highest was recorded in chemical industry and lowest in ghee industry effluents. The BOD ranged from 1.94 to 2.41 mg/l and highest BOD was observed in the effluent of paper industry and lowest in ghee industry.

The values of COD ranged from 313 mg/l (Textile) to 1425 mg/l (chemical). The content of Zn and Mn ranged from 0.21 to 1.96 mg/l and 0.99 to 1.95 mg/l and highest value was recorded in chemical industry and lowest in ghee industry. The content of Cu varied from 0.95 to 6.68 mg/l and highest content was recorded in paper industry and lowest in textile industry. The content of Fe ranged from 1.01 to 8.15 mg/l and highest was recorded in pharmaceutical industry and lowest was recorded in ghee industry. Cd ranged from 0.00 to 0.028 mg/l and highest content was observed in textile industry and lowest in ghee industry. Pb ranged from 0.023 to 0.178 mg/l and highest was recorded in pharmaceutical industry and lowest was observed in ghee industry. The content of Ni varied from 0.018 to 0.059 mg/l and highest was recorded in chemical industry and lowest in ghee industry. Total nitrogen content ranged from 0.34 to 8.0 mg/l and highest was found in ghee and chemical industry and lowest was recorded in textile industry. Likewise, P ranged from 3.97 to 16.45 mg/l and highest content was recorded in chemical industry and lowest in paper industry. The potassium ranged from 38.00 to 49.80 mg/l and highest was noticed in chemical industry and lowest in ghee industry effluents.

It is apparent from the study that due to more discharge of effluents during monsoon the values in post-monsoon season were higher than those in pre-monsoon season.

## 4.2 Water characteristics

### 4.2.1 River water

The data in Table 4.2 represents the chemical characteristics of water from Sirsa river upstream Balad Nadi (SUB), Sirsa river downstream Balad Nadi and upstream Sandouli *nullha* (SDB&USa) and Sirsa river downstream Sandouli *nullha* (SDSa) during pre-monsoon and post-monsoon seasons. The average values of pH in pre and post-monsoon season was 8.17 and 8.20, respectively. Further, irrespective of seasons, pH of river water ranged from 8.29 to 8.07. The highest pH value of 8.29 was recorded in the water of Sirsa river downstream Balad Nadi and upstream Sandouli *nullha* (SDB&USa) during both seasons and lowest pH value of 8.04 was recorded in the water of Sirsa river downstream Sandouli *nullha* (SDSa) in pre-monsoon season. The mean value of EC during pre and post-monsoon season was recorded to be 3417.60 and 3533.20  $\mu$ Siemens/cm, respectively. Among different sources of water, EC ranged from 418.30 - 9162.00  $\mu$ Siemens/cm. Taking into consideration both sources and seasons, it was found that highest EC of water was recorded in SDSa (9324.00  $\mu$ Siemens/cm) during post-monsoon season and lowest in Sirsa river downstream Balad Nadi and upstream Sandouli *nullha* (SDB&USa) i.e. 414.00  $\mu$ Siemens/cm during pre-monsoon season. The total suspended solids (TSS) concentration in pre and post-monsoon season was found to be 54.00 and 58.78 mg/l, respectively. Further, irrespective of seasons, TSS concentration ranged from 22.83 - 109.33 mg/l. The interaction effect indicated that highest TSS values of 113.33 mg/l was recorded in the water of Sirsa river downstream Sandouli *nullha* (SDSa) during post-monsoon season and lowest (21.33 mg/l) in Sirsa river upstream Balad Nadi (SUB) during pre-monsoon season, respectively.

The data presented in the Table 4.3 revealed that during pre and post-monsoon season, water contains 497.67 and 510.11 mg/l of chloride, respectively. Further, irrespective of seasons, the concentration of  $\text{Cl}^-$  (mg/l) among different river and *nullha's* water ranged from 90.33 - 1259.83 mg/l. The interaction data indicated that highest  $\text{Cl}^-$  concentration of 1269.00 mg/l was recorded in Sirsa river downstream Sandouli *nullha* (SDSa) water during post-monsoon season and lowest (87.67 mg/l) in Sirsa river upstream Balad nadi (SUB) during pre-monsoon season. The  $\text{HCO}_3^-$  content during pre and post-monsoon season was found to be 141.22 and 148.00 mg/l, respectively. Among different sources of water,  $\text{HCO}_3^-$

concentration ranged as 124.17 - 162.50 mg/l. Taking into consideration both source of water and seasons, it was observed that highest  $\text{HCO}_3^-$  concentration (165.00 mg/l) was recorded in Sirsa river downstream Balad nadi and upstream Sandouli *nullha* (SDB&USa) water during post-monsoon season and lowest (121.00 mg/l) in Sirsa river upstream Balad Nadi (SUB) during pre-monsoon season, respectively. The water sample taken in pre and post-monsoon season registered 53.11 and 60.89 mg/l of  $\text{CO}_3^{2-}$ , respectively. Further, irrespective of seasons,  $\text{CO}_3^{2-}$  concentration of different water sources varied from 23.67 - 81.83 mg/l. The interaction effect indicated that highest  $\text{CO}_3^{2-}$  concentration (85.00 mg/l) was recorded in Sirsa river downstream Sandouli *nullha* (SDSa) during post-monsoon season and lowest (21.33 mg/l) in Sirsa river upstream Balad Nadi (SUB) during pre-monsoon season, (Table 4.3).

As evinced from the Table 4.4, pre and post-monsoon season water contains 116.00 and 123.78 mg/l of calcium, respectively. Further, irrespective of seasons, calcium concentration of river water ranged from 94.00 - 165.67 mg/l. The interaction data indicated that highest calcium concentration (169.00 mg/l) was recorded in Sirsa river downstream Sandouli *nullha* (SDSa) during post-monsoon seasons and lowest (91.00 mg/l) in Sirsa river upstream Balad nadi (SUB) in pre-monsoon season. The concentration of magnesium was found to be 27.78 mg/l and 34.33 mg/l during pre and post-monsoon season, respectively. The magnesium concentration in the water of river and *nullhas* ranged from 20.50 to 36.67 mg/l. Taking into consideration both sources of water and seasons, highest magnesium concentration (42.00 mg/l) was found to be in Sirsa river downstream Balad nadi and upstream Sandouli *nullha* (SDB&USa) water during post-monsoon season. However, lowest concentration of 19.33 mg/l was recorded in Sirsa river upstream Balad Nadi (SUB) during pre-monsoon season, respectively. Among seasons, pre and post-monsoon season had sodium concentration of 235.67 and 244.56 mg/l, respectively. Further, irrespective of seasons, sodium concentration of river and *nullhas* ranged from 54.50 to 546.83 mg/l. The interaction effect indicated that highest sodium concentration (554.00 mg/l) was recorded in Sirsa river downstream Sandouli *nullha* (SDSa) water during post-monsoon season and lowest (52.00 mg/l) in Sirsa river upstream Balad Nadi (SUB) water during pre-monsoon season.

**Table 4.2 Status of pH, EC and TSS in the water of river and nullhas**

Parameters	pH				EC( $\mu$ Siemens/cm)				TSS(mg/l)				
	Rivers	SUB	SDB&Usa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean
Season													
Pre monsoon	8.19	8.29	8.04	8.17	838.70	414.00	9000.00	3417.60	21.33	35.33	105.33	54.00	
Post monsoon	8.22	8.29	8.10	8.20	853.00	422.70	9324.00	3533.20	24.33	38.67	113.33	58.78	
Mean	8.20	8.29	8.07		845.8	418.3	9162.00		22.83	37.00	109.33		
	<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		
CD <sub>0.05</sub>	<b>0.032</b>	<b>0.039</b>	<b>0.055</b>		<b>0.731</b>	<b>0.896</b>	<b>1.261</b>		<b>3.250</b>	<b>3.983</b>	<b>5.604</b>		

**Table 4.3 Status of Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>-</sup> in the water of river and nullhas**

Parameters	Cl <sup>-</sup> (mg/l)				HCO <sub>3</sub> <sup>-</sup> (mg/l)				CO <sub>3</sub> <sup>-</sup> (mg/l)				
	Rivers	SUB	SDB&Usa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean
Season													
Premonsoon	87.67	154.67	1250.67	497.67	121.00	160.00	142.67	141.22	21.33	59.33	78.67	53.11	
Post monsoon	93.00	168.33	1269.00	510.11	127.33	165.00	151.67	148.00	26.00	71.67	85.00	60.89	
Mean	90.33	161.50	1259.83		124.17	162.50	147.17		23.67	65.50	81.83		
	<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		
CD <sub>0.05</sub>	<b>0.75</b>	<b>0.92</b>	<b>1.30</b>		<b>1.10</b>	<b>1.35</b>	<b>1.91</b>		<b>1.25</b>	<b>1.53</b>	<b>2.15</b>		

**Table 4.4 Status of Ca<sup>++</sup>, Mg<sup>++</sup> and Na<sup>+</sup> in the water of river and nullhas**

Parameters	Ca <sup>++</sup> (mg/l)				Mg <sup>++</sup> (mg/l)				Na <sup>+</sup> (mg/l)				
	Rivers	SUB	SDB&USa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean	SUB	SDB&USa	SDSa	Mean
Season													
Premonsoon	91.00	94.67	162.33	116.00	19.33	30.00	34.00	27.78	52.00	115.33	539.67	235.67	
Post monsoon	97.00	105.33	169.00	123.78	21.67	42.00	39.33	34.33	57.00	122.67	554.00	244.56	
Mean	94.00	100.00	165.67		20.50	36.00	36.67		54.50	119.00	546.83		
	<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		<b>Season(S)</b>	<b>River(R)</b>	<b>S x R</b>		
CD <sub>0.05</sub>	<b>2.53</b>	<b>3.10</b>	<b>4.36</b>		<b>1.38</b>	<b>1.69</b>	<b>2.39</b>		<b>0.59</b>	<b>0.72</b>	<b>1.02</b>		

The data presented in the Table 4.5 revealed that average values of BOD during pre and post-monsoon season was found to be 68.30 and 62.88 mg/l, respectively. Further, irrespective of seasons, BOD of water from river and *nullhas* ranged from 0.66 to 195.00 mg/l. For interaction data, it was found that highest BOD (203.33 mg/l) of water was recorded in Sirsa river downstream Sandouli *nullha* (SDSa) during pre-monsoon season and lowest (0.54 mg/l) in Sirsa river upstream Balad nadi (SUB) in pre-monsoon season. The COD concentration in the water of river was found to be 185.11 mg/l and 189.77 mg/l during pre and post-monsoon season, respectively. Among different sources of water, COD concentration ranged from 16.83 - 524.00 mg/l. Taking into consideration both sources of water and seasons, it was found that highest COD concentration (527.67 mg/l) was recorded in the water of Sirsa river downstream Sandouli *nullha* (SDSa) during post-monsoon season and lowest (15.33 mg/l) in Sirsa river upstream Balad Nadi (SUB) during pre-monsoon season.

**Table 4.5 Status of BOD and COD in the water of river and *nullhas***

Parameters	BOD(mg/l)				COD(mg/l)				
	Rivers	SUB	SDB&USa	SDSa	Mean	SUB	SDB&Usa	SDSa	Mean
Season									
Pre-monsoon	0.54	1.01	203.33	68.30	15.33	19.67	520.33	185.111	
Post-monsoon	0.78	1.20	186.67	62.88	18.33	23.33	527.67	189.778	
<b>Mean</b>	<b>0.66</b>	<b>1.10</b>	<b>195.00</b>		<b>16.83</b>	<b>21.50</b>	<b>524.00</b>		
	<b>Season</b>	<b>River</b>			<b>Season</b>	<b>River</b>			
	<b>(S)</b>	<b>(R)</b>	<b>S x R</b>		<b>(S)</b>	<b>(R)</b>	<b>S x R</b>		
<b>CD<sub>0.05</sub></b>	<b>23.04</b>	<b>28.23</b>	<b>39.72</b>		<b>0.94</b>	<b>1.16</b>	<b>1.63</b>		

The data presented in Table 4.6 indicated the concentration of micronutrients and heavy metals in water of river and *nullhas* during both seasons. The of data revealed that the concentration of iron were in the order of 0.51 and 0.59; 1.10 and 1.12 and 0.78 and 0.79 mg/l in Sirsa river upstream Balad nadi (SUB), Sirsa river downstream Balad nadi and upstream Sandouli *nullha* (SDB&USa) and Sirsa river downstream Sandouli *nullha* (SDSa) during pre and post-monsoon season, respectively. Copper concentration in water of river and *nullhas* ranged from 0.03 to 0.09 mg/l during both seasons. Likewise, manganese (Mn) concentration were found to be in the order of 0.10 and 0.12; 0.31 and 0.32, and 0.33 and

0.35 mg/l during pre and post-monsoon seasons, respectively. Zinc concentration ranged from 0.04 to 0.12 mg/l irrespective of source of water during pre and post-monsoon season.

**Table 4.6 Micronutrients and heavy metal concentration (mg/l) in the water of river and *nullhas***

Source	SUB		SDB&Usa		SDSa	
Season	Pre-monsoon (Mean value)	Post-monsoon (Mean value)	Pre-monsoon (Mean value)	Post-monsoon (Mean value)	Pre-monsoon (Mean value)	Post-monsoon (Mean value)
Parameter						
Fe(mg/L)	0.51	0.59	1.10	1.12	0.78	0.79
Cu(mg/L)	0.04	0.05	0.08	0.09	0.03	0.04
Mn(mg/L)	0.10	0.12	0.31	0.32	0.33	0.35
Zn(mg/L)	0.04	0.04	0.10	0.12	0.09	0.10
Pb(mg/L)	0.01	0.03	0.02	0.03	0.05	0.06
Ni(mg/L)	0.01	0.02	0.02	0.02	0.03	0.04
Cd(mg/L)	0.03	0.04	0.06	0.08	0.09	0.10

The lead concentration in the water samples were found to be in the tune of 0.01 and 0.03; 0.02 and 0.03; 0.05 and 0.06 mg/l during pre and post-monsoon season in SUB, SDB&Usa and SDSa, respectively. The average nickel concentration recorded in the water of Sirsa river upstream Balad nadi (SUB), Sirsa river downstream Balad nadi and upstream Sandouli *nullha* (SDB&Usa) and Sirsa river downstream Sandouli *nullha* (SDSa) during pre and post-monsoon season were 0.01 and 0.02; 0.02 and 0.02; and 0.03 and 0.04 mg/l, respectively. Cadmium concentration ranged from 0.03 - 0.10 mg/l in different sources of water from river and *nullhas* during both seasons (Table 4.6).

#### 4.2.2 Bore well and tap-water

The data presented in Table 4.7 showed the status of pH in water of bore well and tap during pre and post-monsoon seasons at different locations. Data revealed that the pH of the water significantly varied from 7.73 to 8.81, irrespective of location and seasons. Highest pH of 8.35 (pre-monsoon) and 8.23 (post-monsoon) amongst the three different locations was recorded at Nalagarh followed by Baddi (7.92 and 7.82) and lowest (7.89 and 7.76) was recorded at Barotiwala during pre and post-monsoon season, respectively. Among two different sources of water, the bore well water had mean values of 8.24 and 8.13 and tap-water 7.85 and 7.44 during pre and post-monsoon season, respectively.

**Table 4.7 Status of pH in bore well and tap-water**

Parameter	pH							
	Pre- monsoon			Post- monsoon				
Season	Bore well Water		Tap-water	Mean	Bore well Water		Tap-water	Mean
Location								
Nalagarh	8.81		7.88	8.35	8.71		7.76	8.23
Baddi	8.00		7.83	7.92	7.89		7.73	7.82
Barotiwala	7.92		7.85	7.89	7.79		7.74	7.76
<b>Mean</b>	<b>8.24</b>		<b>7.85</b>		<b>8.13</b>		<b>7.74</b>	
	<b>Location</b>	<b>Source</b>			<b>Location</b>	<b>Source</b>		
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>		<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	
<b>CD<sub>0.05</sub></b>	<b>0.014</b>	<b>0.012</b>	<b>0.020</b>		<b>0.019</b>	<b>0.015</b>	<b>0.027</b>	

Taking into consideration both sources of water and locations it was found that water from bore well of Nalgrah had highest pH (8.81 and 8.71) value, whereas, tap-water of Baddi recorded lowest pH (7.83 and 7.73) during pre and post-monsoon seasons, respectively.

The results of water analysis presented in the Table 4.8 indicated that electrical conductivity (EC) significantly varied from 0.40 to 1.37 dSm<sup>-1</sup>, irrespective of location and seasons. The highest EC of 0.87 dSm<sup>-1</sup> and 0.91 dSm<sup>-1</sup> was recorded at Nalagarh and lowest at Baddi 0.41 dSm<sup>-1</sup> during pre and post-monsoon season, respectively. Among two different sources of water, it was noticed that bore well had electrical conductivity value of 0.71 and 0.74 and tap-water 0.42 dSm<sup>-1</sup> each during pre-monsoon and post-monsoon season, respectively. Taking into consideration both sources of water and locations, it was found that water from bore well of Nalgrah had highest EC of 1.30 and 1.37 dSm<sup>-1</sup> during pre and post-monsoon season, respectively, whereas, tap-water of Baddi had lowest EC values of 0.40 and 0.41 dSm<sup>-1</sup> during pre and post-monsoon season.

The chloride content of water are presented in the Table 4.9. The chloride content significantly varied from 7.33 to 42.33 mg/l irrespective of location and season. Among different locations, highest chloride concentration (37.00 and 35.83 mg/l) was recorded at Nalagarh and lowest (14.00 and 9.33 mg/l) at Baddi during pre and post-monsoon seasons,

**Table 4.8 Status of EC in bore well and tap-water**

Parameter	EC (dSm <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	1.30	0.45	0.87	1.37	0.45	0.91
Baddi	0.41	0.40	0.41	0.42	0.41	0.41
Barotiwala	0.43	0.41	0.42	0.43	0.41	0.42
<b>Mean</b>	<b>0.71</b>	<b>0.42</b>		<b>0.74</b>	<b>0.42</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>0.0020</b>	<b>0.0016</b>	<b>0.0029</b>	<b>0.0015</b>	<b>0.0012</b>	<b>0.0022</b>

respectively. Further, irrespective of location, water from bore well and tap had average chloride concentration of 20.22 and 25.78 mg/l; 18.67 and 20.89 mg/l during pre and post-monsoon season, respectively. The interaction effect indicated that tap-water of Nalgrah had highest chloride concentration of 42.33 and 36.67 mg/l during pre and post-monsoon seasons and bore well water of Baddi had lowest chloride concentration of 11.67 and 7.33mg/l during pre and post-monsoon season, respectively.

**Table 4.9 Status of Cl<sup>-</sup> in bore well and tap-water**

Parameter	Cl <sup>-</sup> (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	31.67	42.33	37.00	35.00	36.67	35.83
Baddi	11.67	16.33	14.00	7.33	11.33	9.33
Barotiwala	17.33	18.67	18.00	13.67	14.67	14.17
<b>Mean</b>	<b>20.22</b>	<b>25.78</b>		<b>18.67</b>	<b>20.89</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>1.38</b>	<b>1.33</b>	<b>1.96</b>	<b>2.06</b>	<b>1.68</b>	<b>NS</b>

The data presented in Table 4.10 indicated that highest HCO<sub>3</sub><sup>-</sup> concentration (128.16 and 135.00 mg/l) in the water of three different locations was recorded at Nalagarh followed

by Barotiwala (117.00 and 122.66 mg/l) and lowest (110.00 and 116.66 mg/l) at Baddi during pre and post-monsoon season, respectively. Among two different sources of water, it was noticed that bore well and tap-water had  $\text{HCO}_3^-$  concentration of 123.22 and 113.56; 131.44 and 118.11 mg/l during pre and post-monsoon season, respectively. Taking into consideration both sources of water and locations, it was found that bore well water of Barotiwala and Nalgrah contained highest  $\text{HCO}_3^-$  concentration of 130.00 (pre-monsoon) and 138.00 mg/l (post-monsoon), respectively. However, tap-water of Barotiwala had lowest  $\text{HCO}_3^-$  concentration of 104.00 and 108.00 mg/l during pre and post-monsoon seasons, respectively.

**Table 4.10 Status of  $\text{HCO}_3^-$  in bore well and tap-water**

Parameter	$\text{HCO}_3^-$ (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	129.33	127.00	128.16	138.00	132.00	135.00
Baddi	110.33	109.67	110.00	119.00	114.33	116.66
Barotiwala	130.00	104.00	117.00	137.33	108.00	122.66
<b>Mean</b>	<b>123.22</b>	<b>113.56</b>		<b>131.44</b>	<b>118.11</b>	
	<b>Location</b>	<b>Source</b>	<b>L x S</b>	<b>Location</b>	<b>Source</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>1.47</b>	<b>1.20</b>	<b>2.09</b>	<b>1.47</b>	<b>1.20</b>	<b>2.09</b>

The concentration of  $\text{CO}_3^-$  was found to be significantly different among locations. Highest  $\text{CO}_3^-$  concentration (18.66 and 22.17 mg/l) was recorded at Nalagarh and lowest (5.84 and 10.00 mg/l) at Barotiwala during pre and post-monsoon seasons, respectively. Among two different sources of water, it was noticed that bore well water had  $\text{CO}_3^-$  concentration of 13.89 and 17.00 mg/l and in the tap-water the values were 7.78 and 12.00 mg/l during pre and post-monsoon season, respectively. Taking into consideration both sources of water and locations it was found that bore well water of Nalgrah had highest  $\text{CO}_3^-$  concentration of 25.33 and 28.67 mg/l during pre and post-monsoon season, respectively. However, tap-water of Barotiwala had lowest (4.67 and 9.67 mg/l) concentration during both seasons (Table 4.11).

**Table 4.11 Status of CO<sub>3</sub><sup>□</sup> in bore well and tap-water**

Parameter	CO <sub>3</sub> <sup>□</sup> (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	25.33	12.00	18.66	28.67	15.67	22.17
Baddi	9.33	6.67	8.00	12.00	10.67	11.33
Barotiwala	7.00	4.67	5.84	10.33	9.67	10.00
<b>Mean</b>	<b>13.89</b>	<b>7.78</b>		<b>17.00</b>	<b>12.00</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>1.42</b>	<b>1.16</b>	<b>2.01</b>	<b>1.52</b>	<b>1.24</b>	<b>2.15</b>

The highest calcium concentration of 50.83 mg/l (pre-monsoon) and 56.66 mg/l (post-monsoon), in the water of different locations was recorded at Nalagarh and lowest values of 32.17 mg/l (pre-monsoon) and 35.83 mg/l (post-monsoon) was recorded at Baddi. Further, irrespective of locations, calcium concentration of bore well and tap-water was 37.44 and 41.22; 43.78 and 45.00 mg/l during pre and post-monsoon season, respectively. The data for interaction effect reveals that bore well water of Nalgrah had highest calcium concentration of 57.67 and 64.33 mg/l during pre-monsoon and post-monsoon seasons, respectively. However, bore well water of Baddi had lowest calcium concentration of 22.67 and 27.67 mg/l during pre and post-monsoon season, respectively (Table 4.12).

**Table 4.12 Status of Ca<sup>++</sup> in bore well and tap-water**

Parameter	Ca <sup>++</sup> (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	57.67	44.00	50.83	64.33	49.00	56.66
Baddi	22.67	41.67	32.17	27.67	44.00	35.83
Barotiwala	32.00	38.00	35.00	39.33	42.00	40.66
<b>Mean</b>	<b>37.44</b>	<b>41.22</b>		<b>43.78</b>	<b>45.00</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>3.99</b>	<b>3.26</b>	<b>5.65</b>	<b>3.54</b>	<b>NS</b>	<b>5.00</b>

Data presented in Table 4.13 revealed that highest magnesium concentration of 21.16 and 22.66 mg/l amongst the water of three different locations was recorded at Nalagarh followed by Baddi (18.16 and 20.50 mg/l) during pre and post-monsoon seasons, respectively. However, lowest magnesium concentration of 14.50 and 20.50 mg/l was recorded at Barotiwala during pre and post-monsoon season, respectively. The mean concentration of  $Mg^{++}$  in bore well and tap-water was found to be 24.22 and 11.67; 28.00 and 14.44 mg/l during pre and post-monsoon season, respectively. During post-monsoon season there was no significant difference in the concentration of magnesium with in locations. Taking into consideration both sources of water and locations it was observed that bore well water of Nalgrah had highest magnesium concentration of 28.00 and 29.00 mg/l and tap-water of Barotiwala had lowest magnesium concentration of 8.33 and 13.33 mg/l during pre and post-monsoon seasons, respectively.

**Table 4.13 Status of  $Mg^{++}$  in bore well and tap-water**

Parameter	$Mg^{++}$ (mg/l)							
	Pre- monsoon			Post- monsoon				
Season	Bore well Water		Tap-water	Mean	Bore well Water		Tap-water	Mean
Source								
Location								
Nalagarh	28.00		14.33	21.16	29.00		16.33	22.66
Baddi	24.00		12.33	18.16	27.33		13.67	20.50
Barotiwala	20.67		8.33	14.50	27.67		13.33	20.50
<b>Mean</b>	<b>24.22</b>		<b>11.67</b>		<b>28.00</b>		<b>14.44</b>	
	<b>Location</b>	<b>Source</b>			<b>Location</b>	<b>Source</b>		
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>		<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	
<b>CD<sub>0.05</sub></b>	<b>3.11</b>	<b>2.54</b>	<b>NS</b>		<b>NS</b>	<b>2.77</b>	<b>NS</b>	

The data depicted in Table 4.14 revealed that  $Na^+$  concentration of water from bore well and tap significantly varied from 17.33 to 43.00 mg/l, irrespective of locations and seasons. The highest sodium concentration (34.00 and 32.00 mg/l) was recorded at Nalagarh and lowest (29.17 and 24.50 mg/l) at Barotiwala during pre and post-monsoon season. The average concentration of  $Na^+$  in the water of bore well and tap was found to be 38.67 and 23.22; 34.67 and 19.33 mg/l during pre and post-monsoon seasons, respectively. Taking into consideration both sources of water and locations it was found that bore well water of Nalgrah had highest sodium concentration of 43.00 and 42.00 mg/l during pre-monsoon and

post-monsoon season, respectively. The tap-water of Baddi had lowest sodium concentration (21.00 and 17.33 mg/l) during pre and post-monsoon seasons, respectively.

**Table 4.14 Status of Na<sup>+</sup> in bore well and tap-water**

Parameter	Na <sup>+</sup> (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	43.00	25.00	34.00	42.00	22.00	32.00
Baddi	38.33	21.00	29.66	31.67	17.33	24.50
Barotiwala	34.67	23.67	29.17	30.33	18.67	24.50
<b>Mean</b>	<b>38.67</b>	<b>23.22</b>		<b>34.67</b>	<b>19.33</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>3.23</b>	<b>2.63</b>	<b>NS</b>	<b>4.86</b>	<b>3.97</b>	<b>NS</b>

An perusal of Table 4.15 indicated that among the water of different locations, highest COD concentration of 8.00 and 11.66 mg/l was recorded at Nalagarh and lowest 3.75 and 7.50 mg/l at Barotiwala during pre and post-monsoon season, respectively. Further,

**Table 4.15 Status of COD in bore well and tap-water**

Parameter	COD (mg/l)					
Season	Pre- monsoon			Post- monsoon		
Source	Bore well Water	Tap-water	Mean	Bore well Water	Tap-water	Mean
Location						
Nalagarh	13.00	3.00	8.00	18.33	5.00	11.66
Baddi	4.33	5.00	4.66	11.33	6.33	8.83
Barotiwala	6.00	1.50	3.75	11.67	3.33	7.50
<b>Mean</b>	<b>7.78</b>	<b>3.17</b>		<b>13.78</b>	<b>4.89</b>	
	<b>Location</b>	<b>Source</b>		<b>Location</b>	<b>Source</b>	
	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>	<b>(L)</b>	<b>(S)</b>	<b>L x S</b>
<b>CD<sub>0.05</sub></b>	<b>2.11</b>	<b>1.72</b>	<b>2.99</b>	<b>2.63</b>	<b>2.15</b>	<b>3.72</b>

irrespective of locations, bore well water had COD concentration of 7.78 and 13.78 mg/l and tap-water 3.17 and 4.89 mg/l during pre and post-monsoon seasons, respectively. For interaction effect, it was found that bore well water of Nalgrah had highest COD concentration of 13.00 and 18.33 mg/l during pre and post-monsoon season, respectively. The tap-water of Barotiwala had lowest COD concentration of 1.50 and 3.33 mg/l during pre and post-monsoon seasons, respectively.

The data presented in Table 4.16 indicated the average values of micronutrients and heavy metals content present in the water samples of Nalagarh. The average iron concentration was found to be 0.70 and 0.93 in bore well water during pre and post-monsoon seasons, respectively. However, average concentration of Fe in tap-water was 0.05 mg/l during both seasons. During pre and post-monsoon seasons, bore well water contains micronutrients and heavy metals in the tune of copper (0.017 and 0.021mg/l), manganese (0.038 and 0.042 mg/l), Zinc (0.036 and 0.039 mg/l) and Nickel (0.017 and 0.019 mg/l). Lead and cadmium was not detectable in the water sample of bore well during both seasons. Further, Cu, Mn, Zn, Pb, Ni and Cd concentration was not detectable in the of water tap during pre and post-monsoon season.

**Table 4.16 Status of micronutrients and heavy metals in bore well and tap-water at Nalagarh**

Parameter	Bore well		Tap-water	
	Pre-monsoon (Mean value)	Post-monsoon (Mean value)	Pre-monsoon (Mean value)	Post-monsoon (Mean value)
Fe (mg/l)	0.70	0.93	0.05	0.05
Cu (mg/l)	0.017	0.021	ND	ND
Mn (mg/l)	0.038	0.042	ND	ND
Zn (mg/l)	0.036	0.039	ND	ND
Pb (mg/l)	*ND	ND	ND	ND
Ni (mg/l)	0.017	0.019	ND	ND
Cd (mg/l)	ND	ND	ND	ND

\*ND- Not detectable

A perusal of Table 4.17 reveals that bore well water of Baddi contains - iron (0.82 and 0.89 mg/l), copper (0.026 and 0.029 mg/l), manganese (0.031 and 0.034 mg/l), zinc (0.041 and 0.045 mg/l), lead (0.014 and 0.017 mg/l) and nickel (0.013 and 0.015 mg/l) during pre and post-monsoon seasons, respectively. Cadmium was not detectable in bore well water during both seasons at Baddi. Further, tap-water of Baddi contains - iron (0.01 and 0.02 mg/l), copper (0.011 and 0.015 mg/l), manganese (0.030 and 0.032 mg/l) and zinc (0.036 and

0.039 mg/l) during pre and post-monsoon seasons, respectively. Lead, nickel, and cadmium were not detectable in the tap-water of Baddi during both seasons.

**Table 4.17 Status of micronutrients and heavy metals in bore well and tap-water at Baddi**

Parameter	Bore well		Tap-water	
	Pre-monsoon (Mean value)	Post-monsoon (Mean value)	Pre-monsoon (Mean value)	Post-monsoon (Mean value)
Fe (mg/l)	0.82	0.89	0.01	0.02
Cu (mg/l)	0.026	0.029	0.011	0.015
Mn (mg/l)	0.031	0.034	0.030	0.032
Zn (mg/l)	0.041	0.045	0.036	0.039
Pb (mg/l)	0.014	0.017	ND	ND
Ni (mg/l)	0.013	0.015	ND	ND
Cd (mg/l)	*ND	ND	ND	ND

\*ND- Not detectable

The water of bore well from Barotiwala contains - iron (0.92 and 0.096 mg/l), copper (0.021 and 0.024 mg/l), manganese (0.036 and 0.039 mg/l) and zinc (0.043 and 0.047 mg/l) during pre and post-monsoon seasons, respectively (Table 4.18). However, lead, nickel and cadmium were not detectable in the water sample of bore well in Barotiwala during both seasons. Tap-water of Barotiwala exhibited only iron concentration (0.01 and 0.02 mg/l), however, copper, manganese, zinc, lead, nickel and cadmium concentrations were not detectable in Barotiwala, during pre and post-monsoon season (Table 4.18).

**Table 4.18 Status of micronutrients and heavy metals in bore well and tap-water at Barotiwala**

Parameter	Bore well		Tap-water	
	Pre-monsoon (Mean value)	Post-monsoon (Mean value)	Pre-monsoon (Mean value)	Post-monsoon (Mean value)
Fe (mg/l)	0.92	0.96	0.01	0.02
Cu (mg/l)	0.021	0.024	ND	ND
Mn (mg/l)	0.036	0.039	ND	ND
Zn (mg/l)	0.043	0.047	ND	ND
Pb (mg/l)	*ND	ND	ND	ND
Ni (mg/l)	ND	ND	ND	ND
Cd (mg/l)	ND	ND	ND	ND

\*ND- Not detectable

### 4.3 Physico - chemical properties of the soils

#### Soil pH

The data (mean values on the basis of three replication) regarding the soil pH for both surface and sub-surface soils during pre and post-monsoon seasons at different locations and sites are given in Table 4.19. The pH of surface soils varied with locations and ranged from 6.87 to 7.01 and 6.99 to 7.12 during pre and post-monsoon season, respectively. Among the three different locations, during pre and post-monsoon season, surface soils of Baddi was having highest pH values of 7.01 and 7.12, respectively, followed by Nalagarh (7.00 and 7.07). However, lowest soil pH values of 6.87 and 6.99 amongst three different locations were recorded at Barotiwala during both pre and post-monsoon seasons, respectively.

The surface soils of different sites in Nalagarh location recorded the highest soil pH value of 7.21 at Dhatowal, which was found to be at par with that of Dhbota (7.17). The lowest 6.83 was recorded at Manpur during pre-monsoon season. However, during post-monsoon season highest soil pH (7.29) was recorded in soils of Dhbota which was found to be at par with Dhatowal (7.27), whereas, lowest soil pH (6.92) was observed at Kishanpura and Manpur each.

The highest surface soil pH (7.38 and 7.41) in different sites of Baddi location was recorded each at Sairajmajra Gujra followed by Gularwala (7.21 and 7.34) and Sairajmajra Labana (7.12 and 7.32) during pre and post-monsoon seasons, respectively. Whereas, lowest soil pH (6.79 and 6.88) was recorded each at Baddi site for both pre and post-monsoon season.

The highest soil pH (7.15 and 7.28) of surface soils in different sites of Barotiwala location was recorded each at Sainsiwala during both seasons which was found to be at par with Kuranwala (7.08) during pre-monsoon season and with those of Sattiwala (7.19) and Kuranwala (7.18) during post-monsoon season. Whereas, lowest soil pH (6.69 and 6.76) was recorded each at Bated for both pre and post-monsoon seasons.

Irrespective of locations, it was noticed that highest soil pH (7.38) was recorded at site 1 (Sairajmajra Gujra) of Baddi followed by (7.21) each at site 5 (Dhatowal) of Nalagarh and

site 10 (Gularwala) of Baddi. Whereas, lowest soil pH (6.69) amongst all the sites of three different locations was recorded at site 2 (Bated) of Barotiwala during pre-monsoon season.

However, during post-monsoon season highest soil pH (7.41) was recorded at site 1 (Sairajmajra Gujra) of Baddi, which was found to be at par with site 2 (Sairajmajra Labana) i.e. 7.32 and site 10 (Gularwala) i.e. 7.34 of Baddi and lowest (6.76) was recorded at site 2 (Bated) of Barotiwala (Table 4.19).

For sub-surface soils, highest pH (7.15 and 7.26) amongst the three different locations was recorded at Baddi, which was found to be at par with Nalagarh (7.13 and 7.24) during both pre and post-monsoon season (Table 4.19). Amongst the three different locations, lowest pH (7.01 and 7.10) was recorded each at Barotiwala during both seasons.

The sub-surface soils of different sites in Nalagarh location recorded highest soil pH (7.33) at Dhatowal which was found to be at par with those of Dhbota (7.30) and Chowkiwala (7.28). Likewise, during post-monsoon season highest pH (7.40) was recorded in the soils of Dhatowal which was found to be at par with Chowkiwala (7.39) and Dhbota (7.34). However, lowest soil pH of 6.96 (pre-monsoon) and 7.12 (post-monsoon) was recorded in the soils of Manpur and Kishanpura, respectively (Table 4.19).

For sub-surface soils of different sites in Baddi location, the highest soil pH (7.46 and 7.59) was recorded each at Sairajmajra Gujra for pre and post-monsoon season, which was found to be at par with Gularwala (7.37 and 7.47). However, lowest soil pH (6.93 and 7.09) was observed at Baddi site for both pre and post-monsoon season.

The highest soil pH value of 7.28 and 7.44 in sub-surface soils of different sites in Barotiwala location was recorded at Sainsiwala during pre and post-monsoon season, respectively and found to be at par with Sattiwala (7.19) during pre-monsoon season. However, lowest soil pH (6.83 and 6.89) was recorded each at Bated for both pre and post-monsoon seasons.

The sub-surface soils irrespective of locations, recorded highest soil pH (7.46) at site 1 (Sairajmajra Gujra) of Baddi followed by site 10 (Gularwala) of Baddi (7.37). Whereas, lowest soil pH (6.83) amongst all the sites of three different locations was recorded at site 2

(Bated) of Barotiwala during pre-monsoon season. However, during post-monsoon season highest pH (7.59) was recorded at site1 (Sairajmajra Gujra) of Baddi followed by 7.47 of site 10 (Gularwala) of Baddi and 7.44 of site 5 (Sainsiwala) of Barotiwala. Whileas, lowest pH (6.89) was recorded at site 2 (Bated) of Barotiwala. The soil pH was found to be non significant amongst all the sites of three different locations.

**Table 4.19 Status of soil pH at different locations and sites**

Parameter	pH					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	6.92	7.38	6.71	6.92	7.41	6.87
S <sub>2</sub>	6.83	7.12	6.69	6.92	7.32	6.76
S <sub>3</sub>	6.87	6.85	6.73	6.94	6.94	6.91
S <sub>4</sub>	7.02	6.96	6.95	7.07	7.08	7.12
S <sub>5</sub>	7.21	6.98	7.15	7.27	7.14	7.28
S <sub>6</sub>	6.98	6.82	6.83	7.06	6.97	6.91
S <sub>7</sub>	7.13	6.88	7.04	7.18	6.94	7.19
S <sub>8</sub>	6.95	6.79	6.82	7.13	6.88	6.86
S <sub>9</sub>	7.17	7.07	7.08	7.29	7.22	7.18
S <sub>10</sub>	6.89	7.21	6.70	6.95	7.34	6.88
<b>Mean</b>	7.00	7.01	6.87	7.07	7.12	6.99
<b>CD<sub>0.05</sub> S</b>	0.074	0.067	0.074	0.097	0.113	0.123
<b>L</b>	0.01			0.03		
<b>S x L</b>	0.03			0.09		
<b>Sub-surface</b>						
S <sub>1</sub>	7.04	7.46	6.86	7.12	7.59	6.93
S <sub>2</sub>	6.96	7.24	6.83	7.13	7.35	6.89
S <sub>3</sub>	6.99	6.99	6.86	7.19	7.11	6.99
S <sub>4</sub>	7.14	7.11	7.11	7.23	7.20	7.20
S <sub>5</sub>	7.33	7.15	7.28	7.40	7.31	7.44
S <sub>6</sub>	7.09	6.97	6.92	7.19	7.10	7.07
S <sub>7</sub>	7.28	7.05	7.19	7.39	7.16	7.21
S <sub>8</sub>	7.11	6.93	6.99	7.22	7.09	7.08
S <sub>9</sub>	7.30	7.21	7.14	7.34	7.24	7.28
S <sub>10</sub>	7.01	7.37	6.89	7.16	7.47	6.94
<b>Mean</b>	7.13	7.15	7.01	7.24	7.26	7.10
<b>CD<sub>0.05</sub> S</b>	0.083	0.114	0.119	0.093	0.120	0.089
<b>L</b>	0.02			0.05		
<b>S x L</b>	0.07			0.09		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhubota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwala, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

## EC

Table 4.20 represented the status of EC (mean values on the basis of three replication) for both surface and sub-surface soils during pre and post-monsoon seasons at different locations and sites. Among the three different locations, Baddi was having the highest EC values of  $0.26 \text{ dSm}^{-1}$  and  $0.23 \text{ dSm}^{-1}$  in surface soils which was found to be at par with Barotiwala ( $0.25 \text{ dSm}^{-1}$  and  $0.22 \text{ dSm}^{-1}$ ) during pre and post-monsoon seasons, respectively. Whereas, lowest EC of  $0.19 \text{ dSm}^{-1}$  and  $0.18 \text{ dSm}^{-1}$  amongst three different locations were recorded each at Nalagarh during pre and post-monsoon seasons, respectively.

The highest EC value ( $0.27 \text{ dSm}^{-1}$  and  $0.28 \text{ dSm}^{-1}$ ) in surface soils of different sites in Nalagarh location was recorded at Salewal. The EC value recorded at Salewal during pre-monsoon season was found to be at par with those of Khroni ( $0.24$ ), Chowkiwala ( $0.23$ ) and Kishanpura ( $0.21$ ), whereas during post-monsoon season it was found to be at par with that of Kishanpura ( $0.23$ ). The lowest value of  $0.11 \text{ dSm}^{-1}$  and  $0.12 \text{ dSm}^{-1}$  was recorded in the soil of Dhbota and Bhatiyar during pre and post-monsoon season, respectively.

The surface soils of different sites in Baddi location, exhibited highest EC ( $0.38 \text{ dSm}^{-1}$  and  $0.34 \text{ dSm}^{-1}$ ) value each at Juddi Khurd during pre and post-monsoon season which was at par with that of Malpur ( $0.34$  and  $0.32$ ) for pre and post-monsoon seasons (Table 4.20). While, the lowest value of EC ( $0.16 \text{ dSm}^{-1}$ ) was observed at Kantha and Billawali Gujra for pre and post-monsoon seasons, respectively.

The surface soils of different sites in Barotiwala location, exhibited highest EC ( $0.35 \text{ dSm}^{-1}$  and  $0.31 \text{ dSm}^{-1}$ ) each at Barotiwala during both seasons which was found to be at par with those of Bated ( $0.33$ ), Panga ( $0.30$ ) and Plankwala ( $0.29$ ) during pre-monsoon season and with Bated ( $0.29$ ), Panga ( $0.29$ ) and Plankwala ( $0.28$ ) during post-monsoon season (Table 4.20). The lowest value of EC ( $0.14 \text{ dSm}^{-1}$ ) was observed at Kuranwala during both seasons.

The highest EC value of  $0.38 \text{ dSm}^{-1}$  was recorded at site 7 (Juddi Khurd) in Baddi which was found to be at par with those of site 9 (Malpur) of Baddi i.e.  $0.34$  and site 6 (Barotiwala) i.e.  $0.35 \text{ dSm}^{-1}$  during pre-monsoon season. During post-monsoon season, highest EC ( $0.34 \text{ dSm}^{-1}$ ) was recorded at site 7 (Juddi Khurd) of Baddi followed by site 9

(Malpur) i.e.  $0.32 \text{ dSm}^{-1}$  of Baddi and site 6 (Barotiwala) i.e.  $0.31 \text{ dSm}^{-1}$  Barotiwala. Whereas, lowest EC values of  $0.11 \text{ dSm}^{-1}$  and  $0.12 \text{ dSm}^{-1}$  amongst all the sites of three different locations was recorded at site 9 (Dhbota) and site 10 (Bhatiyani) of Nalagarh during pre and post-monsoon seasons, respectively.

The sub-surface soils of Barotiwala and Baddi registered highest EC values of  $0.21$  and  $0.20 \text{ dSm}^{-1}$  amongst the three different locations during pre and post-monsoon seasons, respectively. It was noticed that amongst the three different locations, lowest EC value of  $0.15 \text{ dSm}^{-1}$  and  $0.16 \text{ dSm}^{-1}$  was recorded at Nalagarh during pre and post-monsoon seasons.

The EC values in sub-surface soils of different sites in Nalagarh location during pre and post-monsoon season recorded highest EC value of  $0.23 \text{ dSm}^{-1}$  and  $0.21 \text{ dSm}^{-1}$  each at Salewal which was found to be at par with that of Chowkiwala ( $0.20$ ) for pre-monsoon season and with those of Khroni ( $0.19$ ), Kishanpura ( $0.19$ ) and Chowkiwala ( $0.15$ ) for post-monsoon season. The lowest EC ( $0.10 \text{ dSm}^{-1}$ ) was observed at Dhbota for both season.

The highest EC ( $0.26 \text{ dSm}^{-1}$  and  $0.29 \text{ dSm}^{-1}$ ) for sub-surface soils of different sites in Baddi location was recorded each at Juddi Khurd during pre and post- monsoon seasons which was found to be at par with those of Malpur ( $0.25$ ), Baddi ( $0.23$ ), Gularwala ( $0.22$ ) and Juddi Kalan ( $0.21$ ) for pre-monsoon season and Malpur ( $0.26$ ), Juddi Kalan ( $0.23$ ) and Baddi ( $0.23$ ) during post-monsoon season. The lowest EC values of  $0.12 \text{ dSm}^{-1}$  and  $0.11 \text{ dSm}^{-1}$  was recorded at Kantha during pre and post-monsoon season, respectively.

The sub-surface soils of different sites in Barotiwala location exhibited highest EC ( $0.33 \text{ dSm}^{-1}$  and  $0.26 \text{ dSm}^{-1}$ ) at Barotiwala which was found to be at par with that of Bated ( $0.28$ ) and Panga ( $0.27$ ) during pre-monsoon season and with those of Bated ( $0.23$ ), Plankwala ( $0.23$ ) and Panga ( $0.22$ ) during post-monsoon season. However, lowest EC value of  $0.11 \text{ dSm}^{-1}$  was recorded in the soils of Kuranwala during both seasons.

**Table 4.20 Status of EC at different locations and sites**

Parameter	EC (dSm <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Locations (L) Site (S)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalaa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalaa (L <sub>3</sub> )
<b>Surface</b>						
S <sub>1</sub>	0.21	0.24	0.19	0.23	0.22	0.18
S <sub>2</sub>	0.19	0.22	0.33	0.19	0.17	0.29
S <sub>3</sub>	0.16	0.18	0.27	0.18	0.16	0.23
S <sub>4</sub>	0.24	0.20	0.29	0.21	0.18	0.28
S <sub>5</sub>	0.13	0.16	0.23	0.13	0.18	0.23
S <sub>6</sub>	0.18	0.27	0.35	0.17	0.24	0.31
S <sub>7</sub>	0.23	0.38	0.17	0.17	0.34	0.17
S <sub>8</sub>	0.27	0.31	0.30	0.28	0.25	0.28
S <sub>9</sub>	0.11	0.34	0.14	0.15	0.32	0.14
S <sub>10</sub>	0.16	0.25	0.24	0.12	0.22	0.21
<b>Mean</b>	0.19	0.26	0.25	0.18	0.23	0.22
<b>CD<sub>0.05</sub> S</b>	0.072	0.049	0.060	0.063	0.049	0.042
<b>L</b>	0.01			0.01		
<b>S x L</b>	0.04			0.04		
<b>Sub-surface</b>						
S <sub>1</sub>	0.17	0.20	0.15	0.19	0.20	0.15
S <sub>2</sub>	0.14	0.17	0.28	0.14	0.17	0.23
S <sub>3</sub>	0.13	0.15	0.25	0.14	0.15	0.18
S <sub>4</sub>	0.18	0.18	0.23	0.19	0.18	0.23
S <sub>5</sub>	0.12	0.12	0.18	0.13	0.11	0.16
S <sub>6</sub>	0.15	0.21	0.33	0.14	0.23	0.26
S <sub>7</sub>	0.20	0.26	0.13	0.15	0.29	0.14
S <sub>8</sub>	0.23	0.23	0.27	0.21	0.23	0.22
S <sub>9</sub>	0.10	0.25	0.11	0.10	0.26	0.11
S <sub>10</sub>	0.12	0.22	0.19	0.16	0.17	0.18
<b>Mean</b>	0.15	0.20	0.21	0.16	0.20	0.19
<b>CD<sub>0.05</sub> S</b>	0.043	0.053	0.073	0.062	0.055	0.048
<b>L</b>	0.01			0.01		
<b>S x L</b>	0.04			0.05		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhbota and L<sub>1</sub>S<sub>10</sub> – Bhatiyaa

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalaa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

It was also noticed that irrespective of locations during pre-monsoon season, highest EC value of 0.33 dSm<sup>-1</sup> was recorded at site 6 (Barotiwalaa) of Barotiwalaa followed by site 2 (Bated) of Barotiwalaa i.e. (0.28 dSm<sup>-1</sup>). However, highest EC values of 0.29 dSm<sup>-1</sup> during post-monsoon season was recorded at site 7 (Juddi Khurd) of Baddi, which was found to be at par with those of site 9 (Malpur) i.e. 0.26 dSm<sup>-1</sup> and site 6 (Barotiwalaa) i.e. 0.26 dSm<sup>-1</sup>,

whereas, lowest EC ( $0.10 \text{ dSm}^{-1}$ ) amongst all the sites of three different locations was recorded at site 9 (Dhbota) of Nalagarh during pre and post-monsoon season.

### **Organic Carbon**

The data (mean values on the basis of three replication) presented in the Table 4.21 indicated that for surface soils, among the three different locations, the highest organic carbon content of  $4.83 \text{ g kg}^{-1}$  and  $5.48 \text{ g kg}^{-1}$  was recorded at Barotiwala followed by Baddi ( $4.41 \text{ g kg}^{-1}$  and  $5.02 \text{ g kg}^{-1}$ ) during pre and post-monsoon seasons, respectively. Whereas, lowest OC content of  $4.38 \text{ g kg}^{-1}$  and  $4.83 \text{ g kg}^{-1}$  was recorded at Nalagarh during pre and post-monsoon seasons, respectively.

The surface soils of different sites in Nalagarh location during pre-monsoon season recorded highest organic carbon ( $5.85 \text{ g kg}^{-1}$ ) at Chowkiwala which was found to be at par with that of Dhbota ( $5.40$ ) and during post-monsoon season, highest value ( $6.04 \text{ g kg}^{-1}$ ) was recorded again at Chowkiwala followed by Dhbota, Salewal and Khroni. However, the lowest OC content of  $3.00 \text{ g kg}^{-1}$  and  $3.72 \text{ g kg}^{-1}$  was recorded each at Manpur during pre and post-monsoon season, respectively.

The highest organic carbon content ( $7.12 \text{ g kg}^{-1}$  and  $7.45 \text{ g kg}^{-1}$ ) for surface soils of different sites in Baddi location was recorded each at Billawali Labana during pre and post-monsoon season followed by Juddi Kalan, Gularwala and Sairajmajra Gujra. Whereas, lowest OC ( $2.92 \text{ g kg}^{-1}$  and  $3.56 \text{ g kg}^{-1}$ ) was recorded each at Juddi Khurd during both seasons.

The data with respect to organic carbon content for surface soils of different sites in Barotiwala location indicated that highest OC content ( $8.25 \text{ g kg}^{-1}$  and  $8.78 \text{ g kg}^{-1}$ ) was observed each at Sainsiwala followed by Kuranwala ( $6.00 \text{ g kg}^{-1}$  and  $6.62 \text{ g kg}^{-1}$ ), Panga ( $5.25 \text{ g kg}^{-1}$  and  $5.98 \text{ g kg}^{-1}$ ) and Plankwala ( $4.42 \text{ g kg}^{-1}$  and  $5.17 \text{ g kg}^{-1}$ ) during both seasons. However, lowest OC content of  $3.69 \text{ g kg}^{-1}$  and  $4.38 \text{ g kg}^{-1}$  was recorded each at Barotiwala during pre and post- monsoon season, respectively.

The OC was found to be highest at site 5 (Sainsiwala) of Barotiwala ( $8.25 \text{ g kg}^{-1}$  and  $8.78 \text{ g kg}^{-1}$ ) followed by site 4 (Billawali Labana) of Baddi i.e.  $7.12 \text{ g kg}^{-1}$  and  $7.45 \text{ g kg}^{-1}$  and site 9 (Kuranwala) of Barotiwala i.e.  $6.00 \text{ g kg}^{-1}$  and  $6.62 \text{ g kg}^{-1}$  during both seasons irrespective of locations. Whereas, amongst all the sites of three different locations, lowest

OC content of 3.00 g kg<sup>-1</sup> was recorded at site 2 (Manpur) of Nalagarh during pre-monsoon season and at site 7 (Juddi Khurd) i.e. 3.56 g kg<sup>-1</sup> of Baddi during post-monsoon season.

**Table 4.21 Status of organic carbon content at different locations and sites**

Parameter	OC (g kg <sup>-1</sup> )						
Season	Pre- monsoon			Post- monsoon			
Locations (L) Site (S)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	
<b>Surface</b>							
S <sub>1</sub>	4.27	4.72	3.98	4.65	5.32	4.57	
S <sub>2</sub>	3.00	3.59	4.39	3.72	4.30	4.87	
S <sub>3</sub>	4.12	4.02	4.11	4.53	4.65	4.77	
S <sub>4</sub>	4.82	7.12	4.42	5.11	7.45	5.17	
S <sub>5</sub>	4.21	3.42	8.25	4.68	4.13	8.78	
S <sub>6</sub>	3.85	5.62	3.69	4.14	6.22	4.38	
S <sub>7</sub>	5.85	2.92	3.91	6.04	3.56	4.61	
S <sub>8</sub>	4.65	3.75	5.25	5.30	4.45	5.98	
S <sub>9</sub>	5.40	4.07	6.00	5.77	4.68	6.62	
S <sub>10</sub>	3.64	4.87	4.28	4.33	5.39	5.10	
<b>Mean</b>	4.38	4.41	4.83	4.83	5.02	5.48	
<b>CD<sub>0.05</sub></b>	<b>S</b>	0.608	0.368	0.342	0.155	0.123	0.161
	<b>L</b>	0.13			0.04		
	<b>S x L</b>	0.40			0.14		
<b>Sub-surface</b>							
S <sub>1</sub>	3.12	3.68	2.78	3.81	4.55	3.70	
S <sub>2</sub>	2.10	2.19	3.12	2.89	3.65	4.29	
S <sub>3</sub>	3.20	2.40	3.01	3.85	3.94	3.97	
S <sub>4</sub>	3.62	5.35	3.23	4.40	6.72	4.58	
S <sub>5</sub>	2.98	2.92	6.55	3.70	3.36	7.64	
S <sub>6</sub>	2.68	3.55	2.19	3.60	5.44	3.58	
S <sub>7</sub>	4.12	1.25	2.62	5.54	2.64	3.87	
S <sub>8</sub>	3.45	2.15	4.15	4.42	3.60	5.14	
S <sub>9</sub>	4.29	3.00	5.01	5.05	3.87	5.81	
S <sub>10</sub>	2.54	3.25	3.17	3.61	4.67	4.37	
<b>Mean</b>	3.21	2.97	3.58	4.09	4.24	4.69	
<b>CD<sub>0.05</sub></b>	<b>S</b>	0.394	0.330	0.338	0.663	0.372	0.169
	<b>L</b>	0.07			0.10		
	<b>S x L</b>	0.20			0.40		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhbota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

Sub-surface soils exhibited highest organic carbon content (3.58 g kg<sup>-1</sup>) in Barotiwalwa soil amongst the three different locations followed by Nalagarh (3.21 g kg<sup>-1</sup>) and Baddi (2.97 g kg<sup>-1</sup>) during pre-monsoon season. During post-monsoon season, highest OC content of 4.69

g kg<sup>-1</sup> was recorded at Barotiwala followed by Baddi (4.24 g kg<sup>-1</sup>), whereas, lowest (4.09 g kg<sup>-1</sup>) was recorded at Nalagarh.

The sub-surface soils of different sites in Nalagarh location during pre-monsoon season recorded the highest organic carbon (4.29 g kg<sup>-1</sup>) at Dhbota which was at par with Chowkiwala (4.12 g kg<sup>-1</sup>), whereas the lowest OC (2.10 g kg<sup>-1</sup>) was recorded at Manpur. However, for post-monsoon season, highest OC (5.54 g kg<sup>-1</sup>) was recorded at Chowkiwala which was found to be at par with that of Dhbota (5.05 g kg<sup>-1</sup>). The lowest OC content (2.89 g kg<sup>-1</sup>) was recorded at Manpur for post-monsoon season.

The data (Table 4.21) indicated that highest OC content of 5.35 g kg<sup>-1</sup> and 6.72 g kg<sup>-1</sup> for sub-surface soils of different sites in Baddi location was recorded each at Billawali Labana during pre and post-monsoon season, respectively, followed by Sairajmajra Gujra, Juddi Kalan and Gularwala. The organic carbon content in Billawali Labana was significantly higher than other sites during both seasons. However, lowest OC content of 1.25 g kg<sup>-1</sup> and 2.64 g kg<sup>-1</sup> was observed each at Juddi Khurd for pre and post-monsoon season, respectively.

The subsurface soils of different sites in Barotiwala location recorded highest OC content of 6.55 g kg<sup>-1</sup> and 7.64 g kg<sup>-1</sup> each at Sainsiwala followed by those of Kuranwala, Panga and Plankwala during pre and post-monsoon seasons. Lowest OC content (2.19 g kg<sup>-1</sup> and 3.58 g kg<sup>-1</sup>) was observed at Barotiwala site during pre and post-monsoon season, respectively.

The highest OC (6.55 g kg<sup>-1</sup> and 7.64 g kg<sup>-1</sup>) was recorded at site 5 (Sainsiwala) of Barotiwala followed by site 4 (Billawali Labana) of Baddi i.e. 5.35 g kg<sup>-1</sup> and 6.72 g kg<sup>-1</sup> and site 9 (Kuranwala) of Barotiwala i.e. 5.01 g kg<sup>-1</sup> and 5.81 g kg<sup>-1</sup> during pre and post-monsoon season irrespective of locations, respectively. Whereas, amongst all the sites of three different locations, lowest OC (1.25 g kg<sup>-1</sup> and 2.64 g kg<sup>-1</sup>) was recorded at site 7 (Juddi Khurd) of Baddi during pre and post-monsoon seasons (Table 4.21). It was also noticed that there was no significant difference in OC content of surface and sub-surface soils during both seasons with respect to locations.

## CaCO<sub>3</sub>

The data (mean values on the basis of three replication) pertaining to status of CaCO<sub>3</sub> in surface soils (Table 4.22) revealed that highest amount amongst the three different locations was recorded at Nalagarh (5.42 g kg<sup>-1</sup> and 5.16 g kg<sup>-1</sup>) followed by Barotiwala (4.94 g kg<sup>-1</sup> and 4.72 g kg<sup>-1</sup>) during both seasons, whereas lowest at Baddi (4.90 g kg<sup>-1</sup> and 4.63 g kg<sup>-1</sup>) during both seasons. There was no significant difference in the CaCO<sub>3</sub> content of Baddi and Barotiwala soils during both seasons.

The highest CaCO<sub>3</sub> (10.00 g kg<sup>-1</sup> and 9.91 g kg<sup>-1</sup>) for surface soils of different sites in Nalagarh location was recorded at Chowkiwala followed by those of Manpur (8.75 g kg<sup>-1</sup> and 8.36 g kg<sup>-1</sup>), Rajpura (8.35 g kg<sup>-1</sup> and 8.10 g kg<sup>-1</sup>), Dhbotra (7.50 g kg<sup>-1</sup> and 7.24 g kg<sup>-1</sup>) and Salewal (6.25 g kg<sup>-1</sup> and 6.03 g kg<sup>-1</sup>) during both pre and post-monsoon season. Whereas, lowest CaCO<sub>3</sub> (1.25 g kg<sup>-1</sup> and 0.86 g kg<sup>-1</sup>) was recorded at Bhatiyani during pre and post-monsoon season, respectively.

A perusal of data (Table 4.22) revealed that the highest CaCO<sub>3</sub> content (9.25 g kg<sup>-1</sup> and 8.88 g kg<sup>-1</sup>) for surface soils of different sites in Baddi location during both pre and post-monsoon season was recorded at Sairajmajra Gujra which was found to be at par with that of Billawali Gujra (9.08 g kg<sup>-1</sup> and 8.67 g kg<sup>-1</sup>). Whereas, lowest amount of CaCO<sub>3</sub> content (0.80 and 0.65 g kg<sup>-1</sup>) was recorded at Sairajmajra Labana during both pre and post-monsoon seasons.

The surface soils of different sites in Barotiwala location, recorded the highest CaCO<sub>3</sub> content (9.25 g kg<sup>-1</sup> and 9.14 g kg<sup>-1</sup>) at Bated followed by Baurawala, Barotiwala, Panga and Kunjhal during pre and post-monsoon seasons. Whereas, lowest CaCO<sub>3</sub> (0.83 g kg<sup>-1</sup> and 0.62 g kg<sup>-1</sup>) was noticed at Jharmajri during pre and post-monsoon season, respectively.

The highest CaCO<sub>3</sub> (10.00 g kg<sup>-1</sup> and 9.91 g kg<sup>-1</sup>) was recorded at site 7 (Chowkiwala) of Nalagarh followed by site 1 (Sairajmajra Gujra) i.e. 9.25 g kg<sup>-1</sup> and 8.88 g kg<sup>-1</sup>, site 3 (Billawali Gujra) i.e. 9.08 g kg<sup>-1</sup> and 8.67 g kg<sup>-1</sup> of Baddi and site 2 (Bated) of Barotiwala i.e. 9.25 g kg<sup>-1</sup> and 9.14 g kg<sup>-1</sup> during both seasons, irrespective of locations. Whereas, amongst all the sites of three locations, lowest CaCO<sub>3</sub> content of 0.80 g kg<sup>-1</sup> and 0.62 g kg<sup>-1</sup> was recorded at site 2 (Sairajmajra Labana) of Baddi and site 1 (Jharmajri) of Barotiwala during pre and post-monsoon season, respectively.

The data presented in Table 4.22 revealed that sub-surface soils of Nalagarh recorded highest  $\text{CaCO}_3$  ( $5.59 \text{ g kg}^{-1}$ ) content amongst the three different locations followed by Barotiwala ( $5.70 \text{ g kg}^{-1}$ ) during pre-monsoon season. However, lowest content of  $\text{CaCO}_3$  was recorded in Baddi ( $5.08 \text{ g kg}^{-1}$ ) soils during pre-monsoon season. During post-monsoon season, highest  $\text{CaCO}_3$  amongst the three different locations was recorded at Barotiwala ( $5.33 \text{ g kg}^{-1}$ ) followed by Nalagarh ( $5.27 \text{ g kg}^{-1}$ ), whereas lowest was recorded at Baddi ( $4.67 \text{ g kg}^{-1}$ ). There was no significant difference in the  $\text{CaCO}_3$  content of Nalagarh and Barotiwala during post-monsoon season.

As evinced from the Table 4.22 that during pre and post-monsoon season highest  $\text{CaCO}_3$  ( $10.20 \text{ g kg}^{-1}$  and  $10.10 \text{ g kg}^{-1}$ ) in sub-surface soil of different sites of Nalagarh location was recorded at Chowkiwala followed by those of Manpur, Rajpura, Dhбота and Salewal. Further, the values of  $\text{CaCO}_3$  recorded in the soils of Chowkiwala was found to be significantly higher than other sites. Whereas, lowest  $\text{CaCO}_3$  ( $1.35 \text{ g kg}^{-1}$  and  $0.23 \text{ g kg}^{-1}$ ) was recorded at Bhatiyan during pre and post-monsoon season, respectively.

The highest  $\text{CaCO}_3$  content ( $9.38 \text{ g kg}^{-1}$  and  $9.01 \text{ g kg}^{-1}$ ) for sub-surface soils of different sites in Baddi location was recorded at Sairajmajra Gujra which was found to be at par with that of Billawali Gujra ( $9.20 \text{ g kg}^{-1}$  and  $8.96 \text{ g kg}^{-1}$ ) during both pre and post-monsoon seasons, whereas, lowest  $\text{CaCO}_3$  content of  $0.33 \text{ g kg}^{-1}$  and  $0.21 \text{ g kg}^{-1}$  was recorded at Sairajmajra Labana for pre and post-monsoon seasons, respectively.

Sub-surface soils of different sites in Barotiwala location, recorded highest  $\text{CaCO}_3$  content ( $10.19 \text{ g kg}^{-1}$  and  $9.87 \text{ g kg}^{-1}$ ) each at Jharmajri followed by those of Barotiwala ( $8.59 \text{ g kg}^{-1}$  and  $7.95 \text{ g kg}^{-1}$ ), Plankwala ( $7.67 \text{ g kg}^{-1}$  and  $7.44 \text{ g kg}^{-1}$ ), Sattiwala ( $7.23 \text{ g kg}^{-1}$  and  $6.91 \text{ g kg}^{-1}$ ) and Kuranwala ( $6.45 \text{ g kg}^{-1}$  and  $5.76 \text{ g kg}^{-1}$ ) during both the sampling period. Minimum  $\text{CaCO}_3$  content ( $1.38 \text{ g kg}^{-1}$  and  $0.81 \text{ g kg}^{-1}$ ) was noticed at Sainsiwala for both seasons, respectively.

The content of  $\text{CaCO}_3$ , irrespective of locations, registered highest ( $10.20 \text{ g kg}^{-1}$  and  $10.10 \text{ g kg}^{-1}$ ) value at site 7 (Chowkiwala) of Nalagarh followed by site 1 (Sairajmajra Gujra) i.e.  $9.38 \text{ g kg}^{-1}$  and  $9.01 \text{ g kg}^{-1}$ , site 3 (Billawali Gujra) i.e.  $9.20 \text{ g kg}^{-1}$  and  $8.96 \text{ g kg}^{-1}$  of Baddi and site 2 (Bated) of Barotiwala i.e.  $10.19 \text{ g kg}^{-1}$  and  $9.87 \text{ g kg}^{-1}$  during both seasons. Whereas, amongst all the sites of three different locations, lowest  $\text{CaCO}_3$  ( $0.33 \text{ g kg}^{-1}$  and  $0.21 \text{ g kg}^{-1}$ ) was recorded each at site 2 (Sairajmajra Labana) of Baddi during pre and post-

monsoon seasons, respectively. It was also noticed that there was no significant difference in CaCO<sub>3</sub> content within locations and irrespective of locations.

**Table 4.22 Status of CaCO<sub>3</sub> at different locations and sites**

Parameter	CaCO <sub>3</sub> (g kg <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	3.75	9.25	0.83	3.57	8.88	0.62
S <sub>2</sub>	8.75	0.80	9.25	8.36	0.65	9.14
S <sub>3</sub>	3.25	9.08	8.95	3.02	8.67	8.79
S <sub>4</sub>	1.65	3.95	3.95	1.36	3.75	3.69
S <sub>5</sub>	3.45	1.15	1.35	3.18	1.05	1.21
S <sub>6</sub>	8.35	7.00	7.00	8.10	6.69	6.62
S <sub>7</sub>	10.00	1.13	1.38	9.91	1.03	1.28
S <sub>8</sub>	6.25	6.75	6.75	6.03	6.19	6.43
S <sub>9</sub>	7.50	4.39	4.39	7.24	4.25	4.18
S <sub>10</sub>	1.25	5.50	5.50	0.86	5.17	5.23
<b>Mean</b>	5.42	4.90	4.94	5.16	4.63	4.72
<b>CD<sub>0.05</sub> S</b>	0.447	0.172	0.191	0.247	0.219	0.253
<b>L</b>	0.06			0.07		
<b>S x L</b>	0.20			0.24		
<b>Sub-surface</b>						
S <sub>1</sub>	3.85	9.38	2.14	3.68	9.01	1.95
S <sub>2</sub>	8.92	0.33	10.19	8.43	0.21	9.87
S <sub>3</sub>	3.37	9.20	5.95	3.11	8.96	5.76
S <sub>4</sub>	1.85	4.15	7.67	1.46	3.64	7.44
S <sub>5</sub>	3.55	1.62	1.38	3.37	1.45	0.81
S <sub>6</sub>	8.65	7.10	8.59	8.61	7.02	7.95
S <sub>7</sub>	10.20	1.75	7.23	10.10	0.50	6.91
S <sub>8</sub>	6.38	6.95	3.99	6.35	6.28	3.82
S <sub>9</sub>	7.82	4.47	6.45	7.38	4.29	5.76
S <sub>10</sub>	1.35	5.83	3.37	0.23	5.30	3.07
<b>Mean</b>	5.59	5.08	5.70	5.27	4.67	5.33
<b>CD<sub>0.05</sub> S</b>	0.239	0.249	0.295	0.305	0.244	0.264
<b>L</b>	0.06			0.08		
<b>S x L</b>	0.20			0.26		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhubota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The results suggested that soils of the studied area are slightly acidic to alkaline in reaction. The organic carbon content of the area rated as low to medium. The values in post-monsoon season were higher than those in pre-monsoon season.

#### **4.4 Available nutrient status of soils**

##### **4.4.1 Macronutrient status**

##### **Nitrogen**

The data regarding status of available nitrogen in surface and sub-surface soils during pre-monsoon and post-monsoon seasons at different locations and sites are given in the Table 4.23. The highest available nitrogen content of 182.81 kg ha<sup>-1</sup> and 202.69 kg ha<sup>-1</sup>, amongst the surface soils of three locations was recorded at Barotiwala followed by Nalagarh (172.71 kg ha<sup>-1</sup> and 188.33 kg ha<sup>-1</sup>) during pre and post-monsoon seasons, respectively. It was also noticed that amongst the three different locations, lowest available nitrogen content (163.48 kg ha<sup>-1</sup> and 180.63 kg ha<sup>-1</sup>) was recorded at Baddi during both seasons. There was no significant difference in the available nitrogen content within the locations.

The highest available nitrogen (216.38 kg ha<sup>-1</sup> and 233.31 kg ha<sup>-1</sup>) for surface soils of different sites in Nalagarh location was recorded at Chowkiwala followed by Dhubota, Khroni, Salewal and Kishanpura during both pre and post-monsoon season, whereas, lowest available nitrogen content (100.35 kg ha<sup>-1</sup> and 114.26 kg ha<sup>-1</sup>) was recorded each at Manpur for both the seasons.

The surface soils of different sites in Baddi location exhibited the highest available nitrogen content of 225.79 kg ha<sup>-1</sup> and 231.48 kg ha<sup>-1</sup> at Billawalli Labana and Juddi Kalan for pre and post-monsoon seasons, respectively, which was found to be at par with those of Juddi Kalan (213.25 kg ha<sup>-1</sup>) and Gularwala (205.89) during pre-monsoon season and with that of Billawalli Labana (227.99 kg ha<sup>-1</sup>), Gularwala (226.91 kg ha<sup>-1</sup>) and Sairajmajra Gujra (223.24 kg ha<sup>-1</sup>) during post-monsoon season. The lowest available nitrogen content of 84.67 kg ha<sup>-1</sup> and 105.99 kg ha<sup>-1</sup> was recorded at Juddi Khurd during both the seasons, respectively.

An overview of Table 4.23 revealed that highest available nitrogen (232.06 kg ha<sup>-1</sup> and 259.28 kg ha<sup>-1</sup>) for surface soils of different sites in Barotiwala location was recorded at

Sainsiwala followed by those of Kuranwala, Panga, Plankwala and Baurawala during both seasons. However, lowest available nitrogen (131.71 kg ha<sup>-1</sup> and 148.58 kg ha<sup>-1</sup>) was recorded in Barotiwala soil for both seasons.

**Table 4.23 Status of available nitrogen at different locations and sites**

Parameter	N (kg ha <sup>-1</sup> )					
	Season	Pre- monsoon			Post- monsoon	
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	194.43	200.71	153.66	200.84	223.24	175.16
S <sub>2</sub>	100.35	112.90	181.88	114.26	132.24	195.50
S <sub>3</sub>	166.21	156.80	188.16	176.71	169.34	201.59
S <sub>4</sub>	203.84	225.79	191.30	225.71	227.99	232.66
S <sub>5</sub>	172.48	106.62	232.06	194.59	121.52	259.28
S <sub>6</sub>	144.26	213.25	131.71	163.49	231.48	148.58
S <sub>7</sub>	216.38	84.67	147.39	233.31	105.99	162.52
S <sub>8</sub>	197.57	137.98	208.37	213.12	162.58	226.02
S <sub>9</sub>	208.70	190.24	217.89	223.99	204.98	233.46
S <sub>10</sub>	122.89	205.89	175.70	137.28	226.91	192.15
<b>Mean</b>	172.71	163.48	182.81	188.33	180.63	202.69
<b>CD<sub>0.05</sub> S</b>	4.66	21.92	8.95	3.88	9.41	4.14
<b>L</b>	4.13			2.00		
<b>S x L</b>	13.05			6.20		
<b>Sub-surface</b>						
S <sub>1</sub>	159.31	164.72	107.62	163.52	180.52	133.55
S <sub>2</sub>	61.10	79.26	142.31	76.44	93.87	154.70
S <sub>3</sub>	124.89	117.53	153.10	143.50	142.64	173.10
S <sub>4</sub>	156.73	182.21	149.90	177.37	192.50	150.72
S <sub>5</sub>	138.63	74.83	184.80	152.48	92.15	208.10
S <sub>6</sub>	103.39	172.37	94.92	117.42	185.26	113.17
S <sub>7</sub>	171.13	61.72	109.26	189.52	78.10	191.24
S <sub>8</sub>	161.88	96.94	159.23	178.33	107.64	180.49
S <sub>9</sub>	175.62	146.16	178.39	190.12	175.93	194.50
S <sub>10</sub>	83.72	164.71	143.21	102.51	187.44	156.42
<b>Mean</b>	133.54	126.04	142.27	149.12	143.60	165.60
<b>CD<sub>0.05</sub> S</b>	4.49	4.97	4.58	5.21	37.65	34.24
<b>L</b>	0.63			6.35		
<b>S x L</b>	0.20			20.06		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub>– Chowkiwala, L<sub>1</sub>S<sub>8</sub>– Salewal, L<sub>1</sub>S<sub>9</sub>– Dhбота and L<sub>1</sub>S<sub>10</sub>– Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub>– Juddi Khurd, L<sub>2</sub>S<sub>8</sub>– Baddi, L<sub>2</sub>S<sub>9</sub>– Malpur and L<sub>2</sub>S<sub>10</sub>–Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwala, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

Maximum available nitrogen ( $232.06 \text{ kg ha}^{-1}$ ) was recorded in the soil of site 5 (Sainsiwala) of Barotiwala which was found to be at par with that of site 4 (Billawali Labana) of Baddi i.e.  $225.79 \text{ kg ha}^{-1}$  during pre-monsoon season. During post-monsoon season, highest available nitrogen ( $259.28 \text{ kg ha}^{-1}$ ) was also recorded at site 5 (Sainsiwala) of Barotiwala followed by site 9 (Kuranwala) i.e.  $233.46 \text{ kg ha}^{-1}$  of Barotiwla and site 7 (Chowkiwala) i.e.  $233.31 \text{ kg ha}^{-1}$  of Nalagarh. Whereas, lowest available nitrogen ( $84.67 \text{ kg ha}^{-1}$  and  $105.99 \text{ kg ha}^{-1}$ ) amongst all the sites of three different locations was recorded at site 7 (Juddi Khurd) of Baddi during both pre and post-monsoon season, respectively. There was significant difference in the available nitrogen content of surface soils within different sites, irrespective of locations during pre and post-monsoon season.

Data presented in Table 4.23 revealed that in sub-surface soils, highest available nitrogen content ( $142.27 \text{ kg ha}^{-1}$  and  $165.60 \text{ kg ha}^{-1}$ ) amongst the three different locations was recorded in Barotiwala soils followed by Nalagarh ( $133.54 \text{ kg ha}^{-1}$  and  $149.12 \text{ kg ha}^{-1}$ ) during pre and post-monsoon seasons. It was noticed that amongst the three different locations, lowest available nitrogen ( $126.04 \text{ kg ha}^{-1}$  and  $143.60 \text{ kg ha}^{-1}$ ) was recorded at Baddi during both the seasons. There was no significant difference in the content of available nitrogen within the locations during post-monsoon season for sub-surface soils of Nalagarh and Baddi.

The data pertaining to available nitrogen for sub-surface soils of different sites in Nalagarh location (Table 4.23) indicated that highest content of available nitrogen ( $175.62 \text{ kg ha}^{-1}$  and  $190.12 \text{ kg ha}^{-1}$ ) was recorded each at Dhбота which was found to be at par with that of Chowkiwala ( $171.13$  and  $189.52$ ) during both pre and post-monsoon seasons, respectively. However, lowest available nitrogen ( $61.10 \text{ kg ha}^{-1}$  and  $76.44 \text{ kg ha}^{-1}$ ) was recorded at Manpur for both the seasons, respectively.

The sub-surface soils of different sites in Baddi location during pre-monsoon season, exhibited highest available nitrogen content ( $182.21 \text{ kg ha}^{-1}$ ) at Billawalli Labana followed by Juddi Kalan, Sairajmajra Gujra, Gularwala and Malpur. During post-monsoon season, highest available nitrogen ( $192.50 \text{ kg ha}^{-1}$ ) was also recorded in Billawalli Labana which was found to be at par with those of Gularwala ( $187.44 \text{ kg ha}^{-1}$ ), Juddi Kalan ( $185.26 \text{ kg ha}^{-1}$ ), Sairajmajra Gujra ( $180.52 \text{ kg ha}^{-1}$ ) and Malpur ( $175.93 \text{ kg ha}^{-1}$ ). The lowest available nitrogen content of  $61.72 \text{ kg ha}^{-1}$  and  $78.10 \text{ kg ha}^{-1}$  was recorded each at Juddi Khurd for pre and post-monsoon season, respectively.

The highest available nitrogen content ( $184.80 \text{ kg ha}^{-1}$ ) in sub-surface soils of different sites of Barotiwala location was recorded at Sainsiwala followed by Kuranwala, Panga and Baurawala during pre-monsoon season and at Sainsiwala ( $208.10 \text{ kg ha}^{-1}$ ) during post-monsoon season, which was found to be at par with those of Kuranwala ( $194.50 \text{ kg ha}^{-1}$ ), Sattiwala ( $191.24 \text{ kg ha}^{-1}$ ) and Panga ( $180.49 \text{ kg ha}^{-1}$ ). However, lowest available nitrogen ( $94.92 \text{ kg ha}^{-1}$  and  $113.17 \text{ kg ha}^{-1}$ ) was recorded each at Barotiwala for pre and post-monsoon season, respectively.

The sub-surface soils irrespective of locations, highest available nitrogen ( $184.80 \text{ kg ha}^{-1}$ ) was recorded at site 5 (Sainsiwala) of Barotiwala followed by site 4 (Billawali Labana) of Baddi i.e.  $182.21 \text{ kg ha}^{-1}$ , site 9 (Dhбота) of Nalagarh i.e.  $175.62 \text{ kg ha}^{-1}$  and site 9 (Kuranwala) of Barotiwala i.e.  $178.39 \text{ kg ha}^{-1}$  during pre-monsoon season. During post-monsoon season, highest available nitrogen ( $208.10 \text{ kg ha}^{-1}$ ) was also recorded at site 5 (Sainsiwala) of Barotiwala which was found to be at par with those of site 9 (Kuranwala) i.e.  $194.50 \text{ kg ha}^{-1}$  of Barotiwala, site 7 (Sattiwala) i.e.  $191.24 \text{ kg ha}^{-1}$  of Barotiwala, site 4 (Billawali Labana) i.e.  $192.50 \text{ kg ha}^{-1}$  of Baddi and site 7 (Chowkiwala) i.e.  $189.52 \text{ kg ha}^{-1}$  of Nalagarh. Whereas, lowest available nitrogen ( $61.10 \text{ kg ha}^{-1}$  and  $76.44 \text{ kg ha}^{-1}$ ) amongst all the sites of three different locations was recorded in the soils of site 2 (Manpur) of Nalagarh during pre and post-monsoon seasons, respectively. There was significant difference in the available nitrogen content irrespective of locations for sub-surface soils during post-monsoon season.

## **Phosphorus**

The available phosphorus content among the three locations, registered highest values of  $57.68 \text{ kg ha}^{-1}$  and  $71.61 \text{ kg ha}^{-1}$  at Barotiwala followed by  $56.90 \text{ kg ha}^{-1}$  and  $69.54 \text{ kg ha}^{-1}$  at Nalagarh during pre-monsoon and post-monsoon seasons, respectively (Table 4.24). It was also noticed that amongst the three different locations, lowest available phosphorus ( $56.46 \text{ kg ha}^{-1}$  and  $69.06 \text{ kg ha}^{-1}$ ) was recorded at Baddi during both seasons (Table 4.24). There was no significant difference in the available phosphorus content of Nalagarh and Baddi location soils during post-monsoon season.

The highest available phosphorus content of  $67.40 \text{ kg ha}^{-1}$  and  $79.43 \text{ kg ha}^{-1}$  for surface soils of different sites in Nalagarh location was recorded in Khera soil followed by those of

Chowkiwala(64.40 kg ha<sup>-1</sup> and 78.77 kg ha<sup>-1</sup>), Dhatowal(63.20 kg ha<sup>-1</sup> and 78.37 kg ha<sup>-1</sup>), Salewal(59.30 kg ha<sup>-1</sup> and 75.00 kg ha<sup>-1</sup>), Rajpura(57.60 kg ha<sup>-1</sup> and 66.10 kg ha<sup>-1</sup>) and Khroni(56.30 kg ha<sup>-1</sup> and 70.08 kg ha<sup>-1</sup>) during both seasons. The lowest available phosphorus of 44.80 kg ha<sup>-1</sup> and 52.77 kg ha<sup>-1</sup> was recorded each at Kishanpura during pre and post-monsoon season, respectively.

Surface soils of different sites in Baddi location exhibited highest available phosphorus (68.70 kg ha<sup>-1</sup> and 81.39 kg ha<sup>-1</sup>) at Malpur followed by Billawalli Labana (66.70kg ha<sup>-1</sup> and 78.37 kg ha<sup>-1</sup>), Sairajmajra Gujra (62.30kg ha<sup>-1</sup> and 77.57kg ha<sup>-1</sup>) and Juddi Khurd (58.40kg ha<sup>-1</sup> and 70.58kg ha<sup>-1</sup>) during both pre and post-monsoon seasons. It was observed that lowest available phosphorus (45.60 kg ha<sup>-1</sup> and 55.33 kg ha<sup>-1</sup>) was recorded at Juddi Kalan during pre and post-monsoon seasons, respectively.

The highest available phosphorus (69.80 kg ha<sup>-1</sup>) for surface soils of different sites in Barotiwala location was recorded in soils of Bated during pre-monsoon season followed by Kuranwala, Sainsiwala and Plankwala. While, during post-monsoon season, highest available phosphorus (81.51 kg ha<sup>-1</sup>) was also recorded at Bated which was found to be at par with that of Kuranwala (81.16 kg ha<sup>-1</sup>). It was noticed that lowest available phosphorus of 45.60 kg ha<sup>-1</sup> (pre-monsoon) and 58.43 kg ha<sup>-1</sup> (post-monsoon) was recorded at Panga (Table 4.24).

The surface soils irrespective of locations, registered highest available phosphorus content (69.80 kg ha<sup>-1</sup>) at site 2 (Bated) of Barotiwala followed by site 9 (Malpur) of Baddi i.e. 68.70 kg ha<sup>-1</sup>, site 3 (Khera) of Nalagarh i.e. 67.40 kg ha<sup>-1</sup> and site 4 (Billawali Labana) of Baddi i.e. 66.40 kg ha<sup>-1</sup> during pre-monsoon season. During post-monsoon season, highest available phosphorus (81.51 kg ha<sup>-1</sup>) was also recorded at site 2 (Bated) of Barotiwala which was found to be at par with those of site 9 (Malpur) i.e. 81.39 kg ha<sup>-1</sup> of Baddi, site 9 (Kuranwala) i.e. 81.16 kg ha<sup>-1</sup> of Barotiwla. Whereas, lowest available phosphorus (44.80 kg ha<sup>-1</sup> and 52.77 kg ha<sup>-1</sup>) amongst all the sites of three different locations was recorded at site 1 (Kishanpura) of Nalagarh during both pre-monsoon and post-monsoon season (Table 4.24).

The data pertaining to available phosphorus in sub-surface soils (Table 4.24) revealed that highest value amongst the three different locations was recorded at Nalagarh (43.32 kg ha<sup>-1</sup>) followed by Barotiwala (42.89 kg ha<sup>-1</sup>) during pre-monsoon season. During post-monsoon season, highest available phosphorus was recorded at Barotiwala (58.58 kg ha<sup>-1</sup>)

followed by Nalagarh (57.30 kg ha<sup>-1</sup>). It was noticed that amongst the three different locations, lowest available phosphorus (41.88 kg ha<sup>-1</sup> and 56.00 kg ha<sup>-1</sup>) was recorded each at Baddi during both the seasons. There was significant difference in available phosphorus content of Baddi and Barotiwala soils during pre-monsoon season.

The sub-surface soils of different sites in Nalagarh location recorded highest available phosphorus content (52.80 kg ha<sup>-1</sup>) at Khera during pre-monsoon season followed by Dhatowal(49.40 kg ha<sup>-1</sup>), Chowkiwala(48.30 kg ha<sup>-1</sup>), Salewal(45.70 kg ha<sup>-1</sup>) and Rajpura(44.80 kg ha<sup>-1</sup>). For post-monsoon season, highest available phosphorus (65.60 kg ha<sup>-1</sup>) was also recorded at Khera followed by Chowkiwala (63.37kg ha<sup>-1</sup>), Salewal (62.49 kg ha<sup>-1</sup>), Dhatowal (60.92 kg ha<sup>-1</sup>) and Bhatiyani (58.53 kg ha<sup>-1</sup>). The lowest available phosphorus content of 34.60 kg ha<sup>-1</sup> and 41.99 kg ha<sup>-1</sup> was recorded at Kishanpura for pre and post-monsoon seasons, respectively.

The data pertaining to available phosphorus for sub-surface soils of different sites in Baddi location revealed that highest value of 53.50 kg ha<sup>-1</sup> was recorded at Malpur followed by Billawalli Labana (51.50kg ha<sup>-1</sup>), Sairajmajra Gujra (48.60kg ha<sup>-1</sup>), Juddi Khurd (42.70kg ha<sup>-1</sup>), and Sairajmajra Labana (42.60kg ha<sup>-1</sup>) during pre-monsoon season. Whereas, during post-monsoon season, highest available phosphorus (66.67 kg ha<sup>-1</sup>) was also recorded at Malpur, which was at par with that of Billawalli Labana. However, the lowest available phosphorus of 31.40 kg ha<sup>-1</sup> and 42.23 kg ha<sup>-1</sup> was recorded at Juddi Kalan, respectively for pre and post-monsoon seasons.

The data presented in Table 4.24 indicated that highest available phosphorus (53.80 kg ha<sup>-1</sup>) for sub-surface soils in different sites of Barotiwala location was recorded at Bated during pre-monsoon season followed by those of Kuranwala (51.70 kg ha<sup>-1</sup>), Sainsiwala (50.50 kg ha<sup>-1</sup>) and Plankwala (48.80 kg ha<sup>-1</sup>). Whereas, during post-monsoon season, the highest available phosphorus (67.33 kg ha<sup>-1</sup>) was recorded in soils of Kuranwala which was found to be at par with that of Bated (66.97 kg ha<sup>-1</sup>). However, lowest available phosphorus content of 32.30 kg ha<sup>-1</sup> (pre-monsoon) and 45.37 kg ha<sup>-1</sup> (post-monsoon) was recorded at Panga.

**Table 4.24 Status of available phosphorus at different locations and sites**

Parameter	P (kg ha <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	44.80	62.30	48.90	52.77	77.57	64.50
S <sub>2</sub>	54.70	56.50	69.80	62.67	67.33	81.51
S <sub>3</sub>	67.40	47.60	54.80	79.43	61.50	66.93
S <sub>4</sub>	56.30	66.70	63.60	70.08	78.37	77.97
S <sub>5</sub>	63.20	49.30	64.30	78.37	60.92	77.37
S <sub>6</sub>	57.60	45.60	51.70	66.10	55.33	65.80
S <sub>7</sub>	64.40	58.40	51.90	78.77	70.58	68.07
S <sub>8</sub>	59.30	53.90	45.60	75.00	68.40	58.43
S <sub>9</sub>	48.70	68.70	66.40	64.27	81.39	81.16
S <sub>10</sub>	52.60	55.60	59.80	67.93	69.20	74.32
<b>Mean</b>	56.90	56.46	57.68	69.54	69.06	71.61
<b>CD<sub>0.05</sub> S</b>	0.94	0.91	0.89	2.07	1.59	1.77
<b>L</b>	0.07			0.53		
<b>S x L</b>	0.24			1.66		
<b>Sub-surface</b>						
S <sub>1</sub>	34.60	48.60	36.70	41.99	64.13	51.67
S <sub>2</sub>	41.50	42.60	53.80	56.16	53.40	66.97
S <sub>3</sub>	52.80	32.80	39.30	65.60	46.33	52.70
S <sub>4</sub>	42.30	51.50	48.80	56.63	66.64	65.62
S <sub>5</sub>	49.40	37.60	50.50	60.92	50.90	62.37
S <sub>6</sub>	44.80	31.40	37.30	54.30	42.23	54.87
S <sub>7</sub>	48.30	42.70	34.60	63.37	59.40	55.29
S <sub>8</sub>	45.70	36.80	32.30	62.49	55.79	45.37
S <sub>9</sub>	35.20	53.50	51.70	52.98	66.67	67.33
S <sub>10</sub>	38.60	41.30	43.90	58.53	54.49	63.60
<b>Mean</b>	43.32	41.88	42.89	57.30	56.00	58.58
<b>CD<sub>0.05</sub> S</b>	0.96	0.84	0.87	1.67	1.53	1.64
<b>L</b>	0.07			0.49		
<b>S x L</b>	0.22			1.52		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhbota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The highest available phosphorus content of 53.80 kg ha<sup>-1</sup> was recorded at site 2 (Bated) of Barotiwala followed by those of site 9 (Malpur) of Baddi i.e. 53.50 kg ha<sup>-1</sup>, site 3 (Khera) of Nalagarh i.e. 52.80 kg ha<sup>-1</sup> and site 9 (Kuranwala) of Barotiwala i.e. 51.70 kg ha<sup>-1</sup> during pre-monsoon season, irrespective of locations,. During post-monsoon season, highest available phosphorus (67.33 kg ha<sup>-1</sup>) was recorded at site 9 (Kuranwala) of Barotiwala which was found to be at par with those of site 2 (Bated) i.e. 66.97 kg ha<sup>-1</sup> of Barotiwla, site 9 (Malpur) i.e. 66.67 kg ha<sup>-1</sup> of Baddi and site 4 (Billawali Labana) i.e. 66.64 kg ha<sup>-1</sup> of Baddi. Whereas, lowest available phosphorus (31.40 kg ha<sup>-1</sup>) amongst all the sites of three different locations was recorded at site 6 (Juddi Kalan) of Baddi during pre-monsoon season and at site 1 (Kishanpura) of Nalagarh i.e. (41.99 kg ha<sup>-1</sup>) during post-monsoon season, respectively.

### **Potassium**

The status of available potassium for both surface and sub-surface soils during pre and post-monsoon seasons at different locations and sites are presented in Table 4.25. Among the three different locations, Barotiwala was having the highest available potassium (96.26 kg ha<sup>-1</sup>) followed by Nalagarh (94.36 kg ha<sup>-1</sup>) in surface soils during pre-monsoon season. During post-monsoon season, highest available potassium was recorded in the soils of Nalagarh (69.06 kg ha<sup>-1</sup>) followed by Barotiwala (68.32 kg ha<sup>-1</sup>). Whereas, lowest available potassium (91.66 kg ha<sup>-1</sup> and 64.41 kg ha<sup>-1</sup>) was recorded in the soils of Baddi during both seasons amongst the three different locations. There was significant difference in available potassium content within the locations during pre and post-monsoon seasons.

The available K in surface soils of different sites in Nalagarh location exhibited highest available potassium (111.80 kg ha<sup>-1</sup>) at Chowkiwala followed by Dhбота (107.60 kg ha<sup>-1</sup>), Khroni (105.70 kg ha<sup>-1</sup>) and Salewal (99.80 kg ha<sup>-1</sup>) during pre-monsoon season. During post-monsoon season, highest available potassium (81.50 kg ha<sup>-1</sup>) was also found at Chowkiwala followed by Khroni (77.60 kg ha<sup>-1</sup>), Kishanpura (76.80 kg ha<sup>-1</sup>) and Dhбота (75.60 kg ha<sup>-1</sup>). It was observed that lowest available potassium content of 78.60 kg ha<sup>-1</sup> (pre-monsoon) and 55.30 kg ha<sup>-1</sup> (post-monsoon) was recorded in the soil of Manpur and Rajpura, respectively.

For surface soils of different sites in Baddi location, highest available potassium ( $112.40 \text{ kg ha}^{-1}$ ) was observed at Billawalli Labana followed by Juddi Kalan ( $106.70 \text{ kg ha}^{-1}$ ), Gularwala ( $103.50 \text{ kg ha}^{-1}$ ) and Malpur ( $95.40 \text{ kg ha}^{-1}$ ) for pre-monsoon season. During post-monsoon season, highest available potassium ( $85.30 \text{ kg ha}^{-1}$ ) was observed at Billawalli Labana which was found to be at par with Gularwala ( $83.50 \text{ kg ha}^{-1}$ ). The lowest available potassium of  $75.60 \text{ kg ha}^{-1}$  and  $50.70 \text{ kg ha}^{-1}$  was recorded in the soils of Juddi Khurd and Sairajmajra Labana during pre and post-monsoon seasons, respectively.

The highest available potassium content ( $115.60 \text{ kg ha}^{-1}$  and  $88.60 \text{ kg ha}^{-1}$ ) for surface soils of different sites in Barotiwala location was recorded at Sainsiwala followed by that of Kuranwala ( $112.10 \text{ kg ha}^{-1}$  and  $84.50 \text{ kg ha}^{-1}$ ) and Panga ( $106.90 \text{ kg ha}^{-1}$  and  $77.60 \text{ kg ha}^{-1}$ ) soils during both seasons. However, lowest available potassium of ( $82.60 \text{ kg ha}^{-1}$  and  $53.90 \text{ kg ha}^{-1}$ ) was observed each at Barotiwala during pre and post-monsoon seasons, respectively.

The surface soils irrespective of locations, recorded highest available potassium content ( $115.60 \text{ kg ha}^{-1}$  and  $88.60 \text{ kg ha}^{-1}$ ) at site 5 (Sainsiwala) of Barotiwala followed by those of site 4 (Billawali Labana) of Baddi i.e.  $112.40 \text{ kg ha}^{-1}$  and  $85.30 \text{ kg ha}^{-1}$  and site 9 (Kuranwala) of Barotiwala i.e.  $112.10 \text{ kg ha}^{-1}$  and  $84.50 \text{ kg ha}^{-1}$  during pre and post-monsoon season, respectively. Whereas, lowest available potassium ( $75.60 \text{ kg ha}^{-1}$ ) amongst all the sites of three different locations was recorded at site 7 (Juddi Khurd) of Baddi during pre-monsoon season and at site 2 (Sairajmajra Labana) of Baddi i.e.  $50.70 \text{ kg ha}^{-1}$  during post-monsoon season, respectively (Table 4.25). There was significant difference for available potassium content irrespective of locations during both seasons.

Data presented in Table 4.25 revealed that in sub-surface soils, highest available potassium amongst the three different locations was recorded at Nalagarh ( $82.14 \text{ kg ha}^{-1}$  and  $69.38 \text{ kg ha}^{-1}$ ) which was found to be at par with that of Barotiwala ( $82.02 \text{ kg ha}^{-1}$  and  $68.85 \text{ kg ha}^{-1}$ ) during pre and post-monsoon seasons, respectively. It was noticed that amongst the three different locations, lowest available potassium ( $77.50 \text{ kg ha}^{-1}$  and  $64.83 \text{ kg ha}^{-1}$ ) was recorded at Baddi during both seasons. There was no significant difference in the available potassium within soils of Nalagarh and Barotiwala during both the seasons.

**Table 4.25 Status of available potassium at different locations and sites**

Parameter	K (kg ha <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Locations (L) Site (S)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )
<b>Surface</b>						
S <sub>1</sub>	92.80	94.70	85.80	76.80	63.70	58.80
S <sub>2</sub>	78.60	79.20	92.30	62.60	50.70	63.80
S <sub>3</sub>	89.40	86.50	94.80	70.60	57.40	68.40
S <sub>4</sub>	105.70	112.40	96.20	77.60	85.30	65.40
S <sub>5</sub>	90.60	78.80	115.60	65.40	54.80	88.60
S <sub>6</sub>	87.50	106.70	82.60	53.90	74.10	53.90
S <sub>7</sub>	111.80	75.60	84.70	81.50	51.40	58.50
S <sub>8</sub>	99.80	83.80	106.90	71.30	57.90	77.60
S <sub>9</sub>	107.60	95.40	112.10	75.60	65.30	84.50
S <sub>10</sub>	79.80	103.50	91.60	55.30	83.50	63.70
<b>Mean</b>	94.36	91.66	96.26	69.06	64.41	68.32
<b>CD<sub>0.05</sub> S</b>	2.39	1.34	1.10	2.44	2.33	2.57
<b>L</b>	0.24			0.75		
<b>S x L</b>	0.74			2.38		
<b>Sub-surface</b>						
S <sub>1</sub>	81.70	79.70	69.80	78.27	63.37	58.68
S <sub>2</sub>	68.80	62.80	79.70	63.00	51.31	64.40
S <sub>3</sub>	78.40	71.56	81.20	71.48	56.67	69.82
S <sub>4</sub>	94.70	100.60	82.70	78.53	87.07	66.73
S <sub>5</sub>	79.80	64.70	100.80	64.93	54.49	88.17
S <sub>6</sub>	74.50	91.80	67.60	53.88	77.20	55.85
S <sub>7</sub>	98.70	61.70	69.40	81.61	52.13	59.88
S <sub>8</sub>	85.60	69.60	92.30	71.39	57.66	78.50
S <sub>9</sub>	91.80	81.80	97.90	74.13	64.90	83.63
S <sub>10</sub>	67.40	90.70	78.80	56.60	83.50	62.87
<b>Mean</b>	82.14	77.50	82.02	69.38	64.83	68.85
<b>CD<sub>0.05</sub> S</b>	2.42	1.19	1.14	2.53	2.23	2.14
<b>L</b>	0.19			0.62		
<b>S x L</b>	0.60			1.98		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhбота and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwala, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The sub-surface soils of different sites in Nalagarh location reveals that highest available potassium ( $98.70 \text{ kg ha}^{-1}$ ) was recorded at Chowkiwala for pre-monsoon season followed by Khroni ( $94.70 \text{ kg ha}^{-1}$ ), Dhbota ( $91.80 \text{ kg ha}^{-1}$ ) and Salewal ( $85.60 \text{ kg ha}^{-1}$ ), whereas, highest available potassium ( $81.61 \text{ kg ha}^{-1}$ ) during post-monsoon season was recorded also at Chowkiwala followed by Khroni ( $78.53 \text{ kg ha}^{-1}$ ), Kishanpura ( $78.27 \text{ kg ha}^{-1}$ ) and Dhbota ( $74.13 \text{ kg ha}^{-1}$ ). The lowest available potassium in the tune of  $67.40 \text{ kg ha}^{-1}$  and  $56.60 \text{ kg ha}^{-1}$  was recorded at Bhatiyan during pre and post-monsoon season, respectively.

Sub-surface soils of different sites in Baddi location, exhibited highest available potassium ( $100.60 \text{ kg ha}^{-1}$ ) in Billawalli Labana soil followed by Juddi Kalan ( $91.80 \text{ kg ha}^{-1}$ ), Gularwala ( $90.70 \text{ kg ha}^{-1}$ ) and Malpur ( $81.80 \text{ kg ha}^{-1}$ ) for pre-monsoon season. Whileas, during post-monsoon season highest available potassium ( $87.07 \text{ kg ha}^{-1}$ ) was also recorded at Billawalli Labana soil followed by Gularwala ( $83.50 \text{ kg ha}^{-1}$ ) and Juddi Kalan ( $77.20 \text{ kg ha}^{-1}$ ). It was observed that during pre-monsoon season, lowest available potassium content ( $61.70 \text{ kg ha}^{-1}$ ) was found in the soils of Juddi Khurd and at Sairajmajra Labana ( $51.31 \text{ kg ha}^{-1}$ ) during post-monsoon season.

The data presented in Table 4.25 for sub-surface soils of different sites in Barotiwala location revealed that highest available potassium ( $100.80 \text{ kg ha}^{-1}$  and  $88.17 \text{ kg ha}^{-1}$ ) was observed at Sainsiwala followed by Kuranwala ( $97.90 \text{ kg ha}^{-1}$  and  $83.63 \text{ kg ha}^{-1}$ ) and Panga ( $92.30 \text{ kg ha}^{-1}$  and  $78.50 \text{ kg ha}^{-1}$ ) during both seasons, whileas, lowest available potassium of  $67.60 \text{ kg ha}^{-1}$  (pre-monsoon) and  $55.85 \text{ kg ha}^{-1}$  (post-monsoon) was observed in the soil of Barotiwala.

The sub-surface soils irrespective of locations, registered highest available potassium ( $100.80 \text{ kg ha}^{-1}$  and  $88.17 \text{ kg ha}^{-1}$ ) at site 5 (Sainsiwala) of Barotiwala which was found to be at par with that of site 4 (Billawali Labana) of Baddi i.e.  $100.60 \text{ kg ha}^{-1}$  and  $87.07 \text{ kg ha}^{-1}$  during pre and post-monsoon season, respectively. Whereas, lowest available potassium ( $61.70 \text{ kg ha}^{-1}$ ) amongst all the sites of three different locations was recorded at site 7 (Juddi Khurd) of Baddi during pre-monsoon season and at site 2 (Sairajmajra Labana) of Baddi i.e.  $51.31 \text{ kg ha}^{-1}$  during post-monsoon season.

The available nitrogen content decreased with increase in soil depth and rated as low fertility status. However phosphorus content was rated as low to medium in status. The values in post-monsoon season were higher than those in pre-monsoon season.

#### **4.4.2 Micronutrient status and heavy metals**

##### **Manganese**

The status of manganese content for surface and sub-surface soils during pre-monsoon and post-monsoon seasons at different locations and sites are presented in Table 4.26. Data revealed that for surface soils, highest manganese content ( $3.95 \text{ mg kg}^{-1}$ ) amongst the three different locations was recorded at Barotiwala which was found to be at par with that of Baddi ( $3.91 \text{ mg kg}^{-1}$ ). The lowest manganese content of  $3.85 \text{ mg kg}^{-1}$  was recorded at Nalagarh during pre-monsoon. It was noticed that during post-monsoon season amongst the three different locations, highest manganese content ( $4.01 \text{ mg kg}^{-1}$ ) was recorded in the soil of Nalagarh which was at par with those of Barotiwala ( $4.00 \text{ mg kg}^{-1}$ ). However the lowest Mn content ( $3.91 \text{ mg kg}^{-1}$ ) was recorded at Baddi.

The surface soils of different sites in Nalagarh location exhibited highest Mn content of  $6.80 \text{ mg kg}^{-1}$  (pre-monsoon) and  $6.96 \text{ mg kg}^{-1}$  (post-monsoon) at Dhatowal followed by those of Chowkiwala ( $6.34 \text{ mg kg}^{-1}$  and  $6.53 \text{ mg kg}^{-1}$ ) and Rajpura ( $5.56 \text{ mg kg}^{-1}$  and  $5.74 \text{ mg kg}^{-1}$ ) during pre and post-monsoon season. Whileas, lowest Mn content of ( $1.57 \text{ mg kg}^{-1}$  and  $1.65 \text{ mg kg}^{-1}$ ) was recorded at Kishanpura during pre and post-monsoon seasons, respectively.

The highest Mn content of  $7.26 \text{ mg kg}^{-1}$  (pre-monsoon) and  $7.27 \text{ mg kg}^{-1}$  (post-monsoon) for surface soils of different sites in Baddi location was recorded at Sairajmajra Gujra followed by those of Juddi Kalan ( $5.52 \text{ mg kg}^{-1}$  and  $5.42 \text{ mg kg}^{-1}$ ) and Juddi Khurd ( $4.84 \text{ mg kg}^{-1}$  and  $4.74 \text{ mg kg}^{-1}$ ). However, lowest Mn content ( $1.74 \text{ mg kg}^{-1}$  and  $1.92 \text{ mg kg}^{-1}$ ) during both seasons was recorded in the soils of Billawali Labana.

For surface soils of different sites in Barotiwala location, highest Mn content ( $7.43 \text{ mg kg}^{-1}$  and  $7.25 \text{ mg kg}^{-1}$ ) was recorded each at Baurawala followed by Panga ( $4.76 \text{ mg kg}^{-1}$  and  $4.78 \text{ mg kg}^{-1}$ ) and Sainsiwala ( $4.57 \text{ mg kg}^{-1}$  and  $4.59 \text{ mg kg}^{-1}$ ) during both pre and post-monsoon season. Whileas, lowest Mn content ( $1.84 \text{ mg kg}^{-1}$  and  $1.91 \text{ mg kg}^{-1}$ ) was recorded at Bated during pre and post-monsoon season.

The surface soils irrespective of locations, registered highest manganese content ( $7.43 \text{ mg kg}^{-1}$ ) at site 3 (Baurawala) of Barotiwala followed by site 1 (Sairajmajra Gujra) of Baddi i.e.  $7.26 \text{ mg kg}^{-1}$  and site 5 (Dhatowal) of Nalagarh i.e.  $6.80 \text{ mg kg}^{-1}$  during pre-monsoon season. During post-monsoon season, highest manganese content  $7.27 \text{ mg kg}^{-1}$  was recorded at site 1 (Sairajmajra Gujra) of Baddi which was found to be at par with site 3 (Baurawala) of Barotiwala i.e.  $7.25 \text{ mg kg}^{-1}$ . Whereas, lowest manganese content of  $1.57 \text{ mg kg}^{-1}$  (pre-monsoon) and  $1.65 \text{ mg kg}^{-1}$  (post-monsoon) amongst all the sites of three different locations was recorded at site 1 (Kishanpura) of Nalagarh. There was significant difference in manganese content of surface soils irrespective of locations during pre-monsoon season.

The highest manganese content ( $2.80 \text{ mg kg}^{-1}$ ) of sub-surface soils amongst the three different locations was recorded in Nalagarh soils followed by Baddi ( $2.72 \text{ mg kg}^{-1}$ ) and lowest ( $2.70 \text{ mg kg}^{-1}$ ) at Barotiwala during pre-monsoon. It was noticed that amongst the three different locations during post-monsoon season highest manganese content ( $2.89 \text{ mg kg}^{-1}$ ) was recorded at Baddi which was found to be at par with those of Nalagarh ( $2.86 \text{ mg kg}^{-1}$ ) and Barotiwala ( $2.84 \text{ mg kg}^{-1}$ ). There was no significant difference for manganese content in sub-surface soils of three different locations during post-monsoon season.

The data presented (Table 4.26) for sub-surface soils of different sites in Nalagarh location revealed that highest Mn content of  $5.26 \text{ mg kg}^{-1}$  (pre-monsoon) and  $5.18 \text{ mg kg}^{-1}$  (post-monsoon) was recorded at Dhatowal followed by those of Chowkiwala ( $4.77 \text{ mg kg}^{-1}$  and  $4.90 \text{ mg kg}^{-1}$ ) and Salewal ( $4.03 \text{ mg kg}^{-1}$  and  $4.23 \text{ mg kg}^{-1}$ ), whereas, lowest content ( $0.74 \text{ mg kg}^{-1}$  and  $0.94 \text{ mg kg}^{-1}$ ) was recorded at Kishanpura during pre and post-monsoon season.

The sub-surface soils of different sites in Baddi location revealed that highest Mn content of  $5.36 \text{ mg kg}^{-1}$  (pre-monsoon) and  $5.68 \text{ mg kg}^{-1}$  (post-monsoon) was recorded at Sairajmajra Gujra followed by those of Juddi Kalan ( $3.94 \text{ mg kg}^{-1}$  and  $4.02 \text{ mg kg}^{-1}$ ) and Juddi Khurd ( $3.69 \text{ mg kg}^{-1}$  and  $3.83 \text{ mg kg}^{-1}$ ), whereas, lowest Mn content ( $0.79 \text{ mg kg}^{-1}$  and  $0.91 \text{ mg kg}^{-1}$ ) during both seasons was recorded at Billawali Labana.

The highest Mn content ( $5.41 \text{ mg kg}^{-1}$  and  $5.64 \text{ mg kg}^{-1}$ ) for sub-surface soils of different sites in Barotiwala location was recorded at Baurawala followed by Panga ( $3.53 \text{ mg kg}^{-1}$  and  $3.73 \text{ mg kg}^{-1}$ ) and Sainsiwala ( $3.47 \text{ mg kg}^{-1}$  and  $3.50 \text{ mg kg}^{-1}$ ) during both pre and

post-monsoon season. Whileas, lowest Mn content of 0.82 mg kg<sup>-1</sup> and 0.95 mg kg<sup>-1</sup> was recorded in the soils of Bated, during pre and post-monsoon seasons, respectively.

**Table 4.26 Status of manganese at different locations and sites**

Parameter	Mn (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	1.57	7.26	4.18	1.65	7.27	4.29
S <sub>2</sub>	2.23	1.91	1.84	2.26	1.94	1.91
S <sub>3</sub>	4.26	3.49	7.43	4.62	3.45	7.25
S <sub>4</sub>	2.26	1.74	1.95	2.32	1.92	2.12
S <sub>5</sub>	6.80	4.69	4.57	6.96	4.59	4.59
S <sub>6</sub>	5.56	5.52	4.25	5.74	5.42	4.43
S <sub>7</sub>	6.34	4.84	3.93	6.53	4.74	4.05
S <sub>8</sub>	5.23	4.17	4.76	5.53	4.11	4.78
S <sub>9</sub>	1.89	2.45	3.58	2.15	2.57	3.55
S <sub>10</sub>	2.32	2.98	2.99	2.34	3.07	3.07
<b>Mean</b>	3.85	3.91	3.95	4.01	3.91	4.00
<b>CD<sub>0.05</sub> S</b>	0.34	0.23	0.23	0.23	0.16	0.14
<b>L</b>	0.04			0.05		
<b>S x L</b>	0.12			0.16		
<b>Sub-surface</b>						
S <sub>1</sub>	0.74	5.36	3.27	0.94	5.68	3.41
S <sub>2</sub>	1.59	0.84	0.82	1.77	0.94	0.95
S <sub>3</sub>	3.42	2.09	5.41	3.38	2.45	5.64
S <sub>4</sub>	1.51	0.79	0.87	1.71	0.91	0.96
S <sub>5</sub>	5.26	3.57	3.47	5.18	3.35	3.50
S <sub>6</sub>	3.92	3.94	3.39	3.61	4.02	3.48
S <sub>7</sub>	4.77	3.69	2.19	4.90	3.83	2.25
S <sub>8</sub>	4.03	3.33	3.53	4.23	3.73	3.73
S <sub>9</sub>	0.88	1.63	2.06	1.04	1.71	2.18
S <sub>10</sub>	1.86	1.99	1.97	1.86	2.24	2.25
<b>Mean</b>	2.80	2.72	2.70	2.86	2.89	2.84
<b>CD<sub>0.05</sub> S</b>	0.28	0.24	0.25	0.22	0.94	0.16
<b>L</b>	0.03			0.17		
<b>S x L</b>	0.12			0.54		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhubota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The sub-surface soils irrespective of locations, exhibited highest manganese content ( $5.41 \text{ mg kg}^{-1}$ ) at site 3 (Baurawala) of Barotiwala which was found to be at par with that of site 1 (Sairajmajra Gujra) of Baddi i.e.  $5.36 \text{ mg kg}^{-1}$  during pre-monsoon season. During post-monsoon season, highest manganese content ( $5.68 \text{ mg kg}^{-1}$ ) was recorded at site 1 (Sairajmajra Gujra) of Baddi which was found to be at par with site 3 (Baurawala) of Barotiwala i.e.  $5.64 \text{ mg kg}^{-1}$ . Whereas, lowest manganese content ( $0.74 \text{ mg kg}^{-1}$  and  $0.94 \text{ mg kg}^{-1}$ ) amongst all the sites of three different locations was recorded at site 1 (Kishanpura) of Nalagarh during pre and post-monsoon season (Table 4.26).

## Copper

Data presented in Table 4.27 reveals that for surface soils, highest copper content ( $1.53 \text{ mg kg}^{-1}$ ) amongst the three different locations was recorded at Baddi followed by Nalagarh ( $1.42 \text{ mg kg}^{-1}$ ) and lowest ( $1.38 \text{ mg kg}^{-1}$ ) was recorded at Barotiwala during pre-monsoon season. It was noticed that amongst the three different locations during post-monsoon season, highest copper content ( $1.60 \text{ mg kg}^{-1}$ ) was recorded at Baddi, which was found to be at par with that of Barotiwala ( $1.49 \text{ mg kg}^{-1}$ ) and lowest ( $1.48 \text{ mg kg}^{-1}$ ) at Nalagarh.

The highest Cu content ( $3.56 \text{ mg kg}^{-1}$  and  $3.60 \text{ mg kg}^{-1}$ ) for surface soils of different sites in Nalagarh location was recorded at Dhatowal during both pre and post-monsoon seasons followed by Kishanpura ( $2.54 \text{ mg kg}^{-1}$  and  $2.59 \text{ mg kg}^{-1}$ ) and Rajpura ( $1.87 \text{ mg kg}^{-1}$  and  $1.91 \text{ mg kg}^{-1}$ ). It was observed that lowest Cu content ( $0.37 \text{ mg kg}^{-1}$  and  $0.45 \text{ mg kg}^{-1}$ ) was recorded at Salewal during both the seasons.

The highest Cu content ( $3.77 \text{ mg kg}^{-1}$  and  $3.86 \text{ mg kg}^{-1}$ ) for surface soils of different sites in Baddi location was recorded at Kantha during both pre and post-monsoon seasons followed by Juddi Khurd ( $2.38 \text{ mg kg}^{-1}$  and  $2.45 \text{ mg kg}^{-1}$ ) and Sairajmajra Labana ( $2.17 \text{ mg kg}^{-1}$  and  $2.23 \text{ mg kg}^{-1}$ ). However, lowest Cu content ( $0.37 \text{ mg kg}^{-1}$  and  $0.44 \text{ mg kg}^{-1}$ ) was recorded at Billawali Labana during both the seasons.

For surface soils of different sites in Barotiwala location highest Cu content ( $3.49 \text{ mg kg}^{-1}$  and  $3.58 \text{ mg kg}^{-1}$ ) was recorded at Plankwala during both pre and post-monsoon seasons, respectively followed by Sainsiwala ( $2.07 \text{ mg kg}^{-1}$  and  $2.19 \text{ mg kg}^{-1}$ ) and Sattiwala ( $1.86 \text{ mg kg}^{-1}$ ).

kg<sup>-1</sup> and 1.95 mg kg<sup>-1</sup>). It was observed that lowest Cu content (0.32 mg kg<sup>-1</sup> and 0.46 mg kg<sup>-1</sup>) was recorded in the soils of Jharmajri during both the seasons.

The surface soils irrespective of locations, recorded highest copper content (3.77 mg kg<sup>-1</sup> and 3.86 mg kg<sup>-1</sup>) at site 5 (Kantha) of Baddi followed by site 5 (Dhatowal) of Nalagarh (3.56 mg kg<sup>-1</sup> and 3.60 mg kg<sup>-1</sup>) and site 4 (Plankwala) of Barotiwala (3.49 mg kg<sup>-1</sup> and 3.58 mg kg<sup>-1</sup>) during pre-monsoon and post-monsoon season, respectively. Whereas, lowest copper content (0.32 mg kg<sup>-1</sup>) amongst all the sites of three different locations was recorded at site 1 (Jharmajri) of Barotiwala during pre-monsoon season and at site 4 (Billawali Labana) of Baddi (0.44 mg kg<sup>-1</sup>) during post-monsoon season.

The data presented in the Table 4.27 reveals that for sub-surface soils, highest copper content (1.07 mg kg<sup>-1</sup> and 1.15 mg kg<sup>-1</sup>) amongst the three different locations was recorded at Baddi followed by Nalagarh (0.94 mg kg<sup>-1</sup> and 1.07 mg kg<sup>-1</sup>) during pre and post-monsoon seasons, respectively. Amongst the three different locations, lowest copper content of 0.91 mg kg<sup>-1</sup> (pre-monsoon) and 1.04 mg kg<sup>-1</sup> (post-monsoon) was recorded at Barotiwala.

Sub-surface soils of different sites in Nalagarh location recorded highest Cu content (2.13 mg kg<sup>-1</sup>) at Dhatowal which was found to be at par with Kishanpura (2.03 mg kg<sup>-1</sup>) during pre-monsoon season. Whereas, during post-monsoon season highest Cu content (2.20 mg kg<sup>-1</sup>) was recorded at Kishanpura which was found to be at par with Dhatowal (2.18 mg kg<sup>-1</sup>). The lowest Cu content (0.21 mg kg<sup>-1</sup> and 0.34 mg kg<sup>-1</sup>) was recorded at Salewal during both the seasons.

Sub-surface soils of different sites in Baddi location exhibited highest Cu content (2.18 mg kg<sup>-1</sup>) at Kantha which was found to be at par with Sairajmajra Labana (2.09 mg kg<sup>-1</sup>) during pre-monsoon season. Whereas, during post-monsoon season, highest Cu content (2.26 mg kg<sup>-1</sup>) was also recorded at Kantha which was found to be at par with Sairajmajra Labana (2.20 mg kg<sup>-1</sup>) and Juddi Khurd (2.00 mg kg<sup>-1</sup>). The lowest Cu content (0.23 mg kg<sup>-1</sup> and 0.36 mg kg<sup>-1</sup>) was recorded at Billawali Labana during both the seasons.

The highest Cu content (2.11 mg kg<sup>-1</sup> and 2.18 mg kg<sup>-1</sup>) for sub-surface soils of different sites in Barotiwala location was recorded at Plankwala during both pre and post-monsoon seasons followed by Sainsiwala (1.31 mg kg<sup>-1</sup> and 1.47 mg kg<sup>-1</sup>) and Sattiwala (1.16

mg kg<sup>-1</sup> and 1.33 mg kg<sup>-1</sup>). However, lowest Cu content (0.20 mg kg<sup>-1</sup> and 0.28 mg kg<sup>-1</sup>) was recorded at Jharmajri during both the seasons.

**Table 4.27 Status of copper at different locations and sites**

Parameter	Cu (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalā (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalā (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	2.54	0.43	0.32	2.59	0.52	0.46
S <sub>2</sub>	1.36	2.17	1.24	1.43	2.23	1.32
S <sub>3</sub>	0.83	1.49	1.43	0.88	1.55	1.52
S <sub>4</sub>	0.76	0.37	3.49	0.83	0.44	3.58
S <sub>5</sub>	3.56	3.77	2.07	3.60	3.86	2.19
S <sub>6</sub>	1.87	1.17	0.85	1.91	1.23	0.98
S <sub>7</sub>	0.93	2.38	1.86	0.99	2.45	1.95
S <sub>8</sub>	0.37	0.83	0.67	0.45	0.90	0.78
S <sub>9</sub>	0.53	1.73	1.29	0.60	1.82	1.45
S <sub>10</sub>	1.42	0.98	0.54	1.51	1.05	0.70
<b>Mean</b>	1.42	1.53	1.38	1.48	1.60	1.49
<b>CD<sub>0.05</sub> S</b>	0.21	0.21	0.22	0.09	0.11	0.05
<b>L</b>	0.02			0.03		
<b>S x L</b>	0.05			0.08		
<b>Sub-surface</b>						
S <sub>1</sub>	2.03	0.25	0.20	2.20	0.38	0.28
S <sub>2</sub>	0.99	2.09	1.02	1.13	2.20	1.16
S <sub>3</sub>	0.54	1.10	1.12	0.68	1.18	1.28
S <sub>4</sub>	0.42	0.23	2.11	0.51	0.36	2.18
S <sub>5</sub>	2.13	2.18	1.31	2.18	2.26	1.47
S <sub>6</sub>	1.06	0.82	0.59	1.16	0.63	0.77
S <sub>7</sub>	0.69	1.92	1.16	0.84	2.00	1.33
S <sub>8</sub>	0.21	0.52	0.32	0.34	0.65	0.39
S <sub>9</sub>	0.33	0.99	0.96	0.45	1.07	1.11
S <sub>10</sub>	1.02	0.64	0.28	1.16	0.79	0.43
<b>Mean</b>	0.94	1.07	0.91	1.07	1.15	1.04
<b>CD<sub>0.05</sub> S</b>	0.18	0.19	0.15	0.08	0.26	0.11
<b>L</b>	0.01			0.05		
<b>S x L</b>	0.04			0.16		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhubota and L<sub>1</sub>S<sub>10</sub> – Bhatiyān

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalā, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The highest copper content ( $2.18 \text{ mg kg}^{-1}$ ) for sub-surface soils, irrespective of locations, was recorded at site 5 (Kantha) of Baddi followed by those of site 5 (Dhatowal) of Nalagarh ( $2.13 \text{ mg kg}^{-1}$ ) and site 4 (Plankwala) of Barotiwala ( $2.11 \text{ mg kg}^{-1}$ ) during pre-monsoon season. However, during post-monsoon season highest copper content ( $2.26 \text{ mg kg}^{-1}$ ) was recorded at site 5 (Kantha) of Baddi which was found to be at par with those of site 1 (Kishanpura) of Nalagarh; site 2 (Sairajmajra Labana) of Baddi i.e.  $2.20 \text{ mg kg}^{-1}$  and site 5 (Dhatowal) of Nalagarh; site 4 (Plankwala) of Barotiwala i.e.  $2.18 \text{ mg kg}^{-1}$ , respectively. The lowest copper content ( $0.20 \text{ mg kg}^{-1}$  and  $0.28 \text{ mg kg}^{-1}$ ) amongst all the sites of three different locations was recorded at site 1 (Jharmajri) of Barotiwala during pre and post-monsoon seasons, respectively (Table 4.27).

### **Iron**

Data presented in Table 4.28 reveals that for surface soils of different locations, highest iron content of  $15.78 \text{ mg kg}^{-1}$  (pre-monsoon) and  $15.83 \text{ mg kg}^{-1}$  (post-monsoon) was recorded at Barotiwala followed by Baddi ( $15.10 \text{ mg kg}^{-1}$ ) and Nalagarh ( $14.72 \text{ mg kg}^{-1}$ ) during pre-monsoon season. The content of Fe was found to be significantly different within locations during pre-monsoon season.

The highest Fe content ( $30.18 \text{ mg kg}^{-1}$  and  $30.48 \text{ mg kg}^{-1}$ ) for surface soils of different sites in Nalagarh location was recorded at Khera during both seasons followed by Rajpura ( $28.45 \text{ mg kg}^{-1}$  and  $28.58 \text{ mg kg}^{-1}$ ) and Khroni ( $15.26 \text{ mg kg}^{-1}$  and  $15.38 \text{ mg kg}^{-1}$ ). However, lowest Fe content ( $6.96 \text{ mg kg}^{-1}$  and  $7.15 \text{ mg kg}^{-1}$ ) was recorded at Manpur during both seasons.

The surface soils of different sites in Baddi location exhibited highest Fe content ( $28.74 \text{ mg kg}^{-1}$  and  $28.81 \text{ mg kg}^{-1}$ ) at Billawali Labana during both seasons followed by Malpur ( $22.63 \text{ mg kg}^{-1}$  and  $22.78 \text{ mg kg}^{-1}$ ) and Kantha ( $15.64 \text{ mg kg}^{-1}$  and  $15.78 \text{ mg kg}^{-1}$ ). However, lowest Fe content ( $7.28 \text{ mg kg}^{-1}$  and  $7.44 \text{ mg kg}^{-1}$ ) was recorded at Billawali Gujra during both seasons.

The highest Fe content ( $29.64 \text{ mg kg}^{-1}$  and  $29.67 \text{ mg kg}^{-1}$ ) for surface soils of different sites in Barotiwala location was recorded at Plankwala during both seasons followed by Jharmajri ( $26.45 \text{ mg kg}^{-1}$  and  $26.50 \text{ mg kg}^{-1}$ ) and Panga ( $19.63 \text{ mg kg}^{-1}$  and  $19.68 \text{ mg kg}^{-1}$ ).

However, lowest Fe content of 7.37 mg kg<sup>-1</sup> (pre-monsoon) and 7.41 mg kg<sup>-1</sup> (post-monsoon) was recorded at Baurwala.

The surface soils irrespective of locations, registered highest Fe content (30.18 mg kg<sup>-1</sup> and 30.48 mg kg<sup>-1</sup>) at site 3 (Khera) of Nalagarh followed by site 4 (Plankwala) of Barotiwala (29.64 mg kg<sup>-1</sup>), site 4 (Billawali Labana) of Baddi (28.74 mg kg<sup>-1</sup>) and site 6 (Rajpura) of Nalagarh (28.45 mg kg<sup>-1</sup>) during pre-monsoon season, whileas, found to be at par with those of site 4 (Plankwala) of Barotiwala (29.67 mg kg<sup>-1</sup>), site 4 (Billawali Labana) of Baddi (28.81 mg kg<sup>-1</sup>), site 6 (Rajpura) of Nalagarh (28.58 mg kg<sup>-1</sup>) and site 1 (Jharmajri) of Barotiwala (26.50 mg kg<sup>-1</sup>) during post-monsoon season, respectively. Whereas, lowest iron content of 6.96 mg kg<sup>-1</sup> (pre-monsoon) and 7.15 mg kg<sup>-1</sup> (post-monsoon) amongst all the sites of three different locations was recorded at site 2 (Manpur) of Nalagarh.

A perusal of Table 4.28 revealed that for sub-surface soils, highest iron content of 9.70 mg kg<sup>-1</sup> (pre-monsoon) and 9.82 mg kg<sup>-1</sup> (post-monsoon) amongst the three different locations was recorded at Barotiwala followed by Nalagarh (9.59 mg kg<sup>-1</sup> and 9.70 mg kg<sup>-1</sup>). It was noticed that amongst the three different locations, lowest Fe content (9.43 mg kg<sup>-1</sup> and 9.51 mg kg<sup>-1</sup>) was recorded at Baddi during both seasons. There was significant difference in iron content of three different locations.

The data pertaining to sub-surface soils of different sites in Nalagarh location revealed that highest Fe content (20.58 mg kg<sup>-1</sup> and 20.64 mg kg<sup>-1</sup>) was recorded at Khera during both seasons followed by Rajpura (16.36 mg kg<sup>-1</sup> and 16.48 mg kg<sup>-1</sup>) and Khroni (10.11 mg kg<sup>-1</sup> and 10.25 mg kg<sup>-1</sup>). However, lowest Fe content (4.68 mg kg<sup>-1</sup> and 4.81 mg kg<sup>-1</sup>) was recorded at Manpur during both seasons.

The highest Fe content (16.41 mg kg<sup>-1</sup> and 16.48 mg kg<sup>-1</sup>) for sub-surface soils of different sites in Baddi location was recorded at Billawali Labana during both the seasons followed by Malpur (13.31 mg kg<sup>-1</sup> and 13.47 mg kg<sup>-1</sup>) and Kantha (10.36 mg kg<sup>-1</sup> and 10.51 mg kg<sup>-1</sup>). However, lowest Fe content (5.08 mg kg<sup>-1</sup> and 5.22 mg kg<sup>-1</sup>) was recorded at Billawali Gujra during both the seasons.

The sub-surface soils of different sites in Barotiwala location reveals that highest Fe content of 16.53 mg kg<sup>-1</sup> (pre-monsoon) and 16.68 mg kg<sup>-1</sup> (post-monsoon) was recorded at

**Table 4.28 Status of iron at different locations and sites**

Parameter	Fe (mg kg <sup>-1</sup> )					
Season	Pre- monsoon			Post- monsoon		
Locations (L) Site (S)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )
<b>Surface</b>						
S <sub>1</sub>	14.87	13.65	26.45	14.99	13.81	26.50
S <sub>2</sub>	6.96	8.67	8.63	7.15	8.79	8.69
S <sub>3</sub>	30.18	7.28	7.37	30.48	7.44	7.41
S <sub>4</sub>	15.26	28.74	29.64	15.38	28.81	29.67
S <sub>5</sub>	7.12	15.64	14.17	7.28	15.78	14.20
S <sub>6</sub>	28.45	14.96	13.54	28.58	15.07	13.58
S <sub>7</sub>	7.24	12.75	15.19	7.26	12.92	15.26
S <sub>8</sub>	15.09	15.14	19.63	15.23	15.21	19.68
S <sub>9</sub>	8.78	22.63	13.42	8.93	22.78	13.46
S <sub>10</sub>	13.27	11.56	9.78	13.44	11.69	9.81
<b>Mean</b>	14.72	15.10	15.78	14.87	15.23	15.83
<b>CD<sub>0.05</sub> S</b>	0.33	0.27	0.25	0.35	0.07	0.12
<b>L</b>	0.02			1.46		
<b>S x L</b>	0.07			4.60		
<b>Sub-surface</b>						
S <sub>1</sub>	9.79	8.88	15.27	9.86	8.97	15.34
S <sub>2</sub>	4.68	5.61	5.52	4.81	5.71	5.61
S <sub>3</sub>	20.58	5.08	5.13	20.64	5.22	5.22
S <sub>4</sub>	10.11	16.41	16.53	10.25	16.48	16.68
S <sub>5</sub>	4.87	10.36	9.07	4.98	10.51	9.19
S <sub>6</sub>	16.36	9.89	8.81	16.48	9.99	8.95
S <sub>7</sub>	5.04	8.21	10.07	5.16	8.35	10.18
S <sub>8</sub>	9.97	9.72	12.64	10.06	9.85	12.80
S <sub>9</sub>	5.68	13.31	8.12	5.76	13.47	8.27
S <sub>10</sub>	8.84	6.78	5.84	8.98	6.52	5.93
<b>Mean</b>	9.59	9.43	9.70	9.70	9.51	9.82
<b>CD<sub>0.05</sub> S</b>	0.27	0.25	0.24	0.62	0.18	0.10
<b>L</b>	0.02			0.10		
<b>S x L</b>	0.05			0.34		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub>– Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhubota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub>– Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwala, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

Plankwala during both seasons followed by those of Jharmajri (15.27 mg kg<sup>-1</sup> and 15.34 mg kg<sup>-1</sup>) and Panga (12.64 mg kg<sup>-1</sup> and 12.80 mg kg<sup>-1</sup>). However, lowest Fe content (5.13 mg kg<sup>-1</sup> and 5.22 mg kg<sup>-1</sup>) was recorded at Baurwala during both seasons.

The sub-surface soils irrespective of locations, registered highest iron content (20.58 mg kg<sup>-1</sup> and 20.64 mg kg<sup>-1</sup>) at site 3 (Khera) of Nalagarh followed by site 4 (Plankwala) of Barotiwala (16.53 mg kg<sup>-1</sup> and 16.68 mg kg<sup>-1</sup>), site 4 (Billawali Labana) of Baddi (16.41 mg kg<sup>-1</sup> and 16.48 mg kg<sup>-1</sup>) and site 6 (Rajpura) of Nalagarh (16.36 mg kg<sup>-1</sup> and 16.48 mg kg<sup>-1</sup>) during pre-monsoon and post-monsoon season. Whereas, lowest Fe content of 4.68 mg kg<sup>-1</sup> and 4.81 mg kg<sup>-1</sup> amongst all the sites of three different locations was recorded at site 2 (Manpur) of Nalagarh during pre and post-monsoon season, respectively. There was significant difference in iron content in sub-surface soils irrespective of three different locations during both seasons.

## **Zinc**

The data presented in Table 4.29 reveals that for surface soils highest zinc content of 1.22 mg kg<sup>-1</sup> (pre-monsoon) and 1.32 mg kg<sup>-1</sup> (post-monsoon) amongst the three different locations was recorded at Barotiwala followed by Baddi (1.11 mg kg<sup>-1</sup> and 1.20 mg kg<sup>-1</sup>).

It was noticed that amongst the three different locations, lowest Zn content (0.94 mg kg<sup>-1</sup> and 1.03 mg kg<sup>-1</sup>) was recorded at Nalagarh during both seasons. There was significant difference in zinc content of soils during both seasons in surface soils.

The highest Zn content (1.34 mg kg<sup>-1</sup>) for surface soils of different sites in Nalagarh location was recorded at Salewal which was found to be at par with Chowkiwala (1.28 mg kg<sup>-1</sup>) and Khera (1.23 mg kg<sup>-1</sup>) during pre-monsoon season. For post-monsoon season, highest Zn content (1.41 mg kg<sup>-1</sup>) was recorded in the soils of Salewal which was found to be at par with that of Chowkiwala (1.35 mg kg<sup>-1</sup>). The lowest Zn content (0.31 mg kg<sup>-1</sup> and 0.38 mg kg<sup>-1</sup>) was observed at Kishanpura for both the seasons.

The highest Zn content (1.56 mg kg<sup>-1</sup>) for surface soils of different sites in Baddi location was recorded at Sairajmajra Gujra which was found to be at par with that of Baddi site (1.46 mg kg<sup>-1</sup>) during pre-monsoon season, whereas, in post-monsoon season, highest Zn content (1.69 mg kg<sup>-1</sup>) was again recorded with Sairajmajra Gujra soils followed by Baddi

(1.58 mg kg<sup>-1</sup>) and Billawali Gujra (1.33 mg kg<sup>-1</sup>). Lowest Zn content of 0.73 mg kg<sup>-1</sup> (pre-monsoon) and 0.79 mg kg<sup>-1</sup> (post-monsoon) was recorded in the soil of Billawali Labana.

**Table 4.29 Status of zinc at different locations and sites**

Parameter	Zn (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalaa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalaa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	0.31	1.56	1.31	0.38	1.69	1.44
S <sub>2</sub>	1.12	1.07	0.82	1.18	1.14	0.97
S <sub>3</sub>	1.23	1.19	1.25	1.29	1.33	1.35
S <sub>4</sub>	0.72	0.73	1.62	0.83	0.79	1.70
S <sub>5</sub>	1.09	0.98	1.18	1.20	1.03	1.29
S <sub>6</sub>	0.56	1.00	1.51	0.65	1.08	1.59
S <sub>7</sub>	1.28	1.21	1.13	1.35	1.27	1.17
S <sub>8</sub>	1.34	1.46	1.39	1.41	1.58	1.45
S <sub>9</sub>	0.85	0.88	0.96	0.97	0.97	1.06
S <sub>10</sub>	0.93	1.03	1.07	1.02	1.09	1.13
<b>Mean</b>	0.94	1.11	1.22	1.03	1.20	1.32
<b>CD<sub>0.05</sub> S</b>	0.15	0.14	0.13	0.06	0.06	0.07
<b>L</b>	0.02			0.02		
<b>S x L</b>	0.05			0.06		
<b>Sub-surface</b>						
S <sub>1</sub>	0.18	1.17	0.76	0.29	1.22	0.88
S <sub>2</sub>	0.97	0.81	0.51	1.08	0.88	0.57
S <sub>3</sub>	1.02	0.84	0.95	1.11	0.94	0.99
S <sub>4</sub>	0.54	0.46	1.14	0.68	0.58	1.25
S <sub>5</sub>	0.89	0.53	0.80	0.97	0.62	0.89
S <sub>6</sub>	0.38	0.72	1.16	0.54	0.78	1.22
S <sub>7</sub>	1.07	0.87	0.74	1.16	0.98	0.80
S <sub>8</sub>	1.12	1.05	0.91	1.24	1.17	1.06
S <sub>9</sub>	0.69	0.41	0.39	0.74	0.47	0.45
S <sub>10</sub>	0.76	0.78	0.68	0.88	0.85	0.82
<b>Mean</b>	0.76	0.75	0.80	0.87	0.85	0.89
<b>CD<sub>0.05</sub> S</b>	0.13	0.14	0.14	0.09	0.05	0.07
<b>L</b>	0.01			0.01		
<b>S x L</b>	0.03			0.06		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub> – Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhbota and L<sub>1</sub>S<sub>10</sub> – Bhatiyaa

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub> – Juddi Khurd, L<sub>2</sub>S<sub>8</sub> – Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalaa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

The available Zn content for surface soils of different sites in Barotiwala exhibited highest Zn content ( $1.62 \text{ mg kg}^{-1}$ ) at Plankwala which was found to be at par with Barotiwala ( $1.51 \text{ mg kg}^{-1}$ ) during pre-monsoon season. For post-monsoon season, highest Zn content ( $1.70 \text{ mg kg}^{-1}$ ) was also recorded at Plankwala followed by Barotiwala ( $1.59 \text{ mg kg}^{-1}$ ) and Panga ( $1.45 \text{ mg kg}^{-1}$ ). The lowest Zn content ( $0.82 \text{ mg kg}^{-1}$  and  $0.97 \text{ mg kg}^{-1}$ ) was observed at Bated for both the seasons.

The surface soils irrespective of locations during pre-monsoon season, registered highest zinc content ( $1.62 \text{ mg kg}^{-1}$ ) at site 4 (Plankwala) of Barotiwala, followed by site 1 (Sairajmajra Gujra) of Baddi ( $1.56 \text{ mg kg}^{-1}$ ) and site 6 (Barotiwala) of Barotiwala ( $1.51 \text{ mg kg}^{-1}$ ). However, during post-monsoon season highest zinc content ( $1.70 \text{ mg kg}^{-1}$ ) was recorded at site 4 (Plankwala) of Barotiwala which was found to be at par with those of site 1 (Sairajmajra Gujra) of Baddi ( $1.69 \text{ mg kg}^{-1}$ ). Whereas, lowest zinc content ( $0.31 \text{ mg kg}^{-1}$  and  $0.38 \text{ mg kg}^{-1}$ ) amongst all the sites of three different locations was recorded at site 1 (Kishanpura) of Nalagarh during both seasons.

Data presented in Table 4.29 reveals that highest zinc content of  $0.80 \text{ mg kg}^{-1}$  (pre-monsoon) and  $0.89 \text{ mg kg}^{-1}$  (post-monsoon) amongst the three different locations was recorded in the sub-surface soils of Barotiwala followed by Nalagarh ( $0.76 \text{ mg kg}^{-1}$  and  $0.87 \text{ mg kg}^{-1}$ ). It was also noticed that amongst the three different locations lowest zinc content ( $0.75 \text{ mg kg}^{-1}$  and  $0.85 \text{ mg kg}^{-1}$ ) was recorded at Baddi during both seasons. There was no significant difference in the Zn content of Nalagarh and Baddi soils during pre-monsoon season.

Sub-surface soils of different sites in Nalagarh location exhibited highest Zn content ( $1.12 \text{ mg kg}^{-1}$ ) at Salewal, which was found to be at par with those of Chowkiwala ( $1.07 \text{ mg kg}^{-1}$ ) and Khera ( $1.02 \text{ mg kg}^{-1}$ ) during pre-monsoon season. Whereas, during post-monsoon season, highest Zn content ( $1.24 \text{ mg kg}^{-1}$ ) was also recorded at Salewal and found to be at par with that of Chowkiwala ( $1.16 \text{ mg kg}^{-1}$ ). The lowest Zn content ( $0.18 \text{ mg kg}^{-1}$  and  $0.29 \text{ mg kg}^{-1}$ ) was recorded at Kishanpura during both the seasons.

The sub-surface soils of different sites in Baddi location exhibited highest Zn content of  $1.17 \text{ mg kg}^{-1}$  (pre-monsoon) and  $1.22 \text{ mg kg}^{-1}$  (post-monsoon) in Sairajmajra Gujra soil which was found to be at par with that of Baddi site ( $1.05 \text{ mg kg}^{-1}$  and  $1.17 \text{ mg kg}^{-1}$ ). The

lowest Zn content ( $0.41 \text{ mg kg}^{-1}$  and  $0.47 \text{ mg kg}^{-1}$ ) was recorded at Malpur during pre and post-monsoon seasons, respectively.

Sub-surface soils of different sites in Barotiwala location recorded highest Zn content ( $1.16 \text{ mg kg}^{-1}$ ) at Barotiwala which was found to be at par with that of Plankwala ( $1.14 \text{ mg kg}^{-1}$ ) during pre-monsoon season, whereas, during post-monsoon season, highest Zn content ( $1.25 \text{ mg kg}^{-1}$ ) was recorded at Plankwala which was found to be at par with Barotiwala ( $1.22 \text{ mg kg}^{-1}$ ). The lowest Zn content ( $0.39 \text{ mg kg}^{-1}$  and  $0.45 \text{ mg kg}^{-1}$ ) was recorded in Kuranwala soil during both the seasons.

The highest zinc content  $1.17 \text{ mg kg}^{-1}$  irrespective of locations, was recorded at site 1 (Sairajmajra Gujra) of Baddi, which was found to be at par with those of site 6 (Barotiwala) of Barotiwala ( $1.16 \text{ mg kg}^{-1}$ ) and site 4 (Plankwala) of Barotiwala ( $1.14 \text{ mg kg}^{-1}$ ) during premonsoon season. During post-monsoon season, highest zinc content ( $1.25 \text{ mg kg}^{-1}$ ) was recorded at site 4 (Plankwala) of Barotiwala, which was found to be at par with those of site 6 (Barotiwala) of Barotiwala ( $1.22 \text{ mg kg}^{-1}$ ) and site 1 (Sairajmajra Gujra) of Baddi ( $1.22 \text{ mg kg}^{-1}$ ), whereas, lowest zinc content of  $0.18 \text{ mg kg}^{-1}$  (pre-monsoon) and  $0.29 \text{ mg kg}^{-1}$  (post-monsoon) amongst all the sites of three different locations was recorded at site 1 (Kishanpura) of Nalagarh.

## **Lead**

A perusal of Table 4.30 reveals that for surface soils, highest lead content of  $1.16 \text{ mg kg}^{-1}$  (pre-monsoon) and  $1.20 \text{ mg kg}^{-1}$  (post-monsoon) amongst the three different locations was recorded at Baddi followed by Barotiwala ( $1.06 \text{ mg kg}^{-1}$  and  $1.11 \text{ mg kg}^{-1}$ ). It was noticed that amongst the three different locations, lowest lead content in pre-monsoon ( $0.97 \text{ mg kg}^{-1}$ ) and post-monsoon ( $1.02 \text{ mg kg}^{-1}$ ) was recorded at Nalagarh. There was significant difference in the lead content within the locations during pre and post-monsoon season.

The highest lead content ( $1.91 \text{ mg kg}^{-1}$ ) for surface soils of different sites in Nalagarh location was recorded at Rajpura during pre-monsoon season followed by Chowkiwala ( $1.41 \text{ mg kg}^{-1}$ ) and Salewal ( $1.21 \text{ mg kg}^{-1}$ ). Likewise, during post-monsoon season, highest lead content ( $1.96 \text{ mg kg}^{-1}$ ) was also recorded in Rajpura soil followed by Chowkiwala ( $1.46 \text{ mg}$

kg<sup>-1</sup>). It was noticed that lowest lead content of 0.46 mg kg<sup>-1</sup> (pre-monsoon) and 0.50 mg kg<sup>-1</sup> (post-monsoon) was recorded in the soils of Khera.

The surface soils of different sites in Baddi location registered highest lead content (2.18 mg kg<sup>-1</sup>) in Juddi Kalan soil during pre-monsoon season followed by Sairajmajra Gujra (1.53 mg kg<sup>-1</sup>) and Juddi Khurd (1.26 mg kg<sup>-1</sup>). Likewise, during post-monsoon season, highest lead content (2.19 mg kg<sup>-1</sup>) was also recorded at Juddi Kalan followed by Sairajmajra Gujra (1.57 mg kg<sup>-1</sup>) and Juddi Khurd (1.29 mg kg<sup>-1</sup>). However, lowest lead content (0.67 mg kg<sup>-1</sup> and 0.75 mg kg<sup>-1</sup>) was recorded at Baddi for both seasons.

The highest lead content of 1.85 mg kg<sup>-1</sup> (pre-monsoon) and 1.88 mg kg<sup>-1</sup> (post-monsoon) for surface soils of different sites in Barotiwala location was recorded at Plankwala followed by Barotiwala (1.43 mg kg<sup>-1</sup> and 1.52 mg kg<sup>-1</sup>) and Baurawala (1.08 mg kg<sup>-1</sup> and 1.14 mg kg<sup>-1</sup>). Whileas, lowest lead content (0.79 mg kg<sup>-1</sup> and 0.83 mg kg<sup>-1</sup>) was recorded at Sattiwala for both seasons.

During pre and post-monsoon seasons, the surface soils irrespective of locations, recorded highest lead content (2.18 mg kg<sup>-1</sup> and 2.19 mg kg<sup>-1</sup>) at site 6 (Juddi Kalan) of Baddi, followed by site 6 (Rajpura) of Nalagarh (1.91 mg kg<sup>-1</sup> and 1.96 mg kg<sup>-1</sup>), site 4 (Plankwala) of Barotiwala (1.85 mg kg<sup>-1</sup> and 1.88 mg kg<sup>-1</sup>) and site 1 (Sairajmajra Gujra) of Baddi (1.53 mg kg<sup>-1</sup> and 1.57 mg kg<sup>-1</sup>), respectively. Whereas, lowest lead content of 0.46 mg kg<sup>-1</sup> and 0.50 mg kg<sup>-1</sup> amongst all the sites of three different locations was recorded at site 3 (Khera) of Nalagarh during pre and post-monsoon season, respectively.

Data presented in Table 4.30 reveals that for sub-surface soils, highest lead content of 0.85 mg kg<sup>-1</sup> and 0.90 mg kg<sup>-1</sup> amongst the three different locations was recorded at Baddi followed by Barotiwala (0.67 mg kg<sup>-1</sup> and 0.72 mg kg<sup>-1</sup>) during pre and post-monsoon seasons, respectively. It was noticed that amongst the three different locations lowest lead content of 0.56 mg kg<sup>-1</sup> and 0.62 mg kg<sup>-1</sup> was recorded at Nalagarh during pre and post-monsoon seasons, respectively. There was significant difference in Pb content within locations during pre and post-monsoon season.

The highest lead content of 1.24 mg kg<sup>-1</sup> (pre-monsoon) and 1.29 mg kg<sup>-1</sup> (post-monsoon) for sub-surface soils of different sites in Nalagarh location was recorded at Rajpura

followed by those of Chowkiwala (1.02 mg kg<sup>-1</sup> and 1.08 mg kg<sup>-1</sup>) and Salewal (0.84 mg kg<sup>-1</sup> and 0.91 mg kg<sup>-1</sup>). The lowest lead content of 0.19 mg kg<sup>-1</sup> (pre-monsoon) and 0.23 mg kg<sup>-1</sup> (pre-monsoon) was recorded in Khera soils.

**Table 4.30 Status of lead at different locations and sites**

Parameter	Pb (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season	Pre- monsoon			Post- monsoon		
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	0.78	1.53	0.81	0.84	1.57	0.86
S <sub>2</sub>	0.53	1.11	0.93	0.56	1.16	0.97
S <sub>3</sub>	0.46	0.91	1.08	0.50	0.94	1.14
S <sub>4</sub>	0.74	1.15	1.85	0.78	1.18	1.88
S <sub>5</sub>	0.91	1.04	1.06	0.96	1.10	1.09
S <sub>6</sub>	1.91	2.18	1.43	1.96	2.19	1.52
S <sub>7</sub>	1.41	1.26	0.79	1.46	1.29	0.83
S <sub>8</sub>	1.21	0.67	0.83	1.28	0.75	0.88
S <sub>9</sub>	1.13	0.71	0.88	1.19	0.79	0.94
S <sub>10</sub>	0.61	0.99	0.97	0.69	1.04	1.03
<b>Mean</b>	0.97	1.16	1.06	1.02	1.20	1.11
<b>CD<sub>0.05</sub> S</b>	0.13	0.11	0.13	0.05	0.05	0.05
<b>L</b>	0.01			0.01		
<b>S x L</b>	0.03			0.04		
<b>Sub-surface</b>						
S <sub>1</sub>	0.38	1.07	0.36	0.43	1.09	0.44
S <sub>2</sub>	0.21	0.82	0.51	0.24	0.87	0.57
S <sub>3</sub>	0.19	0.69	0.58	0.23	0.76	0.61
S <sub>4</sub>	0.33	0.89	1.57	0.38	0.93	1.63
S <sub>5</sub>	0.50	0.72	0.60	0.59	0.78	0.68
S <sub>6</sub>	1.24	1.69	1.29	1.29	1.71	1.33
S <sub>7</sub>	1.02	0.94	0.34	1.08	0.98	0.39
S <sub>8</sub>	0.84	0.42	0.41	0.91	0.46	0.47
S <sub>9</sub>	0.63	0.48	0.45	0.75	0.54	0.49
S <sub>10</sub>	0.27	0.76	0.56	0.30	0.84	0.64
<b>Mean</b>	0.56	0.85	0.67	0.62	0.90	0.72
<b>CD<sub>0.05</sub> S</b>	0.12	0.13	0.13	0.04	0.06	0.05
<b>L</b>	0.01			0.01		
<b>S x L</b>	0.03			0.04		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub>– Chowkiwala, L<sub>1</sub>S<sub>8</sub>– Salewal, L<sub>1</sub>S<sub>9</sub>– Dhubota and L<sub>1</sub>S<sub>10</sub>– Bhatiyana

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub>– Juddi Khurd, L<sub>2</sub>S<sub>8</sub>– Baddi, L<sub>2</sub>S<sub>9</sub>– Malpur and L<sub>2</sub>S<sub>10</sub>–Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub>– Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub>– Kunjhal

The sub-surface soils of different sites in Baddi location registered highest lead content of 1.69 mg kg<sup>-1</sup> (pre-monsoon) and 1.71 mg kg<sup>-1</sup> (pre-monsoon) at Juddi Kalan followed by Sairajmajra Gujra (1.07 mg kg<sup>-1</sup> and 1.09 mg kg<sup>-1</sup>) and Juddi Khurd (0.94 mg kg<sup>-1</sup> and 0.98 mg kg<sup>-1</sup>). It was noticed that lowest lead content (0.42 mg kg<sup>-1</sup> and 0.46 mg kg<sup>-1</sup>) was recorded at Baddi for both seasons.

During pre and post-monsoon seasons, the highest lead content of 1.57 mg kg<sup>-1</sup> and 1.63 mg kg<sup>-1</sup> for sub-surface soils of different sites in Barotiwala location was recorded at Plankwala, followed by those of Barotiwala (1.29 mg kg<sup>-1</sup> and 1.33 mg kg<sup>-1</sup>) and Sainsiwala (0.60 mg kg<sup>-1</sup> and 0.68 mg kg<sup>-1</sup>). However, lowest lead content of 0.34 mg kg<sup>-1</sup> and 0.39 mg kg<sup>-1</sup> was recorded in Sattiwala soil for pre and post-monsoon season, respectively.

The highest lead content (1.69 mg kg<sup>-1</sup> and 1.71 mg kg<sup>-1</sup>) irrespective of locations, was recorded at site 6 (Juddi Kalan) of Baddi, followed by site 4 (Plankwala) of Barotiwala (1.57 mg kg<sup>-1</sup> and 1.63 mg kg<sup>-1</sup>) and site 6 (Barotiwala) of Barotiwala (1.29 mg kg<sup>-1</sup> and 1.33 mg kg<sup>-1</sup>) during pre and post-monsoon seasons, whereas, lowest lead content of 0.19 mg kg<sup>-1</sup> and 0.23 mg kg<sup>-1</sup> amongst the sites of three different locations was recorded at site 3 (Khera) of Nalagarh during pre and post-monsoon season, respectively.

## **Nickel**

Data presented in Table 4.31 reveals that for surface soils, highest nickel content of 0.45 mg kg<sup>-1</sup> and 0.52 mg kg<sup>-1</sup> was recorded at Barotiwala followed by Nalagarh (0.35 mg kg<sup>-1</sup> and 0.42 mg kg<sup>-1</sup>) amongst the three different locations during pre and post-monsoon seasons. It was noticed that amongst the three different locations lowest nickel content (0.26 mg kg<sup>-1</sup> and 0.29 mg kg<sup>-1</sup>) was recorded each at Baddi during both seasons. There was significant difference in the nickel content within locations during pre and post-monsoon season.

The highest nickel content (0.54 mg kg<sup>-1</sup>) for surface soils in different sites in Nalagarh location was registered in Dhatowal during pre-monsoon season which was found to be at par with those of Chowkiwala (0.48 mg kg<sup>-1</sup>) and Manpur (0.45 mg kg<sup>-1</sup>). For post-monsoon season, highest nickel content (0.56 mg kg<sup>-1</sup>) was also recorded at Dhatowal which was found to be at par with those of Chowkiwala (0.55 mg kg<sup>-1</sup>) and Salewal (0.51 mg kg<sup>-1</sup>).

However, lowest nickel content of 0.19 mg kg<sup>-1</sup> (pre-monsoon) and 0.23 mg kg<sup>-1</sup> (pre-monsoon) was recorded at Kishanpura.

The surface soils of different sites in Baddi location registered highest nickel content (0.42 mg kg<sup>-1</sup>) at Juddi Kalan, which was found to be at par with those of Billawali Gujra (0.36 mg kg<sup>-1</sup>) and Gularwala (0.33 mg kg<sup>-1</sup>) for pre-monsoon season. During post-monsoon season, highest nickel content (0.47 mg kg<sup>-1</sup>) was observed at Juddi Kalan which was found to be at par with that of Billawali Gujra (0.41 mg kg<sup>-1</sup>). Lowest nickel content (0.09 mg kg<sup>-1</sup> and 0.16 mg kg<sup>-1</sup>) was found at Sairajmajra Gujra during both the seasons.

The highest nickel content of 0.62 mg kg<sup>-1</sup> for surface soils in different sites of Barotiwala location was observed at Barotiwala site which was found to be at par with those of Plankwala (0.60 mg kg<sup>-1</sup>) and Jharmajri (0.56 mg kg<sup>-1</sup>) during pre-monsoon season. During post-monsoon season, highest nickel content (0.65 mg kg<sup>-1</sup>) was observed at Barotiwala which was found to be at par with those of Plankwala (0.64 mg kg<sup>-1</sup>), Jharmajri (0.63 mg kg<sup>-1</sup>), Sattiwala (0.59 mg kg<sup>-1</sup>) and Kuranwala (0.59 mg kg<sup>-1</sup>). However, lowest nickel content of 0.28 mg kg<sup>-1</sup> (pre-monsoon) and 0.37 mg kg<sup>-1</sup> (post-monsoon) was registered in the soils of Baurawala.

The surface soils, irrespective of locations, during both seasons, registered highest nickel content (0.62 mg kg<sup>-1</sup> and 0.65 mg kg<sup>-1</sup>) at site 6 (Barotiwala) of Barotiwala, which was found to be at par with those of site 4 (Plankwala) of Barotiwala (0.60 mg kg<sup>-1</sup> and 0.64 mg kg<sup>-1</sup>). However, during post-monsoon season it was also found to be at par with those of site 1 (Jharmajri) of Barotiwala (0.63 mg kg<sup>-1</sup>) and site 9 (Kuranwala) of Barotiwala (0.59 mg kg<sup>-1</sup>), whereas, lowest nickel content (0.09 mg kg<sup>-1</sup> and 0.16 mg kg<sup>-1</sup>) amongst all the sites of three different locations was recorded at site 1 (Sairajmajra Gujra) of Baddi during pre and post-monsoon season, respectively (Table 4.31).

A perusal of Table 4.31 reveals that for sub-surface soils during pre-monsoon season, highest nickel content of 0.23 mg kg<sup>-1</sup> was recorded at Barotiwala followed by Baddi (0.18 mg kg<sup>-1</sup>) and lowest was recorded at Nalagarh (0.16 mg kg<sup>-1</sup>) amongst the three different locations. However, during post-monsoon season, highest nickel content (0.31 mg kg<sup>-1</sup>) amongst the three different locations was recorded at Nalagarh, which was found to be at par with those of Barotiwala (0.29 mg kg<sup>-1</sup>) and lowest (0.23 mg kg<sup>-1</sup>) was recorded at Baddi.

The highest nickel content ( $0.31 \text{ mg kg}^{-1}$ ) for sub-surface soils of different sites in Nalagarh location was recorded at Dhatowal for pre-monsoon season which was found to be at par with those of Chowkiwala ( $0.26 \text{ mg kg}^{-1}$ ) and Manpur ( $0.21 \text{ mg kg}^{-1}$ ). For post-monsoon season, highest nickel content ( $0.35 \text{ mg kg}^{-1}$ ) was recorded in Chowkiwala soil which was found to be at par with that of Dhatowal ( $0.34 \text{ mg kg}^{-1}$ ). The lowest nickel content of  $0.05 \text{ mg kg}^{-1}$  (pre-monsoon) and  $0.10 \text{ mg kg}^{-1}$  (post-monsoon) was found at Kishanpura during pre and post-monsoon season, respectively.

Sub-surface soils of different sites in Baddi location exhibited highest nickel content of  $0.39 \text{ mg kg}^{-1}$  (pre-monsoon) and  $0.44 \text{ mg kg}^{-1}$  (post-monsoon) at Juddi Kalan which was found to be at par with soils of Billawali Gujra ( $0.32 \text{ mg kg}^{-1}$  and  $0.39 \text{ mg kg}^{-1}$ ). It was observed that during both seasons lowest nickel content ( $0.06 \text{ mg kg}^{-1}$  and  $0.11 \text{ mg kg}^{-1}$ ) was recorded at Sairajmajra.

The sub-surface soils of different sites in Barotiwala location reveals that highest nickel content ( $0.44 \text{ mg kg}^{-1}$  and  $0.52 \text{ mg kg}^{-1}$ ) was observed at Plankwala which was found to be at par with those of Jharmajri ( $0.36 \text{ mg kg}^{-1}$  and  $0.48 \text{ mg kg}^{-1}$ ) during both seasons. Whileas, lowest nickel content ( $0.11 \text{ mg kg}^{-1}$  and  $0.13 \text{ mg kg}^{-1}$ ) was observed at Panga for both seasons.

The sub-surface soils irrespective of locations, registered highest nickel content ( $0.44 \text{ mg kg}^{-1}$ ) at site 4 (Plankwala) of Barotiwala, followed by site 6 (Juddi Kalan) of Baddi ( $0.39 \text{ mg kg}^{-1}$ ), site 6 (Barotiwala) of Barotiwala ( $0.37 \text{ mg kg}^{-1}$ ) and site 1 (Jharmajri) of Barotiwala ( $0.36 \text{ mg kg}^{-1}$ ) during pre-monsoon season. The highest value during post-monsoon season was also recorded at site 4 (Plankwala) of Barotiwala ( $0.52 \text{ mg kg}^{-1}$ ) which was found to be at par with that of site 1 (Jharmajri) of Barotiwala ( $0.48 \text{ mg kg}^{-1}$ ). Whereas, lowest nickel content of  $0.05 \text{ mg kg}^{-1}$  and  $0.10 \text{ mg kg}^{-1}$  was recorded in the soils of site1(Kishanpura) of Nalagarh amongst all the sites of three different locations during pre and post-monsoon season, respectively.

**Table 4.31 Status of nickel at different locations and sites**

Parameter	Ni (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwalwa (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	0.19	0.09	0.56	0.23	0.16	0.63
S <sub>2</sub>	0.45	0.12	0.40	0.48	0.23	0.46
S <sub>3</sub>	0.34	0.36	0.28	0.40	0.41	0.37
S <sub>4</sub>	0.23	0.15	0.60	0.30	0.17	0.64
S <sub>5</sub>	0.54	0.21	0.42	0.56	0.38	0.49
S <sub>6</sub>	0.37	0.42	0.62	0.39	0.47	0.65
S <sub>7</sub>	0.48	0.13	0.47	0.55	0.18	0.59
S <sub>8</sub>	0.41	0.25	0.30	0.51	0.29	0.38
S <sub>9</sub>	0.31	0.19	0.52	0.45	0.24	0.59
S <sub>10</sub>	0.20	0.33	0.35	0.27	0.36	0.39
<b>Mean</b>	0.19	0.26	0.25	0.42	0.29	0.52
<b>CD<sub>0.05</sub> S</b>	0.10	0.09	0.09	0.06	0.06	0.13
<b>L</b>	0.01			0.03		
<b>S x L</b>	0.03			0.08		
<b>Sub-surface</b>						
S <sub>1</sub>	0.05	0.06	0.36	0.10	0.11	0.48
S <sub>2</sub>	0.21	0.08	0.16	0.23	0.14	0.19
S <sub>3</sub>	0.15	0.32	0.12	0.22	0.39	0.26
S <sub>4</sub>	0.09	0.11	0.44	0.14	0.15	0.52
S <sub>5</sub>	0.31	0.14	0.13	0.34	0.18	0.19
S <sub>6</sub>	0.12	0.39	0.37	0.18	0.44	0.41
S <sub>7</sub>	0.26	0.10	0.22	0.35	0.14	0.27
S <sub>8</sub>	0.19	0.18	0.11	0.25	0.26	0.13
S <sub>9</sub>	0.13	0.17	0.23	0.18	0.22	0.29
S <sub>10</sub>	0.07	0.29	0.15	1.13	0.31	0.21
<b>Mean</b>	0.16	0.18	0.23	0.31	0.23	0.29
<b>CD<sub>0.05</sub> S</b>	0.09	0.09	0.08	0.03	0.04	0.04
<b>L</b>	0.01			0.03		
<b>S x L</b>	0.03			0.05		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub>– Chowkiwala, L<sub>1</sub>S<sub>8</sub>– Salewal, L<sub>1</sub>S<sub>9</sub>– Dhбота and L<sub>1</sub>S<sub>10</sub>– Bhatiyana

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub>– Juddi Khurd, L<sub>2</sub>S<sub>8</sub>– Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub>–Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwalwa, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

### **Cadmium**

The data presented in the Table 4.32 represented the status of cadmium content for both surface and sub-surface soils during pre-monsoon and post-monsoon seasons at different locations and sites. Data reveals that for surface and sub-surface soils during pre-monsoon

season, average content of cadmium ranged from 1.01 mg kg<sup>-1</sup> to 1.03 mg kg<sup>-1</sup> amongst the three different locations. Highest cadmium content (1.09 mg kg<sup>-1</sup>) was recorded at site 7 (Sattiwala) of Barotiwala in surface soils. However, highest content of Cd (1.05 mg kg<sup>-1</sup>) in sub-surface soils during pre-monsoon season was recorded at site 7 (Sattiwala) of Barotiwala and site 4 (Billawali Labana) of Baddi. There was no significant difference in Cd content of surface soils within locations during pre-monsoon season.

Data presented in Table 4.32 revealed that in surface and sub-surface soils during post-monsoon season highest cadmium content of 0.09 mg kg<sup>-1</sup> and 0.08 mg kg<sup>-1</sup> was recorded at Baddi, respectively followed by Nalagarh and Barotiwala. Further, surface and sub-surface soils, irrespective of locations, registered highest cadmium content (0.21 mg kg<sup>-1</sup> and 0.14 mg kg<sup>-1</sup>) at site 7 (Sattiwala) of Barotiwala. Whereas, lowest cadmium content of 0.02 mg kg<sup>-1</sup> was observed amongst various sites of different locations during post-monsoon season irrespective of depth of the soil.

The highest cadmium content of 0.15 mg kg<sup>-1</sup> (pre-monsoon) and 0.17 mg kg<sup>-1</sup> (post-monsoon) was recorded at Bhatiyar for surface soils of different sites in Nalagarh location followed by Dhatowal (0.13 mg kg<sup>-1</sup> and 0.16 mg kg<sup>-1</sup>). It was noticed that lowest cadmium content was recorded at Kishanpura (0.03 mg kg<sup>-1</sup>) and Manpur (0.02 mg kg<sup>-1</sup>) during pre and post-monsoon season, respectively. During pre-monsoon season, cadmium was not detectable in surface soils of Manpur, Khroni, Chowkiwala and Salewal.

The surface soils of different sites in Baddi location exhibited highest cadmium content (0.16 mg kg<sup>-1</sup>) at Billawalli Labana during pre-monsoon season followed by Malpur (0.14 mg kg<sup>-1</sup>) and Kantha (0.13 mg kg<sup>-1</sup>). Whereas, during post-monsoon season, highest cadmium content (0.17 mg kg<sup>-1</sup>) was recorded at Billawalli Labana followed by Malpur (0.16 mg kg<sup>-1</sup>), Kantha (0.13 mg kg<sup>-1</sup>), Baddi (0.13 mg kg<sup>-1</sup>) and Gularwala (0.13 mg kg<sup>-1</sup>). It was noticed that lowest cadmium content (0.07 mg kg<sup>-1</sup>) was recorded at Juddi Khurd during pre-monsoon season and at Sairajmajra Gujra and Sairajmajra Labana, i.e. (0.02 mg kg<sup>-1</sup>) during post-monsoon season. Cadmium content was not detectable in surface soils of Sairajmajra Gujra, Sairajmajra Labana, Billawalli Gujra and Juddi Kalan during pre-monsoon season.

The highest cadmium content of 0.19 mg kg<sup>-1</sup> (pre-monsoon) and 0.21 mg kg<sup>-1</sup> (post-monsoon) was recorded at Sattiwala for surface soils of different sites in Barotiwala location

followed by Kuranwala (0.17 mg kg<sup>-1</sup> and 0.13 mg kg<sup>-1</sup>) and Baurawala (0.15 mg kg<sup>-1</sup> and 0.18 mg kg<sup>-1</sup>). Whileas, lowest cadmium content (0.03 mg kg<sup>-1</sup>) was recorded at Kunjhal

**Table 4.32 Status of cadmium at different locations and sites**

Parameter	Cd (mg kg <sup>-1</sup> )					
	Pre- monsoon			Post- monsoon		
Season						
Locations (L)	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )	Nalagarh (L <sub>1</sub> )	Baddi (L <sub>2</sub> )	Barotiwala (L <sub>3</sub> )
Site (S)						
<b>Surface</b>						
S <sub>1</sub>	0.03(1.02)	0.00(1.00)	0.04(1.02)	0.05	0.02	0.05
S <sub>2</sub>	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.02	0.02	0.03
S <sub>3</sub>	0.11(1.05)	0.00(1.00)	0.15(1.07)	0.09	0.04	0.18
S <sub>4</sub>	0.00(1.00)	0.16(1.08)	0.00(1.00)	0.03	0.17	0.00
S <sub>5</sub>	0.13(1.06)	0.13(1.06)	0.00(1.00)	0.16	0.13	0.04
S <sub>6</sub>	0.09(1.04)	0.00(1.00)	0.00(1.00)	0.11	0.08	0.05
S <sub>7</sub>	0.00(1.00)	0.07(1.03)	0.19(1.09)	0.02	0.03	0.21
S <sub>8</sub>	0.00(1.00)	0.09(1.04)	0.00(1.00)	0.04	0.13	0.03
S <sub>9</sub>	0.06(1.03)	0.14(1.06)	0.17(1.08)	0.09	0.16	0.13
S <sub>10</sub>	0.15(1.07)	0.10(1.05)	0.03(1.02)	0.17	0.13	0.07
<b>Mean</b>	0.06(1.03)	0.07(1.03)	0.06(1.03)	0.08	0.09	0.07
<b>CD<sub>0.05</sub> S</b>	NS	NS	NS	0.05	0.04	0.08
<b>L</b>	NS			0.04		
<b>S x L</b>	0.02			0.06		
<b>Sub-surface</b>						
S <sub>1</sub>	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.02	0.03	0.02
S <sub>2</sub>	0.00(1.00)	0.00(1.00)	0.00(1.00)	0.04	0.03	0.04
S <sub>3</sub>	0.02(1.01)	0.00(1.00)	0.06(1.03)	0.05	0.05	0.09
S <sub>4</sub>	0.00(1.00)	0.10(1.05)	0.00(1.00)	0.03	0.14	0.00
S <sub>5</sub>	0.06(1.03)	0.07(1.03)	0.00(1.00)	0.09	0.09	0.03
S <sub>6</sub>	0.04(1.02)	0.00(1.00)	0.00(1.00)	0.06	0.04	0.03
S <sub>7</sub>	0.00(1.00)	0.05(1.02)	0.11(1.05)	0.02	0.09	0.14
S <sub>8</sub>	0.00(1.00)	0.09(1.04)	0.00(1.00)	0.03	0.14	0.00
S <sub>9</sub>	0.00(1.00)	0.06(1.03)	0.08(1.04)	0.02	0.09	0.13
S <sub>10</sub>	0.08(1.04)	0.03(1.02)	0.00(1.00)	0.11	0.07	0.03
<b>Mean</b>	0.02(1.01)	0.04(1.02)	0.03(1.01)	0.05	0.08	0.05
<b>CD<sub>0.05</sub> S</b>	NS	NS	NS	0.05	0.03	0.02
<b>L</b>	0.01			0.03		
<b>S x L</b>	0.02			0.05		

L<sub>1</sub>S<sub>1</sub> – Kishanpura, L<sub>1</sub>S<sub>2</sub> – Manpur, L<sub>1</sub>S<sub>3</sub> – Khera, L<sub>1</sub>S<sub>4</sub> – Khroni, L<sub>1</sub>S<sub>5</sub> – Dhatowal, L<sub>1</sub>S<sub>6</sub> –Rajpura, L<sub>1</sub>S<sub>7</sub>– Chowkiwala, L<sub>1</sub>S<sub>8</sub> – Salewal, L<sub>1</sub>S<sub>9</sub> – Dhbota and L<sub>1</sub>S<sub>10</sub> – Bhatiyani

L<sub>2</sub>S<sub>1</sub> – Sairajmajra Gujra, L<sub>2</sub>S<sub>2</sub> – Sairajmajra Labana, L<sub>2</sub>S<sub>3</sub> – Billawali Gujra, L<sub>2</sub>S<sub>4</sub> – Billawali Labana, L<sub>2</sub>S<sub>5</sub> – Kantha, L<sub>2</sub>S<sub>6</sub> – Juddi Kalan, L<sub>2</sub>S<sub>7</sub>– Juddi Khurd, L<sub>2</sub>S<sub>8</sub>– Baddi, L<sub>2</sub>S<sub>9</sub> – Malpur and L<sub>2</sub>S<sub>10</sub> –Gularwala

L<sub>3</sub>S<sub>1</sub> – Jharmajri, L<sub>3</sub>S<sub>2</sub> – Bated, L<sub>3</sub>S<sub>3</sub> – Baurawala, L<sub>3</sub>S<sub>4</sub> – Plankwala, L<sub>3</sub>S<sub>5</sub> – Sainsiwala, L<sub>3</sub>S<sub>6</sub> – Barotiwala, L<sub>3</sub>S<sub>7</sub> – Sattiwala, L<sub>3</sub>S<sub>8</sub> – Panga, L<sub>3</sub>S<sub>9</sub> – Kuranwala and L<sub>3</sub>S<sub>10</sub> – Kunjhal

\*Values in parentheses are square root transformed values.

during pre-monsoon season and at Bated and Panga i.e. ( $0.03 \text{ mg kg}^{-1}$ ) during post-monsoon season. The cadmium was not detectable in surface soils of Bated, Plankwala, Sainsiwala, Barotiwala and Panga during pre-monsoon season.

The highest cadmium content of  $0.08 \text{ mg kg}^{-1}$  (pre-monsoon) and  $0.11 \text{ mg kg}^{-1}$  (post-monsoon) for sub-surface soils of different sites in Nalagarh location was recorded at Bhatiyan followed by Dhatowal ( $0.06 \text{ mg kg}^{-1}$  and  $0.09 \text{ mg kg}^{-1}$ ) and Rajpura ( $0.04 \text{ mg kg}^{-1}$  and  $0.06 \text{ mg kg}^{-1}$ ). The lowest cadmium content ( $0.02 \text{ mg kg}^{-1}$ ) was recorded at Khera during pre-monsoon season and at Kishanpura, Dhbotra and Chowkiwala i.e. ( $0.02 \text{ mg kg}^{-1}$ ) during post-monsoon season. During pre-monsoon season, cadmium was not detectable in sub-surface soils of Kishanpura, Manpur, Khroni, Chowkiwala Salewal and Dhbotra.

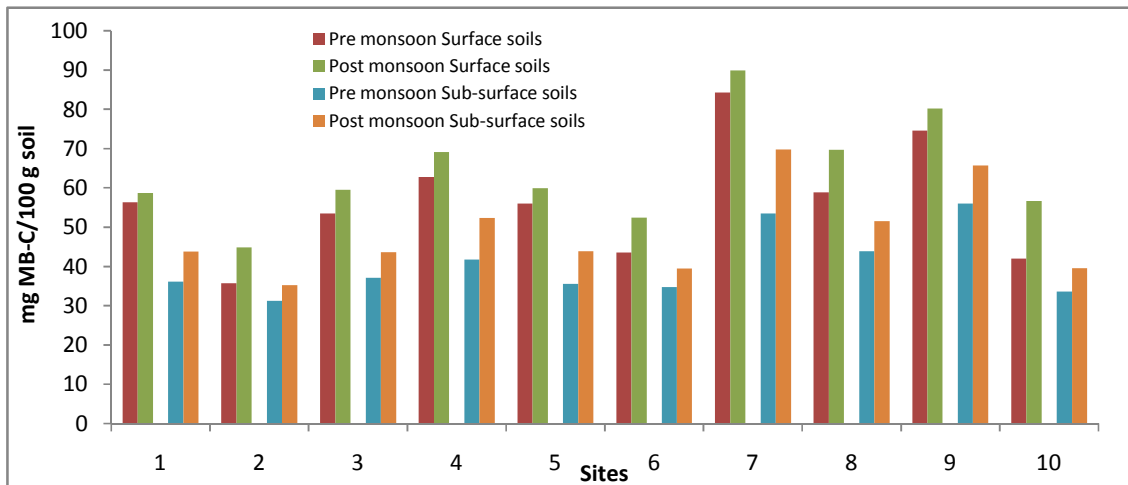
Sub-surface soils of different sites in Baddi location registered highest cadmium content ( $0.10 \text{ mg kg}^{-1}$ ) at Billawalli Labana followed by Baddi ( $0.09 \text{ mg kg}^{-1}$ ) and Kantha ( $0.07 \text{ mg kg}^{-1}$ ) during pre-monsoon season. Whereas, during post-monsoon season, highest cadmium content ( $0.14 \text{ mg kg}^{-1}$ ) was recorded at Billawalli Labana and Baddi followed by Malpur ( $0.09 \text{ mg kg}^{-1}$ ), Juddi Khurd ( $0.09 \text{ mg kg}^{-1}$ ) and Kantha ( $0.09 \text{ mg kg}^{-1}$ ). The lowest content of cadmium content ( $0.03 \text{ mg kg}^{-1}$ ) was recorded at Gularwala during pre-monsoon season and at Sairajmajra Gujra and Sairajmajra Labana, i.e. ( $0.03 \text{ mg kg}^{-1}$ ) during post-monsoon season. The cadmium was not detectable in sub-surface soils of Sairajmajra Gujra, Sairajmajra Labana, Billawalli Gujra and Juddi Kalan during pre-monsoon season.

The highest cadmium content ( $0.11 \text{ mg kg}^{-1}$  and  $0.14 \text{ mg kg}^{-1}$ ) for sub-surface soils of different sites in Barotiwala location was exhibited at Sattiwala during both seasons followed by Kuranwala ( $0.08 \text{ mg kg}^{-1}$  and  $0.13 \text{ mg kg}^{-1}$ ) and Baurawala ( $0.06 \text{ mg kg}^{-1}$  and  $0.09 \text{ mg kg}^{-1}$ ). Whileas, lowest cadmium content of  $0.06 \text{ mg kg}^{-1}$  was recorded at Baurawala during pre-monsoon season and at Jharmajri ( $0.02 \text{ mg kg}^{-1}$ ) during post-monsoon season. During pre-monsoon season, cadmium content was not detectable in sub-surface soils of Jharmajri, Bated, Plankwala, Sainsiwala, Barotiwala, Panga and Kunjhal and at Plankwala and Panga during post-monsoon season.

The DTPA extractable Mn, Cu, Fe and Zn were found to be low to high, high, high and low to high in their status. The results for Pb content in surface and sub-surface soils suggest that values are in permissible level. It is apparent from the results that Cd and Ni content were within permissible level. The values in post-monsoon season were higher than those in pre-monsoon season.

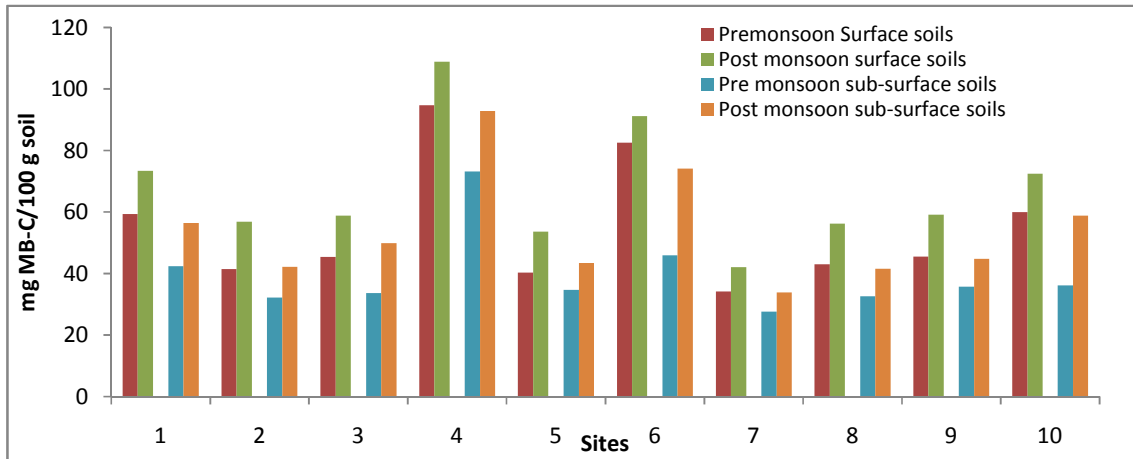
## 4.5 Microbial properties

As evinced from Fig 4.1 & Appendix XXVI, the total microbial biomass in Nalagarh surface soils during pre-monsoon season was highest (84.34 mg MB-C/100g soil) at site 7 (Chowkiwala) and lowest (35.78 mg MB-C/100g soil) was recorded at site 2 (Manpur). During the post-monsoon season, the total microbial biomass follows the same trend as in pre-monsoon and exhibited highest and lowest value of 89.87 and 44.89 mg MB-C/100g soil, respectively. It was noticed that for sub-surface soils in Nalagarh highest microbial biomass of 55.99 mg MB-C/100g soil (pre-monsoon) and 69.72 mg MB-C/100g soil (post-monsoon) was recorded at site 9 (Dhbota) and site 7 (Chowkiwala), respectively. Sub-surface soils exhibited lowest microbial biomass of 31.24 mg MB-C/100g soil (pre-monsoon) and 35.24 mg MB-C/100g soil (post-monsoon) at site 2 (Manpur).



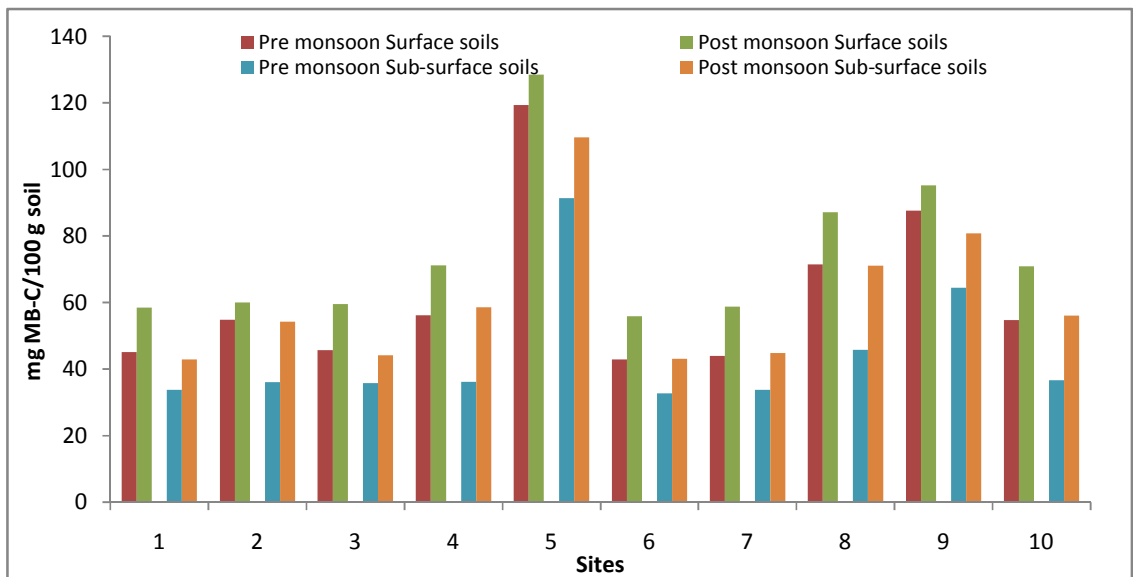
**Fig 4.1 Total microbial biomass at different sites of Nalagarh**

During pre and post-monsoon season, surface soils of Baddi recorded highest microbial biomass (94.76 and 108.83 mg MB-C/100g soil) at site 4 (Billawali Labana) and lowest (34.16 and 42.09 mg MB-C/100g soil) at site 7 (Juddi Khurd). Whereas, in sub-surface soils of Baddi, highest (73.14 and 92.88 mg MB-C/100g soil) and lowest (27.56 and 33.81 mg MB-C/100g soil) microbial biomass follows the same trend as in surface soils during both seasons, respectively (Fig 4.2 & Appendix XXVI).



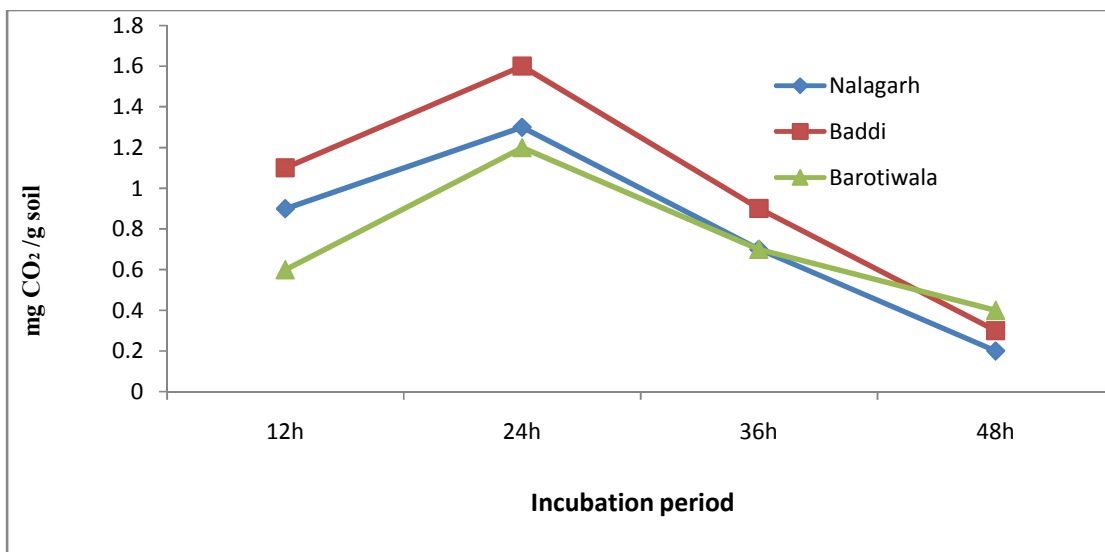
**Fig 4.2 Total microbial biomass at different sites of Baddi**

A glance of Fig 4.3 & Appendix XXVI indicates that highest of microbial biomass (119.26 and 128.45 mg MB-C/100g soil) was recorded at site 5 (Sainsiwala) and lowest (42.93 and 55.88 mg MB-C/100g soil) at site 6 (Barotiwala) in surface soil of Barotiwala during pre and post-monsoon seasons, respectively. Further, it was noticed that during pre-monsoon seasons sub-surface soils of Barotiwala follows the same trend as in surface soils of Barotiwala with regards to microbial biomass at different sites. During post-monsoon season sub-surface soils recorded lowest microbial biomass (42.95 mg MB-C/100g soil) at site 1 (Jharmajri).

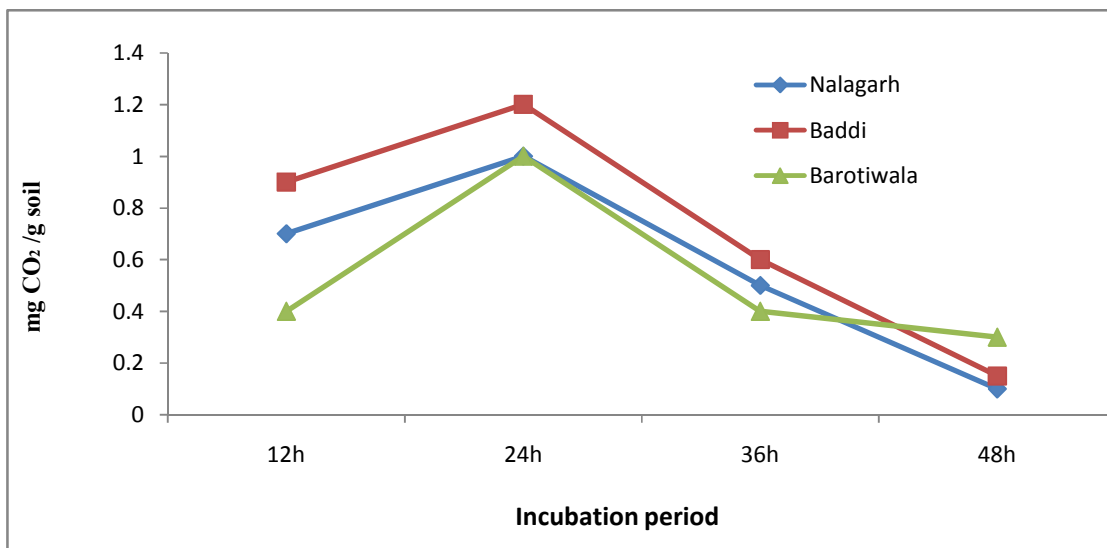


**Fig 4.3 Total microbial biomass at different sites of Barotiwala**

The highest CO<sub>2</sub> evolution was recorded at 24 hr of incubation period in both surface and sub-surface soils of Baddi, Barotiwala and Nalagarh locations. Further, a decreasing trend of CO<sub>2</sub> evolution with increase in incubation period was observed, (Fig 4.4 and 4.5; Appendix XXIV). The trend in both surface and sub-surface soils regarding microbial activity (CO<sub>2</sub> evolution) was almost same, but soils of Baddi location showed more activity followed by Nalagarh and Barotiwala.



**Fig. 4.4 Microbial activity (CO<sub>2</sub> evolution) of surface soils in Nalagarh, Baddi and Barotiwala**



**Fig. 4.5 Microbial activity (CO<sub>2</sub> evolution) of sub-surface soils in Nalagarh, Baddi and Barotiwala**

#### 4.6 Macro and micronutrients concentrations in plants

The data presented in Table 4.33 represented the concentration of macro nutrients in leaves of different vegetable crops during pre-monsoon (Brinjal) and post-monsoon season (Cauliflower) at different locations. The highest percent nitrogen concentration of 2.42 and 2.45 in leaves of brinjal and cauliflower was recorded at Baddi, respectively followed by Nalagarh (2.32 and 2.35 per cent), whereas, lowest concentration of 2.25 (pre-monsoon) and 2.28 (pre-monsoon) was recorded at Barotiwala. There was no significant difference in phosphorus concentration in the leaves of the vegetables within the locations during both seasons. However the concentration of phosphorus in leaves varied from 0.36 to 0.39 percent and 0.36 to 0.38 percent during both pre and post-monsoon seasons, respectively. Whereas, highest percent potassium concentration (0.79 and 0.82) in leaves of brinjal and cauliflower was recorded at Baddi followed by Barotiwala (0.68 and 0.70 per cent) and lowest concentration (0.60 and 0.62 per cent) was recorded at Nalagarh during both pre and post-monsoon seasons, respectively (Table 4.33).

**Table 4.33 N, P and K concentration (per cent) in leaves of brinjal (pre-monsoon) and cauliflower (post-monsoon) at different locations**

Locations	N		P		K	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Baddi	2.42	2.45	0.39	0.42	0.79	0.82
Nalagarh	2.32	2.35	0.38	0.40	0.60	0.62
Barotiwala	2.25	2.28	0.36	0.38	0.68	0.70
<b>CD<sub>0.05</sub></b>	<b>0.15</b>	<b>0.15</b>	<b>NS</b>	<b>NS</b>	<b>0.09</b>	<b>0.08</b>

A perusal of Table 4.34 reveals that highest manganese concentration of 10.04 mg kg<sup>-1</sup> (pre-monsoon) and 10.09 mg kg<sup>-1</sup> (post-monsoon) in leaves of brinjal and cauliflower was recorded at Baddi followed by Nalagarh (8.27 mg kg<sup>-1</sup> and 8.33 mg kg<sup>-1</sup>). Whereas, lowest manganese concentration of 8.10 mg kg<sup>-1</sup> and 8.16 mg kg<sup>-1</sup> in leaves of brinjal and cauliflower was recorded at Barotiwala during both pre and post-monsoon seasons, respectively. There was no significant difference for manganese concentration in leaves of brinjal and cauliflower of Nalagarh and Barotiwala during both seasons. Copper and iron concentration present in the leaves of vegetables were found to be non significant with respect to locations during pre and post-monsoon season. The pre and post-monsoon seasons exhibited highest zinc concentration of 1.59 mg kg<sup>-1</sup> at Barotiwala followed by Nalagarh (1.54 mg kg<sup>-1</sup> and 1.55 mg kg<sup>-1</sup>). However, lowest zinc concentration of 0.74 mg kg<sup>-1</sup> (brinjal)

and 0.75 mg kg<sup>-1</sup> (cauliflower) was recorded at Baddi during both the seasons. The concentration of Zn in the leaves of vegetables were found to be at par with those of Barotiwala and Nalagarh.

**Table 4.34 Micronutrient concentrations (mg kg<sup>-1</sup>) in leaves of brinjal (pre-monsoon) and cauliflower (post-monsoon) at different locations**

Name of Site	Mn		Cu		Fe		Zn	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Baddi	10.04	10.09	0.53	0.54	8.84	8.94	0.74	0.75
Nalagarh	8.27	8.33	0.63	0.64	9.14	9.20	1.54	1.55
Barotiwala	8.10	8.16	0.86	0.92	9.25	9.30	1.59	1.59
<b>CD<sub>0.05</sub></b>	<b>0.29</b>	<b>0.27</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>0.49</b>	<b>0.49</b>

The average concentration of lead in leaves of brinjal and cauliflower during pre and post-monsoon seasons significantly varied from 1.74 to 2.54 mg kg<sup>-1</sup> and 1.79 to 2.55 mg kg<sup>-1</sup> (Table 4.35). The highest lead concentration of 2.54 mg kg<sup>-1</sup> and 2.55 mg kg<sup>-1</sup> in leaves of brinjal and cauliflower was recorded at Barotiwala, respectively, followed by Nalagarh (2.33 mg kg<sup>-1</sup> and 2.36 mg kg<sup>-1</sup>) during both seasons, whereas lowest lead concentration (1.74 mg kg<sup>-1</sup> and 1.79 mg kg<sup>-1</sup>) was recorded at Baddi during both pre and post-monsoon seasons. There was significant difference in Pb concentration within locations during both seasons.

**Table 4.35 Heavy metal concentrations (mg kg<sup>-1</sup>) in leaves of brinjal (pre-monsoon) and cauliflower (post-monsoon) at different locations**

Locations	Pb		Ni		Cd	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Baddi	1.74	1.79	0.38	0.41	0.04	0.03
Nalagarh	2.33	2.36	0.41	0.42	0.03	0.03
Barotiwala	2.54	2.55	0.53	0.52	0.05	0.05
<b>CD<sub>0.05</sub></b>	<b>0.48</b>	<b>0.47</b>	<b>0.08</b>	<b>0.08</b>	<b>0.019</b>	<b>0.018</b>

The highest nickel concentration (0.53 mg kg<sup>-1</sup> and 0.52 mg kg<sup>-1</sup>) in leaves of brinjal and cauliflower was recorded at Barotiwala followed by Nalagarh (0.41 mg kg<sup>-1</sup> and 0.42 mg kg<sup>-1</sup>) and lowest concentration (0.38 mg kg<sup>-1</sup> and 0.41 mg kg<sup>-1</sup>) was recorded at Baddi during both seasons. The lead concentration in vegetable leaves of Baddi and Nalagarh were found to be at par with each other during both seasons. The mean concentration of cadmium in pre and

post-monsoon seasons significantly varied from 0.03 to 0.05 mg kg<sup>-1</sup>. The highest cadmium concentration (0.05 mg kg<sup>-1</sup>) was recorded at Barotiwala followed by Baddi (0.04 mg kg<sup>-1</sup> and 0.03 mg kg<sup>-1</sup>) and lowest concentration (0.03 mg kg<sup>-1</sup>) was recorded at Nalagarh (Table 4.35). There was no significant difference in Cd concentration of vegetables within Baddi and Nalagarh during both seasons.

#### **4.7 Variability analysis**

##### **4.7.1 Variation among different soil characteristics at different locations**

The data were collected from three different locations viz Nalagarh, Baddi and Barotiwala and from each location ten sites were selected randomly. From each site, three soil samples representing the entire site were collected and analyzed for various important characteristics. The Bartlett's Chi-square test was applied to test the significance of variation amongst all the locations for different soil characteristics. The data were analyzed for mean, standard deviation (SD) and coefficient of variation (CV) and the results are presented in Table 4.36 to 4.39.

The calculated values through Bartlett's Chi-square test when compared with table value at 5% level of significance (5.991) revealed that there was no significant variation among different soil characteristics for both surface and sub-surface soils during pre-monsoon and post-monsoon season at different locations.

A perusal of Table 4.36 revealed that highest mean values for different soil characteristics w.r.t three locations of the surface soils during pre-monsoon season were pH (7.01), EC (0.26 dSm<sup>-1</sup>), Cu (1.53 mg kg<sup>-1</sup>), Pb (1.16 mg kg<sup>-1</sup>) and Cd (0.07 mg kg<sup>-1</sup>) which was observed at Baddi. Whereas, highest mean values of OC (4.83 g kg<sup>-1</sup>), CaCO<sub>3</sub>(5.48 g kg<sup>-1</sup>), N (182.81 kg ha<sup>-1</sup>), P (57.68 kg ha<sup>-1</sup>), K (96.26 kg ha<sup>-1</sup>), Mn (3.95 mg kg<sup>-1</sup>), Fe (15.78 mg kg<sup>-1</sup>), Zn (1.22 mg kg<sup>-1</sup>) and Ni (0.45 mg kg<sup>-1</sup>) was observed at Barotiwala. Amongst the different soil characteristics for surface soils during pre-monsoon season, highest coefficient of variation (CV %) of 136.44, 103.97 and 93.54 was observed for Cd at Barotiwala, Nalagarh and Baddi, respectively. The lowest value of coefficient of variation (CV %) was recorded for pH i.e. 2.70, 2.49 and 1.89 at Baddi, Barotiwala and Nalagarh, respectively.

**Table 4.36 Extent of variation in soil characteristics during pre-monsoon season in surface soils at different locations**

Soil characteristics	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
pH	7.00	0.13	1.89	7.01	0.19	2.70	6.87	0.17	2.49	1.10
EC (dSm <sup>-1</sup> )	0.19	0.05	26.75	0.26	0.07	27.81	0.25	0.07	27.69	1.17
OC (g kg <sup>-1</sup> )	4.38	0.84	19.11	4.41	1.23	27.97	4.83	1.39	28.71	2.15
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	5.42	3.14	57.90	4.86	3.21	66.03	5.48	2.85	52.02	0.13
N (kg ha <sup>-1</sup> )	172.71	39.20	22.70	163.48	50.50	30.89	182.81	31.93	17.47	1.80
K (kg ha <sup>-1</sup> )	94.36	11.48	12.17	91.66	12.85	14.02	96.26	11.58	12.03	0.13
P (kg ha <sup>-1</sup> )	56.90	7.07	12.42	56.46	7.80	13.81	57.68	8.21	14.24	0.19
Mn (mg kg <sup>-1</sup> )	3.87	2.04	52.88	3.91	1.74	44.55	3.95	1.59	40.32	0.56
Fe (mg kg <sup>-1</sup> )	14.75	8.49	57.55	15.10	6.37	42.21	15.78	7.39	46.86	0.70
Cu (mg kg <sup>-1</sup> )	1.42	1.00	70.41	1.53	1.04	67.66	1.38	0.93	67.67	0.10
Zn (mg kg <sup>-1</sup> )	0.94	0.34	35.57	1.11	0.25	22.76	1.22	0.25	20.04	1.07
Pb (mg kg <sup>-1</sup> )	0.97	0.45	46.61	1.16	0.44	38.05	1.06	0.33	31.47	0.88
Ni (mg kg <sup>-1</sup> )	0.35	0.12	34.30	0.16	0.08	53.19	0.45	0.12	26.95	1.40
Cd (mg kg <sup>-1</sup> )	0.06	0.06	103.97	0.07	0.06	93.54	0.06	0.08	136.44	0.78

The data presented in the Table 4.37 reveals that for sub-surface soils during pre-monsoon season, the highest average values for different soil characteristics w.r.t three locations such as pH (7.15) and Cu (0.74 mg kg<sup>-1</sup>) were observed at Baddi. The highest average values for EC (0.21 dSm<sup>-1</sup>), OC(3.58 g kg<sup>-1</sup>), CaCO<sub>3</sub>(5.70 g kg<sup>-1</sup>), N (142.27 kg ha<sup>-1</sup>), Pb (0.42 mg kg<sup>-1</sup>) and Ni (0.12 mg kg<sup>-1</sup>) was observed at Barotiwala. However, average values for available P (43.32 kg ha<sup>-1</sup>), K (82.14 kg ha<sup>-1</sup>), Mn (1.67 mg kg<sup>-1</sup>), Fe (5.27 mg kg<sup>-1</sup>) and Zn (0.31 mg kg<sup>-1</sup>) were observed at Nalagarh. It was also observed that Cd(0.04 mg kg<sup>-1</sup>) was found highest both at Baddi and Barotiwala. Amongst the different soil characteristics for sub-surface soils during pre-monsoon season, highest coefficient of variation (CV %) of 64.42 was observed for Cu at Barotiwala followed by 62.43 and 56.96 for CaCO<sub>3</sub> at Baddi and Nalagarh, respectively. The lowest value of coefficient of variation (CV %) was observed for Cd i.e. 0.03 and 0.04 at Baddi and Nalagarh followed by 2.29 for pH at Barotiwala, respectively.

**Table 4.37** Extent of variation in soil characteristics during pre-monsoon season in sub-surface soils at different location

Soil characteristics	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
pH	7.13	0.14	1.90	7.15	0.17	2.44	7.01	0.16	2.29	0.56
EC (dSm <sup>-1</sup> )	0.15	0.04	26.37	0.20	0.04	22.28	0.21	0.07	33.78	3.41
OC(g kg <sup>-1</sup> )	3.21	0.69	21.39	2.97	1.11	37.43	3.58	1.31	36.64	3.41
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	5.59	3.19	56.96	5.08	3.17	62.43	5.70	2.89	50.74	0.10
N (kg ha <sup>-1</sup> )	133.54	39.23	29.38	126.04	45.42	36.03	142.27	30.02	21.10	1.43
K (kg ha <sup>-1</sup> )	82.14	10.60	12.90	77.50	13.59	17.54	82.02	11.76	14.33	0.54
P (kg ha <sup>-1</sup> )	43.32	6.04	13.94	41.88	7.53	17.99	42.89	7.84	18.29	0.64
Mn (mg kg <sup>-1</sup> )	1.67	59.60	2.72	1.49	54.57	2.70	1.39	51.70	51.70	0.29
Fe (mg kg <sup>-1</sup> )	5.27	54.95	9.43	3.45	36.63	9.70	3.99	41.15	41.15	1.63
Cu (mg kg <sup>-1</sup> )	0.67	71.00	1.07	0.74	68.91	0.91	0.58	64.42	64.42	0.48
Zn (mg kg <sup>-1</sup> )	0.31	41.23	0.76	0.25	32.07	0.80	0.25	30.79	30.79	0.71
Pb (mg kg <sup>-1</sup> )	0.36	64.81	0.85	0.36	41.91	0.67	0.42	62.54	49.90	0.26
Ni (mg kg <sup>-1</sup> )	0.08	53.19	0.18	0.11	60.91	0.23	0.12	52.18	40.83	1.12
Cd (mg kg <sup>-1</sup> )	0.03	149.07	0.04	0.04	98.60	0.03	0.04	167.86	56.39	1.06

The data presented in Table 4.38 revealed that highest average values of different soil characteristics w.r.t three locations of the surface soils during post-monsoon season were found to be pH (7.08) , Cu (1.64 mg kg<sup>-1</sup>) ,Pb (1.20 mg kg<sup>-1</sup> ) and Cd(0.09 mg kg<sup>-1</sup>) at Baddi. Whereas, the highest average values for OC (5.49 g kg<sup>-1</sup>), N (203.19 kg ha<sup>-1</sup>), P (71.50 kg ha<sup>-1</sup>), K (82.09 kg ha<sup>-1</sup>) , Mn (3.99 mg kg<sup>-1</sup>) , Fe (15.90 mg kg<sup>-1</sup>) , Zn (1.31 mg kg<sup>-1</sup>) and Ni (0.52 mg kg<sup>-1</sup>) were observed at Barotiwala. The electrical conductivity (0.22 dSm<sup>-1</sup>) was recorded highest at Baddi and Barotiwala; and CaCO<sub>3</sub> (5.04 g kg<sup>-1</sup>) at Nalagarh and Barotiwala, respectively. Amongst the different soil characteristics for surface soils, during post-monsoon season, highest coefficient of variation (CV %) of 94.44 and 75.31 was observed for Cd at Barotiwala and Nalagarh followed by 72.57 for CaCO<sub>3</sub> in Baddi. The lowest value of coefficient of variation (CV %) was observed for pH i.e. 1.66, 2.50 and 2.62 at Nalagarh, Barotiwala and Baddi, respectively.

**Table 4.38 Extent of variation in soil characteristics during post-monsoon season in surface soils at different locations**

Soil characteristics	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
pH	7.06	0.12	1.66	7.08	0.19	2.62	6.95	0.17	2.50	1.87
EC (dSm <sup>-1</sup> )	0.16	0.05	28.90	0.22	0.06	27.93	0.22	0.06	28.26	0.91
OC (g kg <sup>-1</sup> )	4.83	0.74	15.41	5.02	1.14	22.66	5.49	1.36	24.69	2.93
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	5.04	3.28	65.08	4.49	3.26	72.57	5.04	2.97	59.08	0.10
N (kg ha <sup>-1</sup> )	187.72	38.74	20.64	180.92	50.71	28.03	203.19	34.31	16.88	1.41
K (kg ha <sup>-1</sup> )	79.48	10.93	13.75	75.78	13.43	17.72	82.09	11.41	13.90	0.41
P (kg ha <sup>-1</sup> )	68.78	8.38	12.18	68.79	8.66	12.59	71.50	7.66	10.71	0.13
Mn (mg kg <sup>-1</sup> )	3.93	2.01	51.01	3.92	1.68	42.86	3.99	1.52	38.03	0.69
Fe (mg kg <sup>-1</sup> )	14.89	8.49	57.00	15.23	6.36	41.76	15.90	7.38	46.44	0.71
Cu (mg kg <sup>-1</sup> )	1.52	0.98	64.42	1.64	1.03	62.97	1.49	0.92	61.46	0.12
Zn (mg kg <sup>-1</sup> )	1.03	0.33	32.10	1.20	0.28	23.19	1.31	0.23	17.73	1.06
Pb (mg kg <sup>-1</sup> )	1.02	0.45	44.27	1.20	0.43	35.79	1.11	0.33	29.97	0.85
Ni (mg kg <sup>-1</sup> )	0.41	0.12	28.97	0.21	0.09	43.22	0.52	0.12	23.20	0.78
Cd (mg kg <sup>-1</sup> )	0.08	0.06	75.31	0.09	0.06	66.76	0.08	0.08	94.44	0.75

Based on data presented in Table 4.39 for sub-surface soils during post-monsoon season, the highest mean values of different soil characteristics w.r.t three locations were pH (7.22), EC (0.18 dSm<sup>-1</sup>), Cu (0.73 mg kg<sup>-1</sup>) and Pb (0.82 mg kg<sup>-1</sup>) was observed at Baddi. Whereas, the highest average values for OC (4.68 g kg<sup>-1</sup>), CaCO<sub>3</sub> (5.23 g kg<sup>-1</sup>), N (159.54 kg ha<sup>-1</sup>), P (58.19 kg ha<sup>-1</sup>) and Cd (0.05 mg kg<sup>-1</sup>) was observed at Barotiwala, except K (69.06 kg ha<sup>-1</sup>). However, highest values for Mn (1.58 mg kg<sup>-1</sup>), Fe (5.26 mg kg<sup>-1</sup>), Zn (0.30 mg kg<sup>-1</sup>) and Ni (0.30 mg kg<sup>-1</sup>), was observed at Nalagarh. Amongst the different soil characteristics for sub-surface soils during post-monsoon season, highest coefficient of variation (CV %) of 167.86 was observed for Zn in Barotiwala followed by 69.44 and 63.49 for CaCO<sub>3</sub> at Baddi and Nalagarh, respectively. The lowest value of coefficient of variation (CV %) was observed for Cd i.e. 0.05 and 0.07 in Baddi and Nalagarh followed by 0.32 for Ni at Barotiwala, respectively.

**Table 4.39** Extent of variation in soil characteristics during post-monsoon season in sub-surface soils at different locations

Soil characteristics	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
pH	7.20	0.13	1.78	7.22	0.17	2.30	7.10	0.15	2.17	0.58
EC (dSm <sup>-1</sup> )	0.13	0.04	28.41	0.18	0.06	30.29	0.17	0.05	27.93	1.15
OC (g kg <sup>-1</sup> )	3.74	0.74	19.88	4.25	1.20	28.34	4.68	1.25	26.63	2.50
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	5.19	3.29	63.49	4.65	3.23	69.44	5.23	3.00	57.43	0.08
N (kg ha <sup>-1</sup> )	148.91	38.85	26.09	142.10	45.97	32.35	159.54	30.85	19.34	1.32
K (kg ha <sup>-1</sup> )	69.06	9.50	13.75	64.41	12.64	19.62	68.32	11.57	16.93	0.70
P (kg ha <sup>-1</sup> )	56.96	7.09	12.45	56.03	8.31	14.82	58.19	8.07	13.87	0.23
Mn (mg kg <sup>-1</sup> )	1.58	55.27	2.83	1.49	52.47	2.79	1.39	49.90	28.63	0.14
Fe (mg kg <sup>-1</sup> )	5.26	54.14	9.55	3.45	36.11	9.83	4.01	40.83	62.54	1.60
Cu (mg kg <sup>-1</sup> )	0.66	62.24	1.17	0.73	61.97	1.04	0.59	56.39	52.18	0.37
Zn (mg kg <sup>-1</sup> )	0.30	34.69	0.85	0.25	29.06	0.89	0.26	28.63	167.86	0.42
Pb (mg kg <sup>-1</sup> )	0.37	60.48	1.80	0.82	156.85	0.72	0.41	57.29	0.61	0.25
Ni (mg kg <sup>-1</sup> )	0.30	95.44	0.23	0.11	48.76	0.29	0.13	44.93	0.32	0.83
Cd (mg kg <sup>-1</sup> )	0.03	66.56	0.07	0.04	60.50	0.05	0.05	106.46	106.46	0.75

#### 4.7.2 Variation among different plant characteristics at different locations

The data presented in the Table 4.40 reveals that there was significant variation among different plant parameters at different locations, such as Cu (17.922), Zn (20.843), Pb (32.999) and Ni (7.456) during pre-monsoon season and Cu (12.423), Zn (20.657) and Pb (35.795) during post-monsoon.

As evinced from the Table 4.40 the highest average values for different plant parameters during pre-monsoon season such as N (2.418 %), P (0.396 %), K (0.795 %) and Mn (10.043 mg kg<sup>-1</sup>) was observed at Nalagarh, except Cu (0.860 mg kg<sup>-1</sup>). However, the highest average value for Zn (1.594 mg kg<sup>-1</sup>), Fe (9.251 mg kg<sup>-1</sup>), Pb (2.545 mg kg<sup>-1</sup>), Ni (0.532 mg kg<sup>-1</sup>) and Cd (0.048 mg kg<sup>-1</sup>), was observed at Barotiwala. Amongst the different parameters of plants during pre-monsoon season, highest coefficient of variation (CV %) of 113.580 was observed for Cu in Nalagarh followed by 67.922 and 62.548 for Mn at Baddi and Barotiwala, respectively. The lowest value of coefficient of variation (CV %) was observed for Pb i.e. 3.909 and 6.529 at Barotiwala and Baddi followed by 19.014 for K at Nalagarh, respectively.

**Table 4.40 Extent of variation in plant parameters during pre- monsoon season at different locations**

Plant paramrtrs	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
N (%)	2.418	0.529	21.9147	2.323	0.526	22.669	2.255	0.523	23.198	0.001
P (%)	0.396	0.167	42.409	0.384	0.134	34.899	0.363	0.142	39.240	0.480
K (%)	0.795	0.151	19.014	0.601	0.104	17.458	0.681	0.223	32.854	4.722
Cu (mg kg <sup>-1</sup> )	0.535	0.607	113.580	0.637	0.164	25.855	0.860	0.193	22.460	17.922
Zn (mg kg <sup>-1</sup> )	0.747	0.614	82.219	1.543	0.182	11.842	1.594	0.144	9.059	20.843
Fe (mg kg <sup>-1</sup> )	8.841	3.711	41.984	9.142	2.817	30.823	9.251	3.494	37.773	0.683
Mn (mg kg <sup>-1</sup> )	10.043	6.902	68.725	8.268	5.615	67.922	8.109	5.072	62.548	0.865
Pb (mg kg <sup>-1</sup> )	1.744	0.698	40.054	2.331	0.152	6.529	2.545	0.099	3.909	32.999
Ni (mg kg <sup>-1</sup> )	0.388	0.103	26.607	0.412	0.070	17.055	0.532	0.038	7.204	7.456
Cd (mg kg <sup>-1</sup> )	0.040	0.023	57.120	0.031	0.014	45.771	0.048	0.023	48.214	2.477

**Table 4.41 Extent of variation in different plant parameters during post-monsoon season at different locations**

Plant paramrtrs	Nalagarh (n=10)			Baddi (n=10)			Barotiwala (n=10)			Bartlett's Chi-square test
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
N (%)	2.450	0.532	21.743	2.356	0.520	22.076	2.286	0.518	22.677	0.007
P (%)	0.426	0.169	39.778	0.404	0.131	32.487	0.383	0.140	36.781	0.614
K (%)	0.822	0.151	18.465	0.622	0.106	17.061	0.706	0.219	31.134	4.379
Cu (mg kg <sup>-1</sup> )	0.541	0.607	112.218	0.643	0.164	25.504	0.928	0.348	37.548	12.423
Zn (mg kg <sup>-1</sup> )	0.754	0.614	81.529	1.550	0.182	11.752	1.594	0.146	9.202	20.657
Fe (mg kg <sup>-1</sup> )	8.948	3.780	42.245	9.201	2.817	30.629	9.308	3.493	37.529	0.755
Mn (mg kg <sup>-1</sup> )	10.093	6.901	68.383	8.329	5.613	67.398	8.167	5.070	62.081	0.868
Pb (mg kg <sup>-1</sup> )	1.795	0.689	38.402	2.360	0.124	5.287	2.552	0.098	3.853	35.795
Ni (mg kg <sup>-1</sup> )	0.413	0.102	24.877	0.421	0.076	18.231	0.522	0.064	12.364	1.941
Cd (mg kg <sup>-1</sup> )	0.037	0.017	47.448	0.035	0.013	39.003	0.054	0.023	43.377	2.402

Perusal of Table 4.41 reveals that the highest average values for different plant parameters during post-monsoon season such as N (2.450 %), P (0.426 %), K (0.822 %) and Mn (10.093 mg kg<sup>-1</sup>) was observed at Nalagarh, except Cu (0.928 mg kg<sup>-1</sup>). However, the average value for Zn (1.594 mg kg<sup>-1</sup>), Fe (9.308 mg kg<sup>-1</sup>), Pb (2.552 mg kg<sup>-1</sup>), Ni (0.522 mg kg<sup>-1</sup>) and Cd (0.054 mg kg<sup>-1</sup>), was observed at Barotiwala. For post-monsoon season the highest coefficient of variation (CV %) of 112.218 was observed for Cu in Nalagarh followed by 67.398 and 62.081 for Mn at Baddi and Barotiwala, respectively. The lowest value of coefficient of variation (CV %) was observed for Pb i.e. 3.853 and 5.287 at Barotiwala and Baddi followed by 18.465 for K at Nalagarh, respectively.

## **CHAPTER-5**

# **DISCUSSION**

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In recent years, it has been noticed that people of Baddi, Barotiwala and Nalagarh industrial area are facing many problems due to industrial effluents, sewage and other pollutants released from industries. The problem of soil and water pollution has been frequently raised by the local people in media. It has been reported that the Sirsa river is getting polluted due to industrial pollution and the news of dying of fishes in this river is a serious threat for people residing in these areas. The presence of heavy metals in river water (being used for irrigation) have the potential to contaminate crops especially vegetables growing in vicinity of industrial areas. Keeping this in view, the present study was carried out to know the impact of industries on water quality and soil properties. The results emanated from the present study have been discussed under the following heads:

- 5.1 Chemical characteristics of industrial effluents**
- 5.2 Water characteristics**
- 5.3 Physico - chemical properties of the soils**
- 5.4 Available nutrient status of soils**
- 5.5 Microbial properties**
- 5.6 Macro and micronutrients concentration in plants**
- 5.7 Variability analysis**

### **5.1 Chemical characteristics of industrial effluents**

There is a large variability in the quality of industrial effluents which varies with industrial processes. The effluents discharged by different industries had a varied range of physico-chemical characteristics/parameters like pH, EC, TSS, chloride, bicarbonate, carbonate, chemical oxygen demand, biological oxygen demand, total nitrogen, phosphorus, potassium, micronutrients and heavy metals (Zn, Mn, Cu, Fe, Cd, Pb and Ni). The general physical and chemical analysis of the effluents are given in Table 4.1a and 4.1b. The effluents were alkaline in reaction. The effluent of textile industry recorded a highest pH value of 8.65

and 8.94, whereas, lowest pH value of 7.89 (paper industry) and 7.97 (ghee industry) was recorded in the effluents during pre and post-monsoon season. The pH values of industrial effluents were in permissible limit (6.5 – 9.0) as suggested by Bureau of Indian Standards (BIS), (Table 3.6.). This is in accordance with the findings of Sial *et al.* (2006), who have also reported alkaline pH in different industrial effluents. It was also noticed that the pH values were higher in post-monsoon season, which might be due to the discharge of more effluents by the industries during monsoon season. The effluents from textile industry registered comparatively higher EC (4.34 & 4.49 dSm<sup>-1</sup>) during pre and post-monsoon season. The highest TSS values of 2538 and 2599 mg/l was observed in chemical industry effluents during pre and post-monsoon season. However, effluents of pharmaceutical industry registered lowest EC value of 1.49 and 1.54 dSm<sup>-1</sup> during pre and post-monsoon seasons, respectively. Paper industry effluents registered lowest TSS values of 169.00 and 181.00 mg/l during pre and post-monsoon season. All the effluents contained TSS more than the BIS permissible limit of 100.00 mg/l (Table 3.6). Similar results were also reported by Patel *et al.* (2004). In general, EC and TSS values are directly proportional to each other. These results are consistent with those of Bohn *et al.* (1976). Post-monsoon season registered comparatively higher EC and TSS values which might be due to discharge of effluents by the industries in monsoon season. The highest contents of chloride i.e. 624.00 mg/l (pre-monsoon) and 645.00 mg/l (post-monsoon) was registered in the effluents of pharmaceutical industry. However, chloride present in the effluents of pharmaceutical, textile and chemical industry were above the permissible limit of 600.00 mg/l. Similar results have been also reported by Jain and Sharma (2001). Bicarbonates in the effluents of industries were more than the permissible limit for irrigation water. These results are in agreement with the findings of Sial *et al.* (2006).

A critical appraisal of data presented in the Table 4.1a and 4.1b indicated that during pre and post-monsoon season the highest BOD values of 2.35 and 2.41 mg/l was registered in paper industry, whereas lowest BOD values of 1.88 and 1.94 was registered in ghee industry effluents. The values of BOD were within permissible limit. The highest COD (1403.00 and 1425.00 mg/l) was registered in chemical industry and lowest (303.00 and 313.00 mg/l) in textile industry during pre and post-monsoon season. All the effluents contained COD more than permissible limit of 250.00 mg/l. Hence, the COD of these effluents renders them unfit

for irrigation and need further reduction in COD through proper treatment methods before irrigation (Totawal *et al.* 1996).

The analytical results of micronutrients and heavy metals during pre and post-monsoon seasons in effluents are presented in Table 4.1a and 4.1b. In general, the content of micronutrients and heavy metals in industrial effluents followed the order of  $Cd < Ni < Zn < Mn < Fe < Cu$  during both seasons. The industrial effluents from chemical and paper industry contained harmful levels of Cu ( $> 3.0$  mg/l) during both seasons, whereas, pharmaceutical and chemical industry effluents during both seasons contained Pb above the prescribed limits (0.1 mg/l). The chemical industry also contained Mn more than permissible limit of 1.50 mg/l during both seasons. The concentration of Fe, Cd, Zn and Ni were within the permissible limits during both seasons. The content of micronutrients and heavy metals of industrial effluents was observed to be higher during post-monsoon season which might be due to the fact that all industries discharged their effluents during rainy season. The results are in close agreement with the findings of Singh and Chandel (2006).

## 5.2 Water characteristics

Water samples from different sources viz. rivers, *nullhas*, tap and bore well were collected and analyzed for different parameters. The pH of water from river and *nullhas* during pre and post-monsoon seasons ranged from 8.04 to 8.29 (Table 4.2), whereas, in bore well and tap-water ranged from 7.73 to 8.81, irrespective of season and location (Table 4.7). The pH of bore well water at Nalagarh during both seasons is not fit for irrigation as it is above the permissible limit of 6.5 – 8.4 (Table 3.7). However, rest of the water from other sources was fit for irrigation. The pH values were found to be higher during post-monsoon season. The lower pH values during monsoon season is due to high turbidity and temperature which causes excessive production of CO<sub>2</sub>. Wetzel (1975), Khan and Khan (1985) and Narayani (1990) also reported similar results. The electrical conductivity values of water samples of river and *nullhas* ranged between 414.00 - 9324.00  $\mu$ Siemens/cm irrespective of season (Table 4.2). Whileas, EC of bore well and tap-water ranged from 0.40 to 1.37 dSm<sup>-1</sup>, irrespective of season and location (Table 4.8). The EC values of Sirsa river upstream Balad nadi (SUB) and Sirsa river downstream Sandouli *nullha* (Table 3.7) during pre and post-monsoon season render the water unfit for irrigation (  $>$  permissible limit of 700

$\mu\text{Siemens/cm}$  ). The water of different sources had higher values of EC during post-monsoon season. The higher EC during post-monsoon season is due to high concentration of ions and dissolved solid content in the water.

The total suspended solids of river and *nullhas* water ranged between 21.33 to 113.33 mg/l (Table 4.2). The values of TSS were found to be high during post-monsoon season. The high concentration of TSS during post-monsoon may be ascribed to the addition of solids from the runoff of water during monsoon. The amount of total suspended solids are influenced by the activity of plankton and organic materials which were more in post-monsoon season Marker (1997). The TSS of Sirsa river downstream Sandouli *nullha* (SDSa) during pre and post-monsoon season is not fit for irrigation as it is above the permissible limit of 100 mg/L. The  $\text{Cl}^-$  content of water from river and *nullhas* during pre and post-monsoon seasons ranged from 87.67 to 1269.00 mg/l (Table 4.3), whereas in bore well and tap-water ranged from 7.33 to 42.33 mg/l, irrespective of season and location (Table 4.9). The chloride content during post-monsoon were found to be more than pre-monsoon season which could be due to industrial effluents mixing as it was discharged during rainy season. The  $\text{Cl}^-$  content of Sirsa river downstream Sandouli *nullha* (SDSa) during pre and post-monsoon season is not fit for irrigation as the values were above the permissible limit of 1050 mg/l (Table 3.7), rest of the water sources were fit for irrigation. The carbonate and bicarbonate concentration of water from river and *nullhas* ranged from 121.00 to 165.00 and 21.33 to 85.00 mg/l, respectively (Table 4.3), whereas bicarbonate and carbonate concentration of bore well and tap-water ranged from 104.00 to 138.00 and 4.67 to 28.67 mg/l, respectively (Table 4.10 and 4.11). The  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  concentration of different water sources during pre and post-monsoon season are fit for irrigation as their concentration were within permissible limit (Table 3.7).

During pre and post-monsoon seasons, the concentration of calcium, magnesium and sodium in water of river and *nullhas* ranged from 91.00 to 169.00, 19.33 to 42.00 and 52.00 to 554.00 mg/l, respectively (Table 4.4), whereas, the values in bore well and tap-water ranged from 22.67 to 64.33, 8.33 to 29.00 and 17.33 to 43.00 mg/l, respectively (Table 4.12-4.14). The concentration of calcium, magnesium and sodium in different water sources during pre and post-monsoon season are found to be fit for irrigation as their values were within permissible limit of 400, 0 to 60 and 920 mg/l (Table 3.7).

The concentration of dissolved oxygen indicates water quality and its relation to the distribution and abundance of various algal species in river. In the present study, BOD and COD concentration in water of river and *nullhas* ranged from 0.54 to 203.33 and 15.33 to 527.67 mg/l, respectively (Table 4.5), whileas, COD concentration of bore well and tap-water ranged from 1.50 to 18.33 mg/l, irrespective of season and location (Table 4.15). The concentration of BOD and COD during pre and post-monsoon season were very high in Sirsa river downstream Sandouli *nullha* (SDSa) which might be due to the reason that all industries discharged their effluents in Sandhouli *nullha*. The addition of variety of biodegradable pollutants from domestic and industrial sources stimulates the growth of microorganisms, which consumes dissolved oxygen. These values decreased during pre-monsoon season because of high temperature the oxygen holding capacity of water decreased (Verghese *et al.* 1992). Pandey and Soni (1993) had also observed high values of free carbon dioxide, alkalinity and pH in highly polluted lake water of Naukuchiyatal lake situated in Kumaon.

The concentration of Fe, Cu, Mn and Cd in the water of river and *nullhas* ranged from 0.51 to 1.12, 0.03 to 0.09, 0.10 to 0.35 and 0.03 to 0.10 mg/l, respectively (Table 4.6). The concentration of Fe, Mn and Cd in the water of river and *nullhas* are not fit for irrigation as their values were above the permissible limit of 0.3, 0.1 and 0.01 mg/l, respectively (Table 3.7). Further, the concentration of Cu in water sample of Sirsa river downstream Balad nadi and upstream Sandouli *Nullha* during pre and post-monsoon season is also not fit for irrigation as their values were above the permissible limit of 0.05 mg/l (Table 3.7). The results imply that water of Sandhouli *nullha* and Sirsa river contains high amounts of some of the micronutrients and heavy metals (above permissible limit) due to discharge of industrial effluents and sewage water into them. This is in agreement with the findings of Rahmani (2007) and Prabu (2009). The concentration of Zn, Pb and Ni in river and *nullhas* water were in safer limit and the water was fit for irrigation. However, bore well water at different locations during both the seasons are not fit for irrigation as concentration of Fe was above the permissible limit of 0.3 mg/l (Table 3.7).

### **5.3 Physico - chemical properties of the soils**

The soils of the industrial area recorded slightly acidic to slightly alkaline reaction. Irrespective of location and season, the pH in surface soils of different sites during pre and

post-monsoon season ranged from 6.70 to 7.38 and 6.86 to 7.41, respectively. However, among different locations pH varied from 6.87 to 7.01 (pre-monsoon) and 6.99 to 7.12 (post-monsoon). The pH values in subsurface soils ranged from 6.83 to 7.46 and 6.89 to 7.59 among sites and 7.01 to 7.13 and 7.10 to 7.26 among locations during pre and post-monsoon season, respectively (Table 4.19). Soil pH increased with depth which may be attributed to lower content of organic matter and weathered soil conditions at lower depths. Similar results were also reported by Sharma (1994) and Verma (2003). Generally, during different processes involved in industries various acids like nitric, sulphuric and hydrochloric acids are used and these acids are also released with the effluents of chemical industries which results in more free acids. This might be the reason for slight acidic pH of some soils contaminated by these effluents. Similar findings were also reported by Manivasakam (1987). The alkaline soil reaction might be attributed to the addition of alkaline earth metals like  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and alkali metals like  $\text{Na}^+$ , which are present in higher proportion in the effluents of different industries. Similar results of increased soil pH due to textile effluent irrigation have been reported by Srinivaschari *et al.* (2000).

The data presented in Table 4.20 indicated that EC values in surface soils at different sites during pre and post-monsoon season ranged from 0.11 to 0.38 and 0.12 to 0.34  $\text{dSm}^{-1}$ , respectively and in different locations ranged from 0.19 to 0.26 and 0.18 to 0.22  $\text{dSm}^{-1}$ . The sub-surface soils of different sites registered EC values in the range of 0.10 to 0.33 and 0.10 to 0.29  $\text{dSm}^{-1}$  and in locations ranged from 0.15 to 0.21 and 0.16 to 0.20  $\text{dSm}^{-1}$  during pre and post-monsoon season, respectively and the values decreased with increase in soil depth. Post-monsoon season registered higher EC values as compared to pre-monsoon season. A high value of EC indicated enrichment of soil with soluble cations and anions such as  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{++}$  and  $\text{Cl}^-$  through the use of effluents. Similar results have also been reported by Prashanti *et al.* (1999).

The organic carbon content in surface soil during pre and post-monsoon season at different sites was in the range of 3.00 - 8.25 and 3.72 - 8.78  $\text{g kg}^{-1}$ , respectively. The corresponding values for locations were 4.38 - 4.83 and 4.83 - 5.48  $\text{g kg}^{-1}$ . However, in the sub-surface soils, the organic carbon content at different sites ranged from 1.25 - 6.55 and 2.89 - 7.64  $\text{g kg}^{-1}$ , whereas corresponding values for locations were 2.97 to 3.58 and 4.09 to 4.69  $\text{g kg}^{-1}$  during pre and post-monsoon season, respectively (Table 4.21). The organic

carbon content decreased with increase in soil depth. This may be ascribed to the addition of organic manures and litter fall on the surface of the soils. Further, the effluents also contain organic matter or residues which increases the organic carbon content of the soil. These observations are in accordance with findings of Pal *et al.* (1985); Baddesha *et al.* (1997) and Taywade and Prasad (2008).

The CaCO<sub>3</sub> content in surface soils during pre and post-monsoon season ranged from 0.80 - 10.00 and 0.62 - 9.91 g kg<sup>-1</sup> in different sites and 4.90 - 5.42 and 4.63 - 5.16 g kg<sup>-1</sup> at different locations during pre and post-monsoon season, respectively. However, in sub-surface soils, CaCO<sub>3</sub> content ranged from 0.33 - 10.20 and 0.21 - 10.10 g kg<sup>-1</sup> at different sites 5.08 - 5.70 and 4.67 - 5.33 g kg<sup>-1</sup> at different locations during pre and post-monsoon season, respectively (Table 4.22). The CaCO<sub>3</sub> content was more in pre-monsoon season as compared to post-monsoon season and sub-surface soils registered higher content as compared to surface soils. Similar observations have also been reported by Thompson and Kelly (1983) and Mitra *et al.* (1990).

#### **5.4 Available nutrient status of soils**

The available nitrogen content in surface soils at different sites was found to vary from 84.67 - 232.06 and 105.99 - 259.28 kg ha<sup>-1</sup>, whereas among locations it ranged from 163.48 to 182.81 and 180.63 to 202.69 kg ha<sup>-1</sup> during pre and post-monsoon season, respectively (Table 4.23). In sub-surface soils, the available nitrogen content during pre and post-monsoon season ranged from 61.10 to 184.80 and 76.44 to 208.10 kg ha<sup>-1</sup> in different sites and 126.04 to 142.27 and 143.60 to 165.60 kg ha<sup>-1</sup> at different locations, respectively (Table 4.23). Post-monsoon season registered higher available nitrogen content as compared to pre-monsoon season which might be due to addition of nitrogenous fertilizers and organic manures for vegetable production. The available nitrogen content decreased with increase in soil depth which might be due to decrease in organic carbon content.

The available phosphorus in surface soils of different sites during pre and post-monsoon season ranged from 44.80 to 69.80 and 52.77 to 81.51 kg ha<sup>-1</sup>, respectively (Table 4.24). The different locations registered available phosphorus values of 56.46 to 57.68 and 69.06 to 71.61 kg ha<sup>-1</sup> during pre and post-monsoon season, respectively (Table 4.24). However, available phosphorus in subsurface soils ranged from 31.40 to 53.80 and 41.99 to

66.97 kg ha<sup>-1</sup> among sites and for locations ranged from 41.88 to 43.32 and 56.00 to 58.5897 kg ha<sup>-1</sup> during pre and post-monsoon season, respectively (Table 4.24). The available P decreased with depth which might be due to the higher organic matter content in surface soils (Ghosh *et al.* 1981). In the light of suggested critical limits (Table 3.3), soils of the studied area were rated high in their available P status. Similar results were also reported by Singh and Singh (2005). The available phosphorus was high in post-monsoon season as compared to pre-monsoon season.

The available potassium in surface soils of different sites during pre and post-monsoon season ranged between 75.60 to 115.60 and 50.70 to 88.60 kg ha<sup>-1</sup>, whileas, at different locations 91.66 to 96.26 and 64.41 to 69.06 kg ha<sup>-1</sup>, respectively (Table 4.25). The corresponding values for sub-surface soils were 61.70 to 100.80 and 51.31 to 88.17 kg ha<sup>-1</sup> in different sites and 77.50 to 82.02 and 64.83 to 69.38 kg ha<sup>-1</sup> at different locations during pre and post-monsoon season, respectively (Table 4.25). Pre-monsoon season registered higher available potassium as compared to post-monsoon season which may be due to leaching of K during rainy season. The higher K content was noticed in surface soils. This could be attributed to more intense weathering and release of labile K from organic residue. Similar results were also reported by Thangasamy *et al.* (2005).

The data on DTPA extractable micronutrients viz. Fe, Mn, Zn, Cu and heavy metals viz. Pb, Ni and Cd in the soils of different sites and locations are presented in Tables 4.26 to 4.32. The manganese content in surface soils of different sites ranged from 1.57 to 7.43 and 1.65 to 7.27 mg kg<sup>-1</sup>, whereas in locations ranged from 3.85 to 3.95 and 3.91 to 4.01 mg kg<sup>-1</sup> during pre and post-monsoon seasons, respectively (Table 4.26). Manganese content in sub-surface soils of sites ranged from 0.74 to 5.41 and 0.91 to 5.68 mg kg<sup>-1</sup> and of locations ranged from 2.70 to 2.80 and 2.84 to 2.89 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Surface soils exhibited higher manganese content as compared to sub-surface. The values of Mn content irrespective of soil depth, site, location and season varied from 0.74 to 7.43 mg kg<sup>-1</sup>, thus suggesting, in general, low to high status in these soils (Table 3.3).

The copper content in surface soils of different sites during pre and post-monsoon season varied between 0.32 - 3.77 and 0.44 - 3.86 mg kg<sup>-1</sup>, whereas, at different locations, it ranged from 1.38 to 1.53 and 1.48 to 1.60 mg kg<sup>-1</sup>, respectively. For sub-surface soils, the

content of copper during pre and post-monsoon season ranged from 0.20 to 2.18 and 0.28 to 2.26 mg kg<sup>-1</sup> in different sites and 0.91 to 1.07 and 1.04 to 1.15 mg kg<sup>-1</sup> at different locations, respectively (Table 4.27). Post-monsoon season registered more copper content as compared to pre-monsoon season and decreased with depth. The Cu content irrespective of soil depth, site, location and season varied from 0.20 – 3.86 mg kg<sup>-1</sup>, thus, suggesting, in general, a high status in the soil.

The iron content in surface soils during pre and post-monsoon season in different sites ranged from 6.96 to 30.18 and 7.15 to 30.48 mg kg<sup>-1</sup> and at different locations 14.72 - 15.78 and 14.87 - 15.83 mg kg<sup>-1</sup>, respectively. However, in sub-surface soils iron content in different sites and locations ranged from 4.68 to 20.58 and 4.81 to 20.64 mg kg<sup>-1</sup>; 9.43 to 9.70 and 9.51 to 9.82 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively (Table 4.28). The content of iron was higher in post-monsoon season as compared to pre-monsoon season and surface soils registered more iron content as compared to sub-surface soils. The Fe content irrespective of soil depth, site, location and season varied from 4.86 to 30.48 mg kg<sup>-1</sup>, therefore, rated as high in status.

The zinc content in surface soils among the different sites during pre and post-monsoon season ranged from 0.31 to 1.62 and 0.38 to 1.70 mg kg<sup>-1</sup> and at locations from 0.94 to 1.22 and 1.03 to 1.32 mg kg<sup>-1</sup>, respectively. The corresponding values for sub-surface soils varied from 0.18 - 1.17 and 0.29 - 1.25 mg kg<sup>-1</sup>; 0.75 - 0.80 and 0.85 - 0.89 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively (Table 4.29). Surface soils had higher content of DTPA- extractable Zn in post-monsoon season and decreased with depth. The Zn content irrespective of soil depth, site, location and season varied from 0.18 to 1.70 mg kg<sup>-1</sup>, therefore, in light of suggested critical values (Table 3.3), soils were rated as low to high in their status.

Lead content in surface soils of different sites during pre and post-monsoon season ranged from 0.46 to 2.18 and 0.50 to 2.19 mg kg<sup>-1</sup>, whileas, in different locations ranged from 0.97 to 1.16 and 1.02 to 1.20 mg kg<sup>-1</sup>, respectively (Table 4.30). The sub-surface soils of different sites registered 0.19 to 1.69 and 0.23 to 1.71 mg kg<sup>-1</sup> Pb and at locations 0.56 to 0.85 and 0.62 to 0.90 mg kg<sup>-1</sup> Pb during pre and post-monsoon season, respectively. Post-monsoon season, recorded high lead content as compared to pre-monsoon season and decreased with

depth. In the light of suggested permissible limit of  $5.00 \text{ mg kg}^{-1}$  (Table 3.4), all the samples were rated below the permissible limit in their Pb status.

Nickel content in surface soils of different sites ranged from 0.09 to 0.62 and 0.16 to  $0.65 \text{ mg kg}^{-1}$ , whereas at different locations ranged from 0.26 to 0.45 and 0.29 to  $0.52 \text{ mg kg}^{-1}$ , during pre and post-monsoon season, respectively (Table 4.31). Sub-surface soils of sites and locations registered nickel content from 0.05 to 0.44 and 0.10 to  $0.52 \text{ mg kg}^{-1}$ ; 0.16 to 0.23 and 0.23 to  $0.31 \text{ mg kg}^{-1}$  during pre and post-monsoon season, respectively. Soils of post-monsoon season exhibited high nickel content and decreased with depth. The Ni content in the soils were below the permissible limit of  $2.00 \text{ mg kg}^{-1}$ .

The cadmium content ranged from 1.00 to 1.09 and 0.02 to  $0.21 \text{ mg kg}^{-1}$  during pre and post-monsoon season in surface soils of different sites, whereas, in locations it ranged from 0.057 to 0.069 and 0.07 to  $0.09 \text{ mg kg}^{-1}$ , respectively (Table 4.32). The respective values for sub-surface soils of sites and locations varied between 1.00 - 1.05 and 0.02 -  $0.14 \text{ mg kg}^{-1}$  and 0.02 to 0.04 and 0.05 to  $0.08 \text{ mg kg}^{-1}$  during pre and post-monsoon season, respectively. Surface soils exhibited high cadmium content as compared to sub-surface soils and post-monsoon season registered high cadmium content as compared to pre-monsoon season. The Cd content in the soils were found to be below the permissible limit of  $0.50 \text{ mg kg}^{-1}$ . Cadmium content was not detected in the soils of some of the sites.

In general, surface soils irrespective of site, location and season had higher content of micronutrient and heavy metals. It indicates that organic compounds present in the surface soils might have prevented the mobility of metals to the lower depths or horizons by forming insoluble complex with organic matter which might have been induced by relatively higher pH in the lower horizons. Sakal *et al.* (1992), Sarswat *et al.* (2005) and Taywade and Prasad (2008) also reported similar findings.

## **5.5 Microbial properties**

Soil is a living dynamic body, wherein, microorganisms play a significant role in transformation of various elements through bio chemical transformations and make the nutrients available to the plants (Rao, 1998). The microbial biomass carbon in the surface soils of Nalagarh, Baddi and Barotiwala during pre and post-monsoon season ranged from

35.78 to 89.87, 34.16 to 108.83 and 42.93 to 128.45 mg MB-C/100g soil, whereas in sub-surface soils ranged from 31.24 to 69.72, 27.56 to 92.88 and 32.69 to 109.67 mg MB-C/100g soil, respectively (Fig 4.1, 4.2 and 4.3). The highest microbial biomass carbon was recorded at site 7 (Chowkiwala) in Nalagarh, Site 4 (Billawali Labana) in Baddi and at site 5 (Sainsiwala) in Barotiwala. Which might be due to high organic carbon content in soils of these sites as the microbial biomass carbon comprises 1-3% of total organic carbon. The microbial activity was higher at interval of 24 hr incubation period and decreased with incubation period. The findings are in accordance with the observations of Anderson and Domsch (1978) who reported that the microbial biomass carbon in soil ranged from 15 to 240 mg MB-C/100g soil.

## 5.6 Macro and micronutrients concentration in plants

The concentration of macro and micronutrients in the leaves of vegetable crops are presented in Table 4.33 - 4.35. The average percent concentrations of N, P and K in leaves of brinjal was variable such as N (2.25 to 2.42), P (0.36 to 0.39) and K (0.60 to 0.79) at different location during pre-monsoon season. The respective values for post-monsoon season was 2.28 to 2.45, 0.38 to 0.42 and 0.62 to 0.82 percent in leaves of cauliflower (Table 4.33). The values of N, P and K content were in optimum range. The concentration of percent nitrogen, phosphorus and potassium in leaves of vegetables were high during post-monsoon season. The Mn, Cu, Fe and Zn content at different location ranged from 8.10 to 10.04, 0.53 to 0.86, 8.84 to 9.25 and 0.74 to 1.59 mg kg<sup>-1</sup> during pre-monsoon season. The corresponding values for post-monsoon season were 8.16 to 10.09, 0.54 to 0.92, 8.94 to 9.30 and 0.75 to 1.59 mg kg<sup>-1</sup>. The concentration of Mn, Cu, Fe and Zn in leaves of brinjal and cauliflower were found to be less than permissible limit (Table 3.5). In general, among all micronutrients, Fe registered higher concentration in leaves of vegetables. Patel *et al.* (2004) also reported that different vegetable crops accumulate invariably high amounts of Fe irrespective of the type of effluents/water used for irrigation, indicating the facts of variable uptake as a function of crop species, cultivars and selectivity of elements. The concentrations of heavy metals were variable such as Cd (0.03 to 0.05 mg kg<sup>-1</sup>), Ni (0.38 to 0.53 mg kg<sup>-1</sup>) and Pb (1.74 to 2.54 mg kg<sup>-1</sup>) during pre-monsoon season. The corresponding values for post-monsoon season were 1.79 - 2.55, 0.41 - 0.52 and 0.03 - 0.05 mg kg<sup>-1</sup>, respectively. The concentration of Ni and Cd were within the permissible limit in the leaves of brinjal and cauliflower. However, the leaves

of vegetable crops exhibited higher accumulation of Pb and these values were above the permissible limit ( $0.30 \text{ mg kg}^{-1}$ ). The concentration of micronutrients and heavy metals in leaves of cauliflower was more during post-monsoon season this might be due to high content of these elements in soils during post-monsoon season. Further, the high concentration of Pb in leaves of vegetable might be due to foliar absorption of atmospheric deposits on plant leaves. Similar observations have also been reported by Michio (2005).

### **5.7 Variability analysis**

There was not any significant variation among the different soil characteristics in surface and sub surface soils during pre and post-monsoon season at different locations. The reason might be due to that all three different locations are situated in the nearby area. However, there was a significant variation among different plant parameters at different locations, such as Cu (17.922), Zn (20.843), Pb (32.999) and Ni (7.456) during pre-monsoon season and Cu (12.423), Zn (20.657) and Pb (35.795) during post-monsoon season (Table 4.40-4.41). These observations through variability analysis were used in statistical analysis and are quite useful for soil and plant sampling in the studied area for further study as it gives insight of the soil and plant variations with respect to various characteristics.

## **CHAPTER-6**

### **SUMMARY AND CONCLUSIONS**

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The present investigations entitled “**Impact of industrialization on water quality and soil health in Baddi- Barotiwala-Nalagarh industrial hubs of Himachal Pradesh**” was carried out in Solan district of Himachal Pradesh during the year 2008-2009. On the basis of reconnaissance survey of the study area, it was noticed that industries discharged their effluents during rainy season into the surroundings *nullhas* and *khuds*. The Sandhouli *nullha* is most polluted one and water of this *nullha* merges into the Sirsa river which is the main source of irrigation in the surrounding area and Ropar district of Punjab. Farmers residing in this area mainly grow vegetable crops and the source of irrigation is bore well and tap-water, but occasionally they also use the water of nearby *nullhas* and *khuds* during monsoon season. The soil, water and plant samples were collected from three different locations namely Nalagarh, Baddi and Barotiwala and from each location ten sites were selected to study the impact of industrialization. The soil samples were collected at two depths (0-15 cm and 15-30 cm) and water samples were collected from Sirsa river, Sandhouli *nullha*, Balad khud, bore well and tap during pre and post-monsoon seasons. The results obtained are summarized as below:

#### **Chemical characteristics of industrial effluents**

The effluents discharged by different industries contain a varied range of physico-chemical characteristics/parameters like pH, EC, TSS,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ , COD, BOD, N, P, K, Zn, Mn, Cu, Fe, Cd, Pb and Ni. The content/concentration of all these parameters were high during post-monsoon season as majority of the industries discharged their effluents during monsoon season. The pH of effluents varied from 7.89 to 8.94 and could be considered as normal. The highest and lowest pH was registered in the effluents of textile and

paper industry, respectively. There was a wide range of EC and TSS in the industrial effluents. The effluents from textile and pharmaceutical industries registered highest (4.49 dS m<sup>-1</sup>) and lowest (1.49 dS m<sup>-1</sup>) electrical conductivity, respectively. Whereas, highest TSS (2599 mg/l) and lowest TSS (169 mg/l) was recorded in effluents of chemical and paper industry, respectively, which were quite above the BIS permissible limit (100 mg/l). The chloride content present in the effluents of industries were ranged from 496 to 645 mg/l and found to be above permissible limit of BIS (600 mg/l) in the case of pharmaceutical, textile and chemical industry. Similarly, the bicarbonate content in the effluents of industries were also above the permissible limit for irrigation.

The BOD values varied from 1.88 to 2.41 and found to be within safer limit (30 mg/l). The highest COD (1403.00 mg/l) was registered with chemical industry and lowest (303 mg/l) in textile industry. The COD values in all the effluents were above the permissible limit (250 mg/l). The amount of copper present in the effluents of chemical and paper industry was above the permissible limit as suggested by BIS. Lead contents in effluents from pharmaceutical and chemical industry were higher than BIS limits. The manganese concentration was also higher than BIS limits. The content of Fe, Cd, Zn and Ni in all effluents were within the permissible limits.

### **Water characteristics**

The pH of water from river and *nullhas* ranged from 8.04 to 8.29, irrespective of season. However, pH of bore well and tap-water ranged from 7.73 to 8.81. The pH of bore well water at Nalagarh, during both seasons is above the permissible limit of 6.5 – 8.4. The EC values of water from river and *nullha* irrespective of season, ranged from 414.00 to 9324.00  $\mu$ Siemens/cm. The corresponding values for bore well and tap-water ranged from 0.40 to 1.37 dSm<sup>-1</sup>. The EC values of Sirsa river upstream Balad nadi (SUB) and Sirsa river downstream Sandouli *nullha* (SDSa) were above the permissible limit of 700  $\mu$ Siemens/cm. Total suspended solids of river and *nullhas* water ranged from 21.33 to 113.33 mg/l. The TSS of Sirsa river downstream Sandouli *nullha* (SDSa) were above the permissible limit of 100 mg/l. The Cl<sup>□</sup> content of water from river and *nullhas*; well and tap ranged from 87.67 to 1269.00 mg/l; 7.33 to 42.33 mg/l, irrespective of season. The Cl<sup>□</sup> content of Sirsa river

downstream Sandouli *nullha* (SDSa) were above the permissible limit of 1050 mg/l. The  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  content of river and *nullhas* water varied between 121.00 to 165.00 and 21.33 to 85.00 mg/l, irrespective of season. The values for bore well and tap-water ranged from 104.00 to 138.00 and 4.67 to 28.67 mg/l. The  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  concentrations were within permissible limit. The concentration of  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{Na}^+$  irrespective of season, in river and *nullhas* water ranged from 91.00 to 169.00, 19.33 to 42.00 and 52.00 to 554.00 mg/l, respectively. However, concentrations in the water of bore well and tap ranged from 22.67 to 64.33, 8.33 to 29.00 and 17.33 to 43.00 mg/l and their concentration were within permissible limit. The BOD and COD concentration of water from river and *nullhas* ranged from 0.54 to 203.33 and 15.33 to 527.67 mg/l. However, COD concentration of water from bore well and tap ranged from 1.50 to 18.33 mg/l. The concentration of BOD and COD during pre and post-monsoon season was very high in Sirsa river downstream Sandouli *nullha* (SDSa).

The concentration of Fe, Cu, Mn and Cd in the water of river and *nullhas* ranged from 0.51 to 1.12, 0.03 to 0.09, 0.10 to 0.35 and 0.03 to 0.10 mg/l, respectively. The content of Fe, Mn and Cd in the water of river and *nullhas* were found to be above the permissible limit of 0.3, 0.1 and 0.01 mg/l, respectively. The water of Sirsa river downstream Balad nadi and upstream Sandouli *Nullha* (SDB&USa) is not fit for irrigation as the concentration of Cu was above the permissible limit of 0.05 mg/l. The concentration of Zn, Pb and Ni in the water of river and *nullhas* were in safer limit, therefore, fit for irrigation. On the other hand, Fe content in bore well water at different locations during pre and post-monsoon season were above the permissible limit of 0.3 mg/l.

### **Physico - chemical properties of the soils**

The soils of the industrial area registered slightly acidic to slightly alkaline pH. Irrespective of site, location and season, the pH of surface soils of different sites during pre and post-monsoon season ranged from 6.70 to 7.38 and 6.86 to 7.41, respectively. The corresponding values for location ranged from 6.87 to 7.01 and 6.99 to 7.12. However, pH values in subsurface soils ranged from 6.83 to 7.46 and 6.89 to 7.59 among different sites and 7.01 to 7.13 and 7.10 to 7.26 at different locations during pre and post-monsoon season,

respectively. It was found that sub-surface soils registered high soil pH as compared to surface soils.

The EC values of surface soils during pre and post-monsoon season in different sites ranged from 0.11 to 0.38 and 0.12 to 0.34  $\text{dSm}^{-1}$ , whereas at different locations ranged from 0.19 to 0.26 and 0.18 to 0.22  $\text{dSm}^{-1}$ , respectively. Sub-surface soils of different sites registered EC values of 0.10 to 0.33 and 0.10 to 0.29  $\text{dSm}^{-1}$  and in locations 0.15 to 0.21 and 0.16 to 0.20  $\text{dSm}^{-1}$  during pre and post-monsoon season, respectively. Post-monsoon season registered higher EC values as compared to pre-monsoon season and decreased with depth.

The organic carbon content in surface soils of different sites varied between 3.00 - 8.25 and 3.72 - 8.78  $\text{g kg}^{-1}$ , whereas in locations varied from 4.38 to 4.83 and 4.83 to 5.48  $\text{g kg}^{-1}$  during pre and post-monsoon season, respectively. Organic carbon content in sub-surface soils of sites and locations ranged from 1.25 to 6.55 and 2.89 to 7.64  $\text{g kg}^{-1}$ ; 2.97 to 3.58 and 4.09 to 4.69  $\text{g kg}^{-1}$  during pre and post-monsoon season, respectively. Surface soils exhibited more organic carbon content as compared to sub-surface.

The content of  $\text{CaCO}_3$  in surface soils during pre and post-monsoon season ranged from 0.80 to 10.00 and 0.62 to 9.91  $\text{g kg}^{-1}$ , respectively in different sites. The respective values for different locations ranged from 4.90 to 5.42 and 4.63 to 5.16  $\text{g kg}^{-1}$ . The content of  $\text{CaCO}_3$  was higher in pre-monsoon season as compared to post-monsoon and increased with the depth.

#### **Available nutrient status of soils**

The available nitrogen content in surface soils of different sites varied from 84.67 - 232.06 and 105.99 - 259.28  $\text{kg ha}^{-1}$ , whereas in locations, ranged from 163.48 to 182.81 and 180.63 to 202.69  $\text{kg ha}^{-1}$  during pre and post-monsoon season, respectively. For sub-surface soils, the available nitrogen content during pre and post-monsoon season ranged from 61.10 to 184.80 and 76.44 to 208.10  $\text{kg ha}^{-1}$  in different sites and 126.04 to 142.27 and 143.60 to 165.60  $\text{kg ha}^{-1}$  at different locations, respectively. Post-monsoon season registered more available nitrogen content as compared to pre-monsoon season. The available nitrogen content decreased with increase in soil depth.

The available phosphorus of surface soils in different sites during pre and post-monsoon season ranged from 44.80 to 69.80 and 52.77 to 81.51 kg ha<sup>-1</sup>, respectively. The different locations registered available phosphorus values of 56.46 to 57.68 and 69.06 to 71.61 kg ha<sup>-1</sup> during pre and post-monsoon season, respectively. However, available phosphorus in subsurface soils of different sites and locations varied between 31.40 to 53.80 and 41.99 to 66.97 kg ha<sup>-1</sup>; 41.88 to 43.32 and 56.00 to 58.5897 kg ha<sup>-1</sup> during pre and post-monsoon season, respectively. In the light of suggested critical limits, soils of the studied area were rated high in their available P status. The post-monsoon season registered higher values of available phosphorus and decreased with depth.

The available potassium content in surface soils of different sites during pre and post-monsoon ranged between 75.60 to 115.60 and 50.70 to 88.60 kg ha<sup>-1</sup>, whileas, in different locations 91.66 to 96.26 and 64.41 to 69.06 kg ha<sup>-1</sup>, respectively. The corresponding values for sub-surface soils were 61.70 to 100.80 and 51.31 to 88.17 kg ha<sup>-1</sup> in different sites and 77.50 to 82.02 and 64.83 to 69.38 kg ha<sup>-1</sup> at different locations during pre and post-monsoon season, respectively. Pre-monsoon season registered higher available potassium as compared to post-monsoon season and decreased with depth.

The manganese content in surface soils of different sites ranged from 1.57 to 7.43 and 1.65 to 7.27 mg kg<sup>-1</sup> during pre and post-monsoon season respectively. The values for different locations were from 3.85 to 3.95 and 3.91 to 4.01 mg kg<sup>-1</sup> during pre and post-monsoon seasons, respectively. Manganese content in sub-surface soils of sites and locations ranged from 0.74 to 5.41 and 0.91 to 5.68 mg kg<sup>-1</sup>; 2.70 to 2.80 and 2.84 to 2.89 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Surface soils recorded more manganese content as compared to sub-surface.

The iron content in surface soils, during pre and post-monsoon season ranged from 6.96 to 30.18 and 7.15 to 30.48 mg kg<sup>-1</sup> in different sites and respective values at different locations were 14.72 - 15.78 and 14.87 - 15.83 mg kg<sup>-1</sup>. However, in sub-surface soils iron content in different sites and locations ranged from 4.68 to 20.58 and 4.81 to 20.64 mg kg<sup>-1</sup>; and 9.43 to 9.70 and 9.51 to 9.82 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively.

The content of iron was higher in post-monsoon season as compared to pre-monsoon season and surface soils registered more iron content as compared to sub-surface soils.

The copper content in surface soils of different sites during pre and post-monsoon season varied from 0.32 - 3.77 and 0.44 - 3.86 mg kg<sup>-1</sup>, whereas at different locations, it ranged from 1.38 to 1.53 and 1.48 to 1.60 mg kg<sup>-1</sup>, respectively. For sub-surface soils, the content of copper during pre and post-monsoon season ranged from 0.20 to 2.18 and 0.28 to 2.26 mg kg<sup>-1</sup> in different sites and 0.91 to 1.07 and 1.04 to 1.15 mg kg<sup>-1</sup> at different locations, respectively. Post-monsoon season registered more copper content as compared to pre-monsoon season and decreased with the depth.

The zinc content in the surface soils of different sites and locations during pre and post-monsoon season ranged from 0.31 to 1.62 and 0.38 to 1.70 mg kg<sup>-1</sup>; 0.94 to 1.22 and 1.03 to 1.32 mg kg<sup>-1</sup>, respectively. The corresponding values for sub-surface soils were 0.18 - 1.17 and 0.29 - 1.25 mg kg<sup>-1</sup>; 0.75 - 0.80 and 0.85 - 0.89 mg kg<sup>-1</sup> during pre and post-monsoon season. Surface soils had higher DTPA- extractable Zn in post-monsoon season and decreased with depth.

Lead content in surface soils, during pre and post-monsoon season of different sites ranged from 0.46 to 2.18 and 0.50 to 2.19 mg kg<sup>-1</sup>, whileas, in different locations the values were 0.97 to 1.16 and 1.02 to 1.20 mg kg<sup>-1</sup>, respectively. The sub-surface soils of different sites and locations registered 0.19 to 1.69 and 0.23 to 1.71 mg kg<sup>-1</sup>; 0.56 to 0.85 and 0.62 to 0.90 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Post-monsoon season recorded high lead content as compared to pre-monsoon season and decreased with depth.

Nickel content in surface soils of different sites ranged from 0.09 to 0.62 and 0.16 to 0.65 mg kg<sup>-1</sup>, whereas, at different locations ranged from 0.26 to 0.45 and 0.29 to 0.52 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Sub-surface soils of different sites and locations registered nickel content of 0.05 to 0.44 and 0.10 to 0.52 mg kg<sup>-1</sup>; 0.16 to 0.23 and 0.23 to 0.31 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Soils of post-monsoon season exhibited more nickel content and decreased with depth.

The cadmium content ranged from 1.00 to 1.09 and 0.02 to 0.21 mg kg<sup>-1</sup> during pre and post-monsoon season in surface soils of different sites, whereas in locations it ranged from 0.057 to 0.069 and 0.07 to 0.09 mg kg<sup>-1</sup>, respectively. The respective values for sub-surface soils varied between 1.00 - 1.05 and 0.02 - 0.14 mg kg<sup>-1</sup>; 0.02 to 0.04 and 0.05 to 0.08 mg kg<sup>-1</sup> during pre and post-monsoon season, respectively. Surface soils recorded higher cadmium content as compared to sub-surface soil. Likewise, post-monsoon season registered higher cadmium content as compared to pre-monsoon season. Cadmium content was not detectable in some of the soils of sites

The available N, P and K were rated as low, high and low to medium, respectively considering the critical limits of these elements. However, DTPA extractable Mn, Fe, Cu and Zn were found to be low to high, high, high and low to high in their status, respectively. Further, the content of Pb, Ni and Cd were below permissible limit of 5.00, 2.00 and 0.05 mg kg<sup>-1</sup>, respectively.

### **Microbial properties**

The microbial biomass carbon in surface soils of Nalagarh, Baddi and Barotiwala irrespective of season, varied between 35.78 - 89.87, 34.16 - 108.83 and 42.93 - 128.45 mg MB-C/100g soil, whereas in sub-surface soils ranged from 31.24 to 69.72, 27.56 to 92.88 and 32.69 to 109.67 mg MB-C/100g soil. The high microbial biomass carbon was recorded at site 7 (Chowkiwala) in Nalagarh, Site 4 (Billawali Labana) in Baddi and at site 5 (Sainsiwala) in Barotiwala. The microbial activity is more in surface soils as compared to sub-surface.

### **Macro and micronutrients concentration in plants**

The percent concentration of nitrogen, phosphorus and potassium in the leaves of vegetable (brinjal) ranged from 2.25 to 2.42, 0.36 to 0.39 and 0.60 to 0.79 at different locations during pre-monsoon season, respectively. The respective values during post-monsoon season (cauliflower) were 2.28 to 2.45, 0.38 to 0.42 and 0.62 to 0.82. Concentration of Mn, Cu, Fe and Zn ranged from 8.10 to 10.04, 0.53 to 0.86, 8.84 to 9.25 and 0.74 to 1.59 mg kg<sup>-1</sup> at different locations during pre-monsoon season and ranged from 8.16 to 10.09, 0.54 to 0.92, 8.94 to 9.30 and 0.75 to 1.59 mg kg<sup>-1</sup> during post-monsoon season. The concentration

of nitrogen, phosphorus, potassium, Mn, Cu, Fe and Zn in leaves of brinjal and cauliflower was in safer limit. The content of Pb, Ni and Cd during pre-monsoon in the leaves of vegetable crops ranged between 1.74 to 2.54, 0.38 to 0.53 and 0.03 to 0.05 mg kg<sup>-1</sup> and respective values during post-monsoon season were 1.79 to 2.55, 0.41 to 0.52 and 0.03 to 0.05 mg kg<sup>-1</sup>. The concentration of Pb was above the permissible limit in vegetable leaves. However, content of Cd and Ni was found to be in safer limit as suggested by WHO and FAO. There was a significant variation among different plant parameters at different locations, such as Cu (17.922 mg kg<sup>-1</sup>), Zn (20.843 mg kg<sup>-1</sup>), Pb (32.999 mg kg<sup>-1</sup>) and Ni (7.456 mg kg<sup>-1</sup>) during pre-monsoon season and Cu (12.423 mg kg<sup>-1</sup>), Zn (20.657 mg kg<sup>-1</sup>) and Pb (35.795 mg kg<sup>-1</sup>) during post-monsoon season.

## CONCLUSIONS

It is concluded that quality characteristics varied markedly among effluents of different industries. The TSS and COD values were found to be above permissible limit in all industrial effluents. The Cl<sup>□</sup>, Cu, Pb and Mn content were above permissible limit in chemical industry effluents. The content of Cl<sup>□</sup>, Cu and Pb were also above permissible limit in pharmaceutical industry effluent. The available N, P and K were rated as low, high and low to medium, respectively. However, DTPA extractable Mn, Fe, Cu and Zn were found to be low to high, high, high and low to high in their status, respectively. Further, the content of Pb, Ni and Cd were below permissible limit of 5.00, 2.00 and 0.05 mg kg<sup>-1</sup>, respectively. Among all the DTPA extractable metals Fe was found to be highest in vegetable leaves. Pb concentration was above permissible limit in the leaves of vegetables. The values of EC, Cl<sup>□</sup> and TSS were above permissible limit in the water of Sirsa river and Sandhouli *nullha*. The content of Fe, Mn and Cd in the water of river and *nullhas* were above permissible limit. The pH of bore well water from Nalagarh location was found to be above permissible limit. Thus, continuous monitoring of soil, plant and water quality together with prevention of metals entering vegetables is a prerequisite in order to prevent potential health hazards to human beings. The waste water treatment technology should involve steps to remove heavy metal which causes risk to human health.

## **CHAPTER-7**

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**Dr. Y. S. Parmar University of Horticulture and Forestry,  
Nauni-173 230, Solan (H.P.)  
Department of Soil Science and Water Management**

**Title of Thesis** : **“Impact of industrialization on water quality and soil health in Baddi-Barotiwala-Nalagarh industrial hubs of Himachal Pradesh”**

**Name of the Student** : **Neetan Khajuria**

**Admission Number** : F-2006-07-D

**Major Advisor** : **Dr. D.Tripathi**

**Major Field** : Soil Science and Water Management

**Minor Field(s)** : i) Silviculture  
ii) Plant Physiology

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**ABSTRACT**

The present investigations entitled “Impact of industrialization on water quality and soil health in Baddi-Barotiwala-Nalagarh industrial hubs of Himachal Pradesh” was carried out in Solan district of Himachal Pradesh during the year 2008-2009. The soil, water and plant samples were collected from thirty sites of three locations. The soil samples were collected at two depths (0-15 cm and 15-30 cm) and water samples were collected from Sirsa river, Sandhouli *nullha*, Balad *khud*, borewell and tap during pre and post monsoon seasons. The pH ranged from 7.89 to 8.65 and highest was recorded in textile industry effluent and lowest in paper industry effluent. The effluents from textile and pharmaceutical industries registered maximum (4.49 dS m<sup>-1</sup>) and minimum (1.49 dS m<sup>-1</sup>) electrical conductivity, respectively. Whereas, highest TSS (2599 mg/l) and lowest TSS (169 mg/l) was recorded in effluents of chemical and paper industry, respectively, which were quite above the BIS standard limits (100 mg/l). The contents of chloride present in the effluents of industries were ranged from 496 to 645 mg/l. The BOD values varied from 1.88 to 2.41 and found to be within safer limit (30 mg/l). The highest COD (1403.00 mg/l) was registered with chemical industry and minimum (303 mg/l) in textile industry. The soils of the industrial area registered slightly acidic to slightly alkaline pH. The EC values in surface soils, during pre and post monsoon season at different sites ranged from 0.11 to 0.38 and 0.12 to 0.34 dSm<sup>-1</sup>. The organic carbon content in surface soils of different sites varied between 3.00 - 8.25 and 3.72 - 8.78 g kg<sup>-1</sup>, whereas in locations from 4.38 to 4.83 and 4.83 to 5.48 g kg<sup>-1</sup> during pre and post monsoon season, respectively. The available N, P and K were rated as low, high and low to medium, respectively considering the critical limits of these elements. However, DTPA extractable Mn, Fe, Cu and Zn were found to be low to high, high, high and low to high in their status, respectively. Further, the content of Pb, Ni and Cd were below permissible limit of 5.00, 2.00 and 0.05 mg kg<sup>-1</sup>, respectively. Lead content in surface soils, during pre and post monsoon season of different sites ranged from 0.46 to 2.18 and 0.50 to 2.19 mg kg<sup>-1</sup>. Nickel content in different sites ranged from 0.09 to 0.62 and 0.16 to 0.65 mg kg<sup>-1</sup> in surface soils. The cadmium content ranged from 1.00 to 1.09 and 0.02 to 0.21 mg kg<sup>-1</sup>. The concentration of Mn, Cu, Fe and Zn in plant samples ranged from 8.10 to 10.04, 0.53 to 0.86, 8.84 to 9.25 and 0.74 to 1.59 mg kg<sup>-1</sup> at different locations during pre monsoon season and ranged from 8.16 to 10.09, 0.54 to 0.92, 8.94 to 9.30 and 0.75 to 1.59 mg kg<sup>-1</sup> during post monsoon season. The concentration of Pb was above the permissible limit. The pH of river and nullhas water ranged from 8.04 to 8.29. The EC values, irrespective of season of river and nullhas water ranged from 414.00 to 9324.00 μSiemens/cm. The corresponding values for bore well and tap water ranged from 0.40 to 1.37 dSm<sup>-1</sup>. The HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>2-</sup> concentration were within permissible limit. The concentration of Ca, Mg and Na in borewell and tap water ranged from 22.67 to 64.33; 8.33 to 29.00 and 17.33 to 43.00 mg/l. The BOD and COD concentration of river and *nullhas* water ranged from 0.54 to 203.33 and 15.33 to 527.67 mg/l. The concentration of Fe, Cu, Mn and Cd in river and *nullhas* water ranged from 0.51 to 1.12; 0.03 to 0.09; 0.10 to 0.35 and 0.03 to 0.10 mg/l. The microbial biomass carbon of Nalagarh, Baddi and Barotiwala in surface soils during pre and post monsoon season varied between 35.78 - 89.87; 34.16 - 108.83 and 42.93 - 128.45 mg MB-C/100g soil, respectively.

**Signature of Major Advisor**

**Signature of student**

**Countersigned**

**Professor and Head  
Department of Soil Science and Water Management  
Dr. Y. S. Parmar University of Horticulture and Forestry,  
Nauni-173 230, Solan (H.P.)**

**APPENDIX I**  
**ANOVA table for site wise soil pH**

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Sub-surface		Surface		Sub-surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.052	0.055	0.060	0.033	0.108	0.091	0.109	0.085	0.088	0.077	0.095	0.095
Error	20	0.002	0.002	0.003	0.003	0.002	0.004	0.004	0.005	0.002	0.004	0.005	0.003
Total	29	0.018	0.019	0.021	0.012	0.034	0.031	0.037	0.030	0.029	0.027	0.033	0.031

**APPENDIX II**  
**ANOVA table for site wise EC in soil**

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.008	0.005	0.007	0.004	0.015	0.006	0.011	0.009	0.014	0.015	0.010	0.007
Error	20	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001
Total	29	0.004	0.002	0.003	0.002	0.005	0.002	0.004	0.004	0.005	0.006	0.004	0.003

**APPENDIX III**  
ANOVA table for site wise OC in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	2.103	1.414	1.585	1.808	4.564	3.686	3.869	4.056	5.764	5.170	5.441	4.620
Error	20	0.129	0.054	0.008	0.152	0.047	0.038	0.005	0.048	0.041	0.040	0.009	0.010
Total	29	0.741	0.476	0.498	0.666	1.449	1.170	1.204	1.292	1.817	1.632	1.695	1.441

**APPENDIX IV**  
ANOVA table for site wise CaCO<sub>3</sub> in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	29.549	30.461	32.860	33.568	30.947	30.155	31.455	31.761	24.409	25.076	26.523	26.269
Error	20	0.069	0.020	0.021	0.032	0.010	0.022	0.017	0.021	0.013	0.030	0.022	0.024
Total	29	9.218	9.467	10.213	10.440	9.611	9.373	9.773	9.871	7.584	7.803	8.246	8.169

**APPENDIX V**  
ANOVA table for site wise available N in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	4610.404	4617.677	4782.301	4557.971	7652.210	6188.432	7079.898	6366.656	3058.953	2703.231	3685.399	2592.400
Error	20	6.920	7.002	5.237	9.409	166.626	8.626	30.697	491.642	27.762	7.282	5.936	406.703
Total	29	1435.588	1437.902	1487.775	1421.032	2489.738	1926.497	2218.380	2314.922	968.476	843.956	1147.838	1085.022

**APPENDIX VI**  
ANOVA table for site wise available P in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	149.927	109.365	220.612	136.976	182.515	170.219	209.523	207.850	202.259	184.610	187.515	172.521
Error	20	0.305	0.324	1.487	0.969	0.288	0.247	0.876	0.817	0.278	0.265	1.088	0.933
Total	29	46.739	34.164	69.491	43.178	56.841	52.997	65.629	65.069	62.962	57.475	58.945	54.184

**APPENDIX VII**  
ANOVA table for site wise available K in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	395.415	350.356	385.417	269.144	495.575	554.311	519.171	522.424	402.441	414.652	419.816	366.217
Error	20	1.979	53.546	2.074	1.582	0.622	0.491	1.890	1.731	0.419	0.450	2.299	1.550
Total	29	124.080	145.660	121.042	84.618	154.228	172.367	162.425	163.325	125.185	128.995	131.874	114.722

**APPENDIX VIII**  
ANOVA table for site wise available Mn in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	12.529	8.342	11.862	7.573	9.079	6.624	8.429	6.529	7.602	5.838	6.931	6.003
Error	20	0.041	0.027	0.018	0.016	0.019	0.020	0.009	0.307	0.019	0.022	0.006	0.009
Total	29	3.917	2.607	3.694	2.362	2.830	2.070	2.622	2.238	2.372	1.827	2.156	1.869

**APPENDIX IX**  
ANOVA table for site wise available Fe in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	216.215	83.336	146.118	80.731	121.906	35.754	121.226	36.381	164.050	47.799	164.002	48.029
Error	20	0.038	0.025	24.221	0.132	0.025	0.022	0.002	0.012	0.022	0.021	0.005	0.003
Total	29	67.128	25.880	62.051	25.146	37.850	11.111	37.623	11.299	50.927	14.848	50.900	14.908

**APPENDIX X**  
ANOVA table for site wise available Cu in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	2.986	1.342	2.926	1.320	3.223	1.643	3.230	1.649	2.601	1.024	2.518	1.027
Error	20	0.016	0.011	0.003	0.002	0.015	0.012	0.004	0.023	0.016	0.009	0.001	0.004
Total	29	0.938	0.424	0.911	0.411	1.011	0.519	1.005	0.528	0.818	0.324	0.782	0.321

**APPENDIX XI**  
ANOVA table site wise for available Zn in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.337	0.296	0.323	0.279	0.192	0.180	0.230	0.178	0.181	0.184	0.168	0.196
Error	20	0.009	0.005	0.002	0.003	0.007	0.007	0.001	0.001	0.006	0.007	0.002	0.002
Total	29	0.111	0.096	0.101	0.088	0.064	0.061	0.072	0.056	0.060	0.062	0.053	0.062

**APPENDIX XII**  
ANOVA table for site wise available Pb in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.612	0.397	0.617	0.419	0.579	0.379	0.530	23.821	0.336	0.522	0.339	0.515
Error	20	0.006	0.005	0.001	0.001	0.005	0.006	0.001	0.001	0.006	0.006	0.001	0.001
Total	29	0.194	0.127	0.192	0.131	0.183	0.122	0.165	7.394	0.108	0.166	0.106	0.160

**APPENDIX XIII**  
ANOVA table for site wise available Ni in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.042	0.021	0.041	0.266	0.059	0.038	0.024	0.040	0.045	0.043	0.043	0.053
Error	20	0.004	0.003	0.001	0.000	0.004	0.003	0.001	0.000	0.003	0.002	0.006	0.001
Total	29	0.016	0.008	0.013	0.083	0.021	0.014	0.008	0.013	0.016	0.015	0.017	0.017

**APPENDIX XIV**  
ANOVA table for site wise available Cd in soil

Source of variation	df	Mean sum of square											
		Nalagarh				Baddi				Barotiwala			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Site	9	0.011	0.003	0.009	0.003	0.012	0.005	0.011	0.005	0.019	0.005	0.011	0.008
Error	20	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.002	0.000
Total	29	0.004	0.001	0.004	0.001	0.004	0.002	0.004	0.002	0.006	0.002	0.005	0.002

**APPENDIX XV**  
ANOVA table for chemical properties of soil in location wise study

Source of variation	df	Mean sum of square															
		Ph				EC				OC				Caco <sub>3</sub>			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface		Surface		Sub-surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Sites	9	0.09453	0.07279	0.09794	0.09404	0.01210	0.00741	0.00695	0.00902	3.01018	2.37942	2.71560	3.59189	25.357	27.4386	26.3351	25.6335
Location	2	0.18151	0.21614	0.12950	0.17167	0.04150	0.01229	0.02414	0.02779	1.87687	2.98151	3.43852	2.90251	3.48133	3.75666	3.46351	3.30736
Interaction	18	0.07674	0.07033	0.08254	0.06478	0.01258	0.00641	0.0106	0.00860	4.71054	4.05232	4.08945	3.33941	29.7735	32.0793	32.2511	30.0292
Error	60	0.0018	0.00358	0.00434	0.00376	0.00129	0.00106	0.00094	0.00114	0.07207	0.07011	0.00754	0.04372	0.03079	0.02573	0.02001	0.02379

**APPENDIX XVI**  
ANOVA table for available N, P and K status of soil in location wise study

Source of variation	df	Mean sum of square											
		N				P				K			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Sites	9	4778.986	3835.28	5151.9	4156.166	133.1116	149.3489	163.8908	115.3566	401.7573	250.8682	392.4502	402.5891
Location	2	2803.704	3928.799	3762.613	1979.244	11.452	49.81915	54.98655	16.393	160.3	186.0111	284.6284	210.2386
Interaction	18	5271.291	4851.311	5197.849	4676.587	200.7942	183.9987	226.8801	174.4186	445.8367	453.4587	465.9771	451.6077
Error	60	67.10261	150.9533	13.95671	7.63709	0.290333	0.906296	1.150478	0.278667	1.006667	1.620778	2.087639	0.820147

**APPENDIX XVII**  
ANOVA table for available micronutrients status of soil in location wise study

Source of variation	df	Mean sum of square															
		Mn				Fe				Cu				Zn			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface		Surface		Sub-surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Sites	9	17.45331	11.95244	18.44764	12.97328	197.97	62.02015	206.0368	62.30822	4.099072	1.63986	36.48802	1.635446	0.186484	0.222967	1.580818	0.192911
Location	2	0.05169	0.043795	0.786221	0.08125	8.229	0.736031	26.47261	0.57589	0.19621	0.102029	0.282722	0.23269	0.59977	0.013693	1.253949	0.01684
Interaction	18	5.878223	4.076931	5.586179	3.914917	152.1002	51.56015	112.6548	52.29046	2.355499	1.178294	41.58332	1.186946	0.261714	0.21524	4.908296	0.233584
Error	60	0.026143	0.110535	0.115798	0.02296	0.028543	0.049018	8.07569	0.02245	0.015777	0.009648	0.176133	0.010663	0.007113	0.001804	0.092133	0.006457

**APPENDIX XVIII**  
ANOVA table for available heavy metals status of soil in location wise study

Source of variation	df	Mean sum of square											
		Pb				Ni				Cd			
		Surface		Sub-surface		Surface		Surface		Sub-surface		Surface	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Sites	9	0.845468	7.523255	7.475627	0.736338	0.029427	201.7435	0.509938	0.015477	0.012471	0.003296	0.094565	0.003117
location	2	0.25948	12.71256	0.487927	0.63183	0.083308	195.8456	1.386949	0.03871	0.00133	0.00798	0.010537	0.00325
Interaction	18	0.340824	8.615879	5.90234	0.280608	0.058108	200.9139	0.569496	0.04311	0.014674	0.006176	0.180738	0.00475
Error	60	0.00537	0.000929	0.053867	0.005873	0.003674	202.1167	0.2092	0.00276	0.000627	0.000176	0.081238	0.00073

**APPENDIX XIX**  
ANOVA table for N, P and K content in vegetable leaves

Source of variation	Df	Mean sum of square					
		N		P		K	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Location	2	0.067	0.068	0.003	0.005	0.095	0.101
Error	27	0.277	0.274	0.022	0.022	0.028	0.028
Total	29	0.263	0.260	0.021	0.021	0.033	0.033

**APPENDIX XX**  
ANOVA table for micronutrients and heavy metals in vegetable leaves

Source of variation	df	Mean sum of square													
		Cu		Zn		Fe		Mn		Pb		Ni		Cd	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Location	2	0.2774	0.4015	2.2549	2.2361	0.4510	0.3413	11.5271	11.4124	1.7208	1.5502	0.0595	0.0366	0.0008	0.0011
Error	27	0.1446	0.1727	0.1441	0.1442	11.3097	11.4777	34.9675	34.9520	0.1738	0.1669	0.0057	0.0069	0.0004	0.0003
Total	29	0.1538	0.1885	0.2897	0.2885	10.5608	10.7097	33.3509	33.3286	0.2805	0.2623	0.0094	0.0089	0.0005	0.0004

**APPENDIX XXI**

**ANOVA table for borewell and tap water parameters during pre monsoon season**

Source of variation	df	Mean sum of square														
		pH	EC	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>-</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	COD	Cu	Fe	Zn	Mn	Pb	Ni
Replicates	2	0.021026	0.000188	74.77778	295.1481	15.81481	9	5.444444	6.259259	0.953704	1.37E-06	1.14E-05	2.67E-05	1E-05	7.04E-07	2.78E-06
Season	2	0.523937	0.253353	109.7778	211.3704	123.1481	1528.444	625.4444	571.1481	49.06481	0.000799	1.669301	0.005706	0.007162	0.000129	0.000385
River	2	0.390415	0.287115	1480.333	315.5926	349.4815	745.3333	22.11111	87.37037	60.00926	0.000338	0.001325	0.00603	0.001697	0.000129	0.00011
Interaction	4	0.192943	0.244557	33.11111	263.3704	50.25926	262.9444	91.55556	14.7037	24.39815	9.59E-06	0.022544	0.002557	0.00013	0.000129	0.00011
Error	16	0.000259	2.11E-06	12.77778	1.273148	20.43981	7.208333	5.527778	4.717593	4.05787	1.09E-05	2.47E-05	4.37E-06	8.04E-06	7.04E-07	1.24E-06

**APPENDIX XXII**

**ANOVA table for borewell and tap water parameters during post monsoon season**

Source of variation	df	Mean sum of square														
		pH	EC	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>-</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	COD	Cu	Fe	Zn	Mn	Pb	Ni
Replicates	2	0.021604	0.000128	98.77778	324.037	18.11111	7.148148	0.703704	1.333333	0.444444	0.000271	8.48E-06	2.86E-05	1.04E-06	1.04E-06	5.78E-06
Season	2	0.491404	0.293877	59.11111	400.5926	100.3333	1236.926	726.9259	562.3333	179.1111	0.000313	2.161576	0.008229	0.00761	0.000171	0.000456
River	2	0.372681	0.329052	1665.444	304.7037	313.4444	746.9259	38.37037	140.1111	70.77778	0.00143	0.006181	0.007606	0.001676	0.000171	0.000124
Interaction	4	0.212526	0.283756	6.055556	289.2593	56.11111	267.5926	41.42593	14.94444	19.88889	0.000361	0.00537	0.002932	0.000169	0.000171	0.000124
Error	16	0.00017	2.78E-06	2.486111	1.412037	27.90278	6.314815	5.412037	10.33333	5.652778	0.000278	2.24E-05	3.51E-06	9.12E-06	1.04E-06	2.61E-06

**APPENDIX XXIII**  
**ANOVA table for river water parameters**

Source of variation	df	Mean sum of square																	
		pH	EC	TSS	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>3</sub> <sup>-</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	BOD	COD	Cu	Fe	Zn	Mn	Cd	Pb	Ni
Replicates	2	0.000706	60.22222	5.722222	80.72222	301.3889	113.1667	12.72222	24.22222	30.38889	526.3789	32.88889	0.000113	0.000145	7.74E-05	4.36E-05	7.77E-05	0.00078	3.5E-06
Season	1	0.004356	60204.5	102.7222	696.8889	206.7222	272.2222	272.2222	193.3889	355.5556	131.9771	98	0.000321	0.006536	0.000338	0.000534	5E-05	0.000968	6.81E-05
River	2	0.074572	1.46E+08	12915.06	2579131	2233.556	5400.167	9484.222	502.0556	429593.7	75364.15	509746.1	88	0.47877	0.01419	0.09311	5.77E-05	0.000134	0.000229
Interaction	2	0.001206	48840.17	11.72222	65.05556	6.222222	24.38889	9.555556	36.72222	35.38889	142.4118	8.166667	5.06E-06	0.001645	4.87E-05	5.72E-06	5E-07	0.000649	2.89E-06
Error	10	0.000939	0.488889	9.655556	0.522222	1.122222	1.433333	5.855556	1.755556	0.322222	485.2614	0.822222	2.67E-07	6.56E-07	3.22E-07	1.07E-05	8.56E-07	0.00056	1.28E-05

**APPENDIX XXIV**  
**ANOVA table for microbial activity in surface soils**

	<b>12h</b>	<b>24h</b>	<b>36h</b>	<b>48h</b>
Nalagarh	0.9	1.3	0.7	0.2
Baddi	1.1	1.6	0.9	0.3
Barotiwala	0.6	1.2	0.7	0.4

**APPENDIX XXV**  
**ANOVA table for microbial activity in sub- surface soils**

	<b>12h</b>	<b>24h</b>	<b>36h</b>	<b>48h</b>
Nalagarh	0.7	1	0.5	0.1
Baddi	0.9	1.2	0.6	0.15
Barotiwala	0.4	1	0.4	0.3

**APPENDIX XXVI**  
**ANOVA table for microbial biomass at Nalagarh**

<b>Pre-monsoon</b>		<b>Post-monsoon</b>	
<b>Surface soils</b>	<b>Sub-Surface soils</b>	<b>Surface soils</b>	<b>Sub-Surface soils</b>
56.34	58.72	36.14	43.78
35.78	44.89	31.24	35.24
53.45	59.46	37.14	43.62
62.79	69.12	41.75	52.36
55.96	59.99	35.55	43.88
43.56	52.45	34.78	39.44
84.34	89.87	53.48	69.72
58.87	69.67	43.84	51.54
74.59	80.19	55.99	65.67
41.97	56.68	33.65	39.56

**APPENDIX XXVII**  
ANOVA table for microbial biomass at Baddi

Pre-monsoon		Post-monsoon	
Surface soils	Sub-Surface soils	Surface soils	Sub-Surface soils
59.34	73.45	42.34	56.45
41.45	56.87	32.15	42.16
45.39	58.89	33.66	49.87
94.76	108.83	73.14	92.88
40.34	53.57	34.69	43.43
82.56	91.22	45.98	74.15
34.16	42.09	27.56	33.81
43.04	56.2	32.56	41.54
45.49	59.13	35.69	44.83
59.92	72.45	36.18	58.91

**APPENDIX XXVIII**  
ANOVA table for microbial biomass at Barotiwala

Pre-monsoon		Post-monsoon	
Surface soils	Sub-Surface soils	Surface soils	Sub-Surface soils
45.14	58.52	33.78	42.95
54.89	59.98	36.02	54.19
45.62	59.53	35.83	44.12
56.12	71.14	36.14	58.54
119.26	128.45	91.35	109.67
42.93	55.88	32.69	43.07
43.91	58.76	33.76	44.86
71.52	87.14	45.73	71.02
87.59	95.15	64.43	80.78
54.67	70.83	36.56	56.03

## *CURRICULUM VITAE*

**Name** : Mr. Neetan Khajuria

**Father's Name** : Sh. N. L. Khajuria

**Date of Birth** : 30 NOV, 1981

**Sex** : Male

**Marital status** : Unmarried

**Nationality** : Indian

**Educational qualifications:**

Certificate/Degree	Class/Grade	Board/University	Year
Matriculation	First	J&K Board	1997
10+2	First	J&K Board	1999
B.Sc. (Forestry)	First	UHF, Nauni, Solan	2003
M.Sc. (Soil Science and Water Management)	First	UHF, Nauni, Solan	2005

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other financial assistance received  
during the study period** : Nil

*(Neetan Khajuria)*