INTRODUCTION
Chapter-I

General Introduction

Coffee belongs to the genus *Coffea* of Rubiaceae family. This genus includes over 80 varied species but the commercial exploitation is confined to only two species of *Coffea arabica* (arabica) and *C. canephora* (robusta). The arabica coffee (*C. arabica* L.) is indigenous to Ethiopia, where it was discovered around later part of ninth century and was later cultivated in the Arabian colony of Harar. Further, it spread to Mecca from where Baba Budan, a pilgrim from India introduced it to Chikmagalur in Karnataka state during the dawn of seventeenth century. As the coffee flourished, by the turn of the century, full fledged estates were developed in Chikmagalur and Coorg (Karnataka state) on the southern slopes of the Western Ghats as well as in the Nilgiri Hills (Tamil Nadu) during the later part of eighteenth century. The arabica coffee is a small statured plant with deep rooted system compared to the robusta. For arabica coffee, geographic requirements such as elevation of 1000-1500 m above MSL and terrain slopes of North, East as well as North-East aspects are found to be ideal. The optimal mean temperature variation between $15^\circ$ C and $25^\circ$ C with relative humidity around 70 per cent seems to be congenial. Moreover, arabica coffee tolerates minimum temperature of $12^\circ$ C and maximum of $30^\circ$ C during extreme diurnal temperature fluctuations. A total annual rainfall between 1600 and 2000 mm is favorable. The other species commonly called as robusta (*C. canephora*) owing to its growth and stature
belongs to North Angola (Clarke et al, 1988), is a shallow rooted compared to arabica. The robusta coffee performs well in the elevation of 500-1000 m MSL with land slopes of North, East as well as North-East aspect. Even though the optimal mean temperature is 20 to 30°C, it can tolerate a minimum of 15°C temperature during night. A well distributed total annual rainfall between 1000 and 2000 mm is favorable with the atmospheric humidity around 70 per cent.

In the global scenario coffee is considered as one of the most important beverages. It is an important agricultural commodity in the world market and is widely grown in tropical region between Tropic of Cancer and Tropic of Capricorn (Smith 1985) of about 50 countries. Major coffee producing countries of the world are Brazil (30%), Vietnam (15%), Colombia (10%), Indonesia (5.4%), Ethiopia (5%), Mexico (3.7%) and India (3.6%). On the global scale, out of the annual production (2007-08) of 7.14 million tonnes, about 70 per cent and 30 per cent are contributed by arabica and robusta respectively. However, in India out of 262 thousand tons total production (2008-09) major contribution (70%) is from robusta compared to arabica (30%).

Coffee plants prosper well in deep, permeable, slightly acidic and porous soils with favorable texture. The coffee growing soils of India belong to the red and lateritic soil groups. They differ in texture from sandy loam to clay loam with varying color from light grey to deep red. Usually these soils are rich in organic matter with acidic to near neutral reaction (6.0–6.5 pH). The total
soluble salts are well below the sensitivity limits. These are adequately supplied with potassium but are generally poor in furnishing available phosphorus. They are also poor in calcium and magnesium and the response to liming is evident. Further, manuring and other soil management practices to replenish the limited nutrients were found to reveal favorable results.

In India, coffee is cultivated over an area of 380 thousand hectares mainly in the Southern states of Karnataka (58%), Kerala (22%) and Tamil Nadu (8%), while the remaining area (12%) accounts to the non-traditional regions (Andhra Pradesh, Orissa and North-Eastern states) with the annual production of 260 thousand tonnes during 2007-08 (Database on coffee 2009). However, the yield realized over the past years is subjected to vagaries of monsoon.

Despite the fact that most of the coffee growing areas are confined to heavy rainfall regions; the uniform distribution throughout the year is not ensured. Owing to this the crop is exposed to more periods of dry spells leading retarded vegetative growth besides substantial reduction in yield attributes. During this dry spell the established robusta is generally irrigated (1 to 1.5 inches) with the help of over head sprinkler during second fortnight of February to induce blossom and again after twenty days as backing irrigation (1 to 1.5 inches) for fruit set. On the other hand, the young arabica plants needs irrigation (@ 8 liter/plant once in 10 to 15 days) during dry period from the month of February to May. During this period of dry spell availability of pond water for irrigation is generally a serious constraint in most of the plantations. Moreover
this period normally coincides with the processing schedule in the coffee industry which still worsens the scenario.

Coffee is processed either by wet method or dry method to produce washed and unwashed coffee respectively. The wet method of processing of coffee fruits results in superior quality beans as compared to dry method of processing. Around 75–80 per cent of arabica and 10–15 per cent of robusta is produced by wet method as washed coffee (Shanmukappa et al 2001). In recent times the production of robusta by wet method is gaining momentum owing to the growing demand in the domestic as well as intercontinental market. Robusta berries have a thicker and stickier mucilage layer than arabica (Ramprasad, 1997) and hence require a higher quantity of water to process robusta berries. Depending upon the methods adopted and availability of water for processing, the total quantum of water required for wet processing varies from 8m$^3$ to 20m$^3$ of water per metric tonne of clean coffee (Deshpande et al 2001). As per the report of Ramamurthy et al. (1998), the quantum of waste water generated through coffee processing in India is to the tune of 2.078 X 10$^6$ m$^3$ (1.428 x 10$^6$ m$^3$ for arabica and 0.65 x 10$^6$ m$^3$ for robusta coffee processing).

Coffee processing industry is one of the prime agro-based industries in India. Since coffee occupies an important position among the export commodities invariably it needs proper processing in order to harness the international market besides achieving optimum production by culmination of
water stress in active growth periods. For treating coffee wastewater, planters are using different methods viz., NEERI method (National Environmental Engineering Research Institute, Nagpur), Modified NEERI model, Bioreactors etc (Jayaprakash, 1999). Though the wastewater is subjected to treatment in Effluent Treatment Plants (ETP's), the desired results are not achieved so far and efforts on improvisation are in progress.

At present, because of high cost involvement in ETP's construction and unreachable results on pollution load fixed by Pollution Control Board (PCB) after treatment, coffee growers have been employing rudimentary land based effluent storage and treatment facilities (Damodaran, 1998) and also use as irrigational source for raising crop plants. Continuous application of strong acidic waste waters makes the soil sick, necessitating soil ameliorative measures (Manjunath, 2001).

Indeed low moisture content of the soil slows down the pace of vegetative growth in coffee (Gopal and Vasudeva, 1973) besides affecting the very blossom pattern, fruit set and fruit ripening processes. Even though Mayne (1944) is of the opinion that fruit development has an antagonistic effect on the vegetative growth but optimum vegetative growth should be ensured in order to sustain the productivity of the perennial plant. Generally low growth is observed from December to February (low temperature regime) which characterized as dormant period in coffee (Mayne, 1944; McFarlane, 1949; Boss, 1951) after which it needs to be accelerated by adequate supply of nutrients and water. The nutrient requirement of coffee plants is comparatively on the higher side with
the mandatory dual functions of contribution to the current yield besides
maintenance of optimum vegetative growth for the subsequent season. In order
to produce one ton clean coffee the major nutrients required are 120:90:120 kg
N: P\textsubscript{2}O\textsubscript{5}: K\textsubscript{2}O, respectively per unit area (CCRI recommendation) which will
address the yield obligation along with optimum vegetative growth. There is
little information on nutrient uptake and accumulation in a growing coffee plant.
Studies of Palaniappan (1993) on growth and nutrient accumulation in young C.
Liberica plants revealed that as the yield increased, there was a greater
partitioning of dry mater as well as the nutrients N and P towards berry
development than for vegetative growth but this is not the case in Ca. In trees
yielding 1.5 ton green coffee ha\textsuperscript{-1} yr\textsuperscript{-1}, the amount of nutrients taken by the
plants for berry development and vegetative growth would be 109 kg N, 18 kg
P\textsubscript{2}O\textsubscript{5}, 125 kg K\textsubscript{2}O, 81 kg CaO, 19 kg MgO and 50 kg SO\textsubscript{4}.

Similarly, Cannell (1971.a,b) reported that C. arabica can set and retain
over 8000 fruits each (on a single stem), which will take over 70% of the net
total carbohydrate production of the whole tree and over 90% of the total
amount of mineral nutrients taken up from the soil. According to Wormer and
Gituanja (1970), heavy crop of fruits does not greatly inhibit floral initiation in
coffee, as it is common in some perennial fruit crops.

In order to combat the prime predicament of water scarcity besides
substantial contribution to the nutrition management the option of utilizing the
effluent from the processing industry can be triggered. The direct utility of effluent from the industry without proper treatment for irrigation is not advisable owing to serious environmental repercussions. Moreover, the quantum of pollutants and concurrent impact on BOD and COD on terrestrial as well as aquatic environment are relatively very low in the effluent of coffee processing industries when compared to other industries like chemical, metals, distilleries, leather, textiles, paper and pulp processing units. Despite the lower quantity of discharge charged with lower contaminants from these units, keeping in view the most fragile eco-system evolving adequate amelioration methods achieve least level of pollution forms the framework of the study.

Prior to this it is high time to understand various steps involved in coffee processing and different types of wastes generated in order to meticulously plan the options of irrigation.

In wet processing of coffee, water is used for conveying and gravity sorting of heavy fruits from floats and dried berries. Later water is essential for pulping of fruits, washing and soaking of parchment coffee. The primary waste products from various stages of processing are:

- **Liquid waste**
  - a. Pulper waste (Cellulose, sugars and polyphenolic compounds)
  - b. Aqua washings (Sugars, pectins, proteins and cellulose)
c. Seed wash / soaked water (sugars and pectins)

Solid waste

Coffee pulp (skin)

The effluent emanating from the processing unit will be rich in both suspended and dissolved solids which are biodegradable (Anonymous 2005). This effluent, if discharged without treatment into natural water bodies would pollute the water by depleting dissolved oxygen present in it (Anonymous 2005). Pollution of natural water bodies will have an adverse effect on domestic user, aquatic life, livestock and coffee processing units in the downstream. The problem of water pollution will be aggravated in coffee tracts because the processing period coincides with the dry season when the flow in natural water bodies will be at minimum level. Coffee effluent contains a Biological Oxygen Demand (BOD) level ranging between 12,000 and 30,000 ppm and is highly acidic (Anonymous 2005).

In the wet method coffee with mucilage is obtained after pulping and later mucilage is removed by subjecting coffee fruits to fermentation followed by washing. Biochemically, the fermentation is hydrolysis of pectins caused by pectinolytic enzymes like pectinase, pectase, protopectinase and pectinesterase. Although all these enzymes are present in coffee fruit, microorganisms such as Saccaromyces having pectinolytic properties could accelerate the process.
Development of undesirable microorganisms results in off-flavour of coffee and production of unwanted toxic compounds in effluents (Bernhard, 1980). During fermentation, only little amount of water is absorbed by raw materials and after the wet process; the effluents are discharged as it is composed of 85% water and 15% solids. Solids are known to contain 8.9% protein, 4.1% sugars, 1% pectic acid and 0.7% ash.

During the wet processing of coffee, large quantities of pulp, pulp effluent and husk are generated as major byproducts (Mburu and Mwaura, 1996). Wet coffee processing is a seasonal (45–75 days per year) farm based operation as opposed to year bound industry scale processing. However, methods for evolving economically viable treatment methods for coffee effluents and waste utilization by effective degradation have to be fine-tuned to minimize environmental pollution. Utilization of treated coffee pulp effluent for irrigation would be a viable option for farmers to grow short duration crops like baby corn in paddy falls during rabi-summer or otherwise these effluents will flow into natural watercourses as pollutants (Dhanajaya, 2005). In this study, various physico-chemical properties of soil did not differ significantly due to effluent irrigation except a slight increment in available N, available K₂O and DTPA extractable Mn. Even though, coffee pulp effluent is very poor in phosphorus but it has slightly higher concentration of nitrogen and potassium (N: 0.06, P: 0.003 and K: 0.045 %) which will be supplemented as nutrients. Moreover, it contains appreciable quantity of micronutrients (Fe: 16.09, Mn: 0.48, Zn: 0.55
and Cu: 1.46 ppm) which will address the predominant Zn deficiency in coffee. Higher yields realized in baby corn and fresh fodder upon effluent irrigation with proper dilution and application of soil amendments stands as testimony for coffee performance.

Presently, neutralization of effluent with lime and storing in the storage pits is being adopted for treatment of pulp wastewater, which may not effectively protect the aquatic environment (Alwar, 1998) owing to seepage losses. Hence, there is a great need to conduct environmental impact assessment studies to overcome the problems of pollution and to suggest safer ways of waste disposal for better purposes like irrigation in agriculture in the locales where this effluent is generated.

Therefore, attempts were made in this study to utilize the bio-enriched coffee effluent for irrigating young Arabica and established robusta coffee and also to tackle the problem of pollution and finding some safe ways of disposal of effluent with the following objectives.
Objectives:

1. To characterize the coffee effluent with environmental perspective and suggestion of possible treatment methods using zeolites as ameliorants

2. To assess the impact of levels of coffee pulp effluent application on nutrient dynamics in soil.

3. To utilize the bio-enriched treated and untreated coffee effluents for irrigating coffee plants and study their performance on growth of young arabica and growth and yield of robusta coffee.

The work carried out in the present investigation is discussed in the following chapters:

Chapter -II: To characterize the coffee effluent with the environmental perspective and suggestion of possible treatment methods using zeolites as ameliorants

Chapter-III: Effect of coffee pulp effluent on the performance of young arabica coffee plants and on soil properties.

Chapter-IV: Effect of coffee pulp effluent on the yield attributes, yield of established robusta coffee plants and soil properties