ECOLOGICAL STUDIES ON THE AFFECTED AND NON-AFFECTED FOREST IN COAL MINING AREAS OF CHANGKI IN MOKOKCHUNG DISTRICT, NAGALAND

THESIS SUBMITTED

TO

NAGALAND UNIVERSITY

IN FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF

DOCTOR OF PHILOSOPHY IN BOTANY

By

Mr. KHIKEYA SEMY

Registration No.: Ph. D./BOT/00072

Date: 29th August, 2017

DEPARTMENT OF BOTANY

SCHOOL OF SCIENCES

NAGALAND UNIVERSITY

HQ: LUMAMI – 798627

2022

Nagaland University

(*A central University Estd. by the Act of Parliament No.35 of 1989*)
Headquarters: Lumami, Dist: Zunheboto, Nagaland, India, Pincode-798627

March , 2022

DECLARATION

I, Mr. **Khikeya Semy** bearing Ph.D. Registration No.: Ph.D./BOT/00072 dated 29/8/2017, hereby declare that the subject matter of my Ph.D. thesis entitled "**Ecological studies on the affected and non-affected forest in coal mining areas of Changki in Mokokchung district, Nagaland**" is the record of original work done by me, and that the contents of this thesis did not form the basis of the award for any previous degree to me or to anybody else to the best of my knowledge. This thesis has not been submitted by me for any research degree in any other University/Institute.

This is further certified that the Ph.D. thesis is submitted in compliance with the UGC Regulation 2018 dated 6th August, 2018 (Minimum Standard and Procedure for Award of M. Phil. /Ph.D. Degree). Further, it is certified that the content of the thesis is checked for 'Plagiarism' with licensed software 'URKUND' and satisfies with the norms of 'University Grants Commission', Govt. of India. This thesis is being submitted to Nagaland University for the degree of 'Doctor of Philosophy in Botany'.

Place:

Date:

(Khikeya Semy)	**(Dr. M. Romeo Singh)**	**(Prof. Chitta Ranjan Deb)**
Candidate	Assistant professor Supervisor	Head, Department of Botany

Nagaland University

(*A central University Estd. by the Act of Parliament No.35 of 1989*)
Headquarters: Lumami, Dist: Zunheboto, Nagaland, India, Pincode-798627

CERTIFICATE

This is to certify that the thesis entitled "Ecological studies on the affected and non-affected forest in coal mining areas of Changki in Mokokchung district, Nagaland" is a record of original research work carried out by Mr. Khikeya Semy under my supervision. He is a registered research scholar bearing the registration no.: Ph.D./BOT/00072 dated 29/8/2017 of the Department of Botany and has fulfilled all the requirements of Ph.D. regulations of Nagaland University for submission of thesis. The work is original and neither the thesis nor any part of it has been submitted elsewhere for the award of any degree or distinctions. The thesis is therefore forwarded for adjudication and consideration for the award of degree of Doctor of Philosophy in Botany under Nagaland University.

Place:

Date:

(Khikeya Semy)
Candidate

(Dr. M. Romeo Singh)
Assistant professor
Supervisor

(Prof. Chitta Ranjan Deb)
Head, Department of Botany

Ph. D. Coursework Marksheet and Certificate

Sl. No. : 16- 59055

NAGALAND UNIVERSITY

STATEMENT OF MARKS

Ph. D COURSE WORK EXAMINATION 2017

DEPARTMENT OF BOTANY

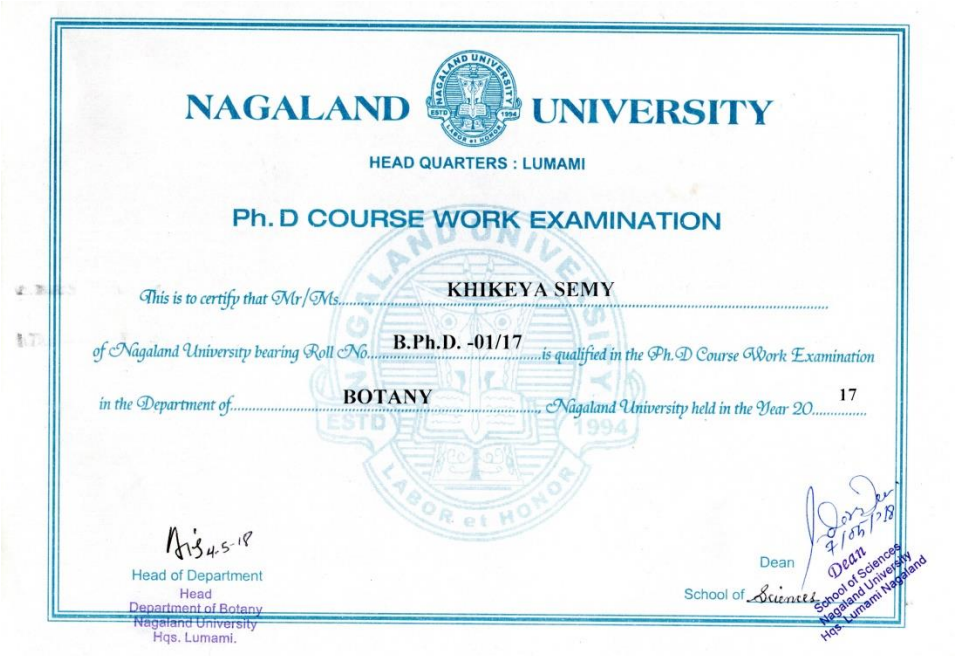
The following are the marks secured by ***Khikeya Semy***
Roll No. ***B.Ph.D. -1/17*** *of Ph.D Course Work Examination held in* **2017**

Subject(s)/Paper(s)	Max. Marks	Minimum Qualifying Marks	Marks Secured
Paper No. B.Ph.D -1 Research Methodology	100	35	**80**
Paper No. B.Ph.D -02 Elective Paper	100	35	**72**
Paper No. B.Ph.D -03 Review of literature, Report Writing & Seminar	100	35	**81**
Total Aggregate Marks			**233**
Average Pass Mark – 55 %			

Result	Division	Percentage
Passed	**I Division**	**77.66%**

Marks compared by : 10 APR 2018

COE/Dy. Reg./AR (Exams)



NAGALAND UNIVERSITY

HEAD QUARTERS : LUMAMI

Ph. D COURSE WORK EXAMINATION

This is to certify that Mr/Ms. **KHIKEYA SEMY**

of Nagaland University bearing Roll No. **B.Ph.D. -01/17** *is qualified in the Ph.D Course Work Examination*

in the Department of **BOTANY** *Nagaland University held in the Year 20* 17

Head of Department
Head
Department of Botany
Nagaland University
Hqs. Lumami.

Dean
School of Sciences

Dean
School of Sciences
Nagaland University
Hqs. Lumami Nagaland

ACKNOWLEDGEMENT

Praise be to God, the research work presented in this thesis would not have possible without God's grace and the many people who have rendered their selfless service. As I finally put my works into writing, I cannot help but remember all those wonderful souls who have relentlessly assisted me through this laborious yet delightful expedition. I take this humble opportunity to wholeheartedly thank them all for making this Ph.D. thesis possible.

Firstly, I would like to extend my sincere gratitude and appreciation to my research supervisor **Dr. Maibam Romeo Singh** for his help and dedication throughout my Ph. D. programme. Without his supervision and constructive criticism, the completion of my thesis work would not have been possible. I thank him sincerely for his concern and welfare towards my scientific progress and feel privileged and fortunate to have worked under his direction. I also thank the faculty members of the Botany department for their insightful comments and encouragements including all my fellow researchers for their unwavering support whenever needed.

I am grateful for the financial supports provided to me by Council of Science and Industrial Research (CSIR), Government of India, National Eligibility Test (NET) JRF-fellowship, File no: 09/763(0012)/2017-EMR-I. Besides, I thank the Head Department of Botany for providing all the necessary research facilities. I also sincerely thank the Department of Biological Sciences and Technology Division, CSIR, NEIST, Jorhat for assisting in heavy metal analysis. I am grateful to Remote Sensing Centre, Nagaland Science and Technology Council, Department of Science and Technology for providing the study area map and I convey my sincere gratitude to Soil and Water Conservation Department, Government of Nagaland for the Ombrothermic datas.

I feel a deep sense of gratitude for my parents, families and friends who formed part of my vision and motivated me to proceed with my research. Their patience and sacrifice will forever remain my inspiration and their infallible prayers and love will continue to be my strength. Finally, I dedicated this piece of research to my late mother who unfortunately could not be present to witness the successful completion of this humble work.

(Mr. Khikeya Semy)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTO PLATES

CHAPTER-1

INTRODUCTION AND REVIEW OF LITERATURE

Forest ecosystems are a vital part of the world's biodiversity accounting to 31 % of the global land area (FAO and UNEP, 2020). Indian forests cover 24.62% of its total geographical area and vary from tropical evergreen forests in the Andaman and Nicobar Islands, Western Ghats and Northeastern states to dry alpine scrub in the high Himalayan region (Forest Survey Report, 2021). Among different types of forest, tropical forests are regarded as the most diverse and species rich terrestrial ecosystems of the world (Bhatt and Sachan, 2004). The tropical forests acquire high radiant energy, serve in the global carbon stock and are a crucial source of hydrological fluxes with profound influences on both global and regional climates (Kanae *et al*., 2001). Forests plays a vital role in the economic development of the country as it provides resources for basic livelihood especially for the poor and rural populations which accounts to more than 1.6 billion inhabitants living in the forest including immigrants who are directly dependent on the food, fiber, fodder, fuel and other resources derived from the forest (USAID, 2007). However, rapid industrialization, urbanization and over-exploitation have resulted not only in decline but also in permanent loss of forest cover at an alarming rate (Nagdeve, 2007). The Food and Agricultural Organization (FAO, 2015) coordinated the Global Forest Resources Assessment (FRA) and reported a 3.16% decline in the global forest cover from 1990 to 2015, with total forest cover standing at around 30.6% in the present time compared to 31.6% in 1990. The rate at which the forest cover is declining poses a serious threat in the coming years if not monitored. With

an estimated annual loss of 18.7 million acres, future demands on forest resources will almost certainly lead to intense competition among nations (Bradford, 2018). The relationship between forest change and the variables that drive it are frequently complicated and nonlinear (Mas *et al*., 2004). Increased demand for human necessities has fueled agricultural, logging, and ranching practices, as well as infrastructure development and re-settlement projects, which has proven to be an inexorable factor for deforestation in recent decades. Culas (2009) stated that the dynamic nature of global ecosystems makes environmental changes inevitable which are driven by human-made and natural causes; as human activities have always had an impact on environment the economic activity and the rate of population growth have now increased to the point where the effects of humanity on the environment can no longer be ignored or viewed in isolation while the quality of many of the basic natural elements such as air, water, soil, etc., is deteriorating, due to the widespread depletion of forest resources. Various anthropogenic activities degrade the environmental quality and one such developmental project is 'Coal mining'.

Coal mining is a process of extracting coal by excavating through surface (Open cast) or underground mining depending on the nature of the coal seam. Open cast mining, also known as open pit or open cut mining, is a type of surface mining technique of extracting coals from the earth when coal seams are near the surface while underground mining are required when coal seams are too deep for opencast mining. Coal is a combustible sedimentary rock which is black or brownish-black, formed as rock strata. It is mostly carbon with variable amounts of other elements; chiefly hydrogen, sulfur, oxygen, and nitrogen (Blander, 2010). Unlike most rocks, which consist predominantly of crystalline mineral grains, coal is largely an assemblage of amorphous, degraded plant remains metamorphosed to various degrees and intermixed with a generous sprinkling of minute syngenetic, diagenetic, epigenetic and detrital mineral grains, and containing within its structure consist of water, oils and gases (Orem and Finkelman, 2003). Coal is formed from the remains of dead organic matter that decays into peat and further converted into coal by the heat and pressure of deep burial over millions of years (USIA, 2017). Major deposits of coal originates in former wetlands which are called coal forests as it covered much of the Earth's tropical land areas during the late Carboniferous (Pennsylvanian) and Permian times (Cleal and Thomas, 2005; Sahney *et al*., 2010).

During the historical period of worldwide industrialization, the level of human population has been closely related to the amount of energy used (Krausmann *et al*., 2009). Ever since the Industrial revolution beginning in the mid-18th century, the global socio-economic development has depended heavily on mining industry for provision of resources (Yuan *et al*., 2013). Currently, energy is mostly produced by burning of fossil fuel such as coal (Veziroglu and Sahin, 2008). It is seemingly the cheapest and most essential source of energy and is used from large scale generating power industries to domestic household use. In India, coal is significantly the most important and abundant fossil fuel because with abrupt rise of population, growing economy and a quest for improved quality of life, energy demands in India is rising. Thus, exploitation of coal by government or private sector is a common practice at various parts of the country. Mining not only fulfills the increasing energy demand of industry, but also plays an important role in the economic development of the country (Chaulya and Chakraborty, 1995). In order to counter the energy requisite, the overall coal production and coal mining have staggeringly increased in India, which ranks second amongst top ten coal producing countries and stood fifth in its reservoir (SRWE, 2015). According to the Ministry of Coal mining in India, (MOC, 2005) coal exploitation for commercial purpose began in 1774 by the East India company at Raniganj coalfield, West Bengal along the Western bank of Damodar river. Jharkhand, Odisha, Chhattisgarh, West Bengal, Madhya Pradesh, Telangana and Maharashtra accounts for 98.26% of the total known coal reserves in India while Jharkhand and Odisha have the largest coal deposits of 26.06% and 24.86% respectively (Energy Statistics, 2019). Ministry of Coal (MOC, 2005) reported that the Gondwana and Tertiary coal fields are distributed in different region of the country; the Gondwana coalfields are found in Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Sikkim, Telangana, Uttar Pradesh, and West Bengal while the Tertiary coalfields are located in the states of Arunachal Pradesh, Meghalaya and Nagaland. In North-east India, coal mining was initiated by Medlicott in 1869 and 1874 (Sarma, 2005). Most of the coal extraction in the NE tribal states is done using primitive sub-surface mining method i.e., 'Rat-hole' and the open cast mining. In ortheast India extensive mining are done in Jaintia Hills, Makum, West Daranggiri, Garo Hills, Khasi Hills and Namchik. The constitution of India provides special privileges to the NE Indian states as the Sixth Schedule of constitution and Article 371 of constitution allows the state governments

to formulate its own policy to recognize customary tribal laws. As such, Nagaland and Meghalaya have its own coal policy which allows its natives to mine coal from their respective lands.

In developmental process coal mining is a major industry, which is contributing inadvertently towards the environmental pollution but also plays a vital role for the development of the country. Moreover, the central impact of mining is long term are devastating, as it shades negative impacts on local air and water quality, depletion of natural resources, decrease in rainfall, loss of cultivable land, etc. (OECD, 2002). In India, rapid urbanization, coupled with widespread commercialization of coal to suffice the energy need of the country, has put great pressure on the environment. Every one million tons of coal extracted by surface mining methods damages 4 ha surface area of land (Ghosh, 2002). A report given by MOC (2005) estimated that taking in consideration the rising demand and the need for mining, clearing of forested land will increase from 22000 ha in 2005 to 75000 ha by 2025. Dittmann *et al*. (2002) stated mining as an important source in productions of raw materials and minerals to fulfill industrial and domestic needs. As such major dependency on the mining industry for fuel supply and energy is vital for an economy (Brunn *et al*., 2001). However, as reported by Meng *et al*. (2009); Yang *et al*. (2016); Shi *et al*. (2017) and Wang *et al.* (2017) mining method causes land subsidence, which destroys soil structure, changes its properties and causes eco-environmental damages such as reduction in crop yields restriction of vegetation growth, soil erosion, changes in topographic and hydrologic conditions, and loss of agricultural land and top soil. The impacts can range from minimal to significant level depending on the range of factors associated with nature of ongoing mining activities and also post mining management or rehabilitation of the affected landscapes on a given area. The local environment sensitivity also plays a role in determining the magnitude of the associated problems as ecologically fragile environment are highly vulnerable, attracting long term ecological affects. Seemingly, direct effects of mining includes degradation of arable lands, loss of forests covers and the overall reduction of land productivity; whereas the indirect effects may include soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Xia and Cai, 2002; Wong, 2003). These problems can interact with each other,

develop through time and space and speed up the environmental deterioration of coal mining affected areas.

To infer the mining operation entirely on development and its consequences depicted by various workers can be summed up as; the development projects which have been initiated to reckon the country in the threshold of economic development have always proven to be injurious (Appiah and Buaben, 2012). As such, the drive to accomplish quick economic stability in both developed and developing countries are utterly involved in harnessing the natural resources. Of the development activities, mining plays an important role in improving the economic aspects of a country (Yeboah, 2008). As the obvious reason of mining, diverse range of challenges is occurring, despite voluminous growth, both in the fields of medical science and health, for decades environmental factors remain a prominent cause of diseases and death globally. Even the continuous release of several minute pollutant particles is causing climate change in a wider aspect (Castleden *et al*., 2011). Ecological imbalance is also adding one more feather in the aspect of environmental pollution (Fashola *et al*., 2016). Hence, it can be stated that economy cannot be fortified in its truest sense, whereas the broader impact of mining is on environment (Obiri *et al*., 2016). Frelich (2019) stated that the ecological footprint of mining activity extends well beyond the area directly impacted; it can be divided into primary and secondary areas. The primary footprint is the area directly impacted by the mine excavation, processing/rock crushing facilities, roads and energy transmission network built to accommodate the mine and workers while the secondary footprint comprises adjacent areas affected through mining activities and changes in the landscape that can propagate ecological changes for various distances; this includes such items as fragmentation, changes in forest type within the primary footprint, changes in wildlife migration and habitat use patterns, noise, windblown dust and watershed areas affected by water withdrawals and mine drainage (Shotyk *et al*., 2016). Frelich (2019) reported that the effects of the secondary footprint gradually decline with distance from a mine, and the various types of impacts should always be defined in terms of ecological impacts judged to be significant and the distance and spatial pattern within which those effects are estimated to occur and as such, distances and spatial pattern will vary by type of impact, and the spatial pattern could be directed by flow of water and air, animal movements and seed dispersal away from the mine site.

Nagaland, one of the seven north-eastern states of India possesses rich deposits of various minerals including the fossil fuel "Coal". The state has moderate coal reserves of approximately 316.41 million tonnes and mining takes place across the districts of Mokokchung, Wokha, Dimapur, Longleng, Mon, and Peren (Government of Nagaland, 2009; 2014a, 2014b). Nagaland contributes 21 % of the total tertiary coal reserves in north east (Ministry of Coal, 2014). The first coalfield in Nagaland was founded in 1907 by the East India Company at Borjan and Kongan soil near Naganimora (Nagaland Coal, 2017). According to NPCB (2015), some of the mining sites identified in Nagaland are Kongan, Borjan, Tiru and Pongkong areas in Mon district, Bur Namsang in Longleng, Tsopo, Baghty and Samutra river area in Wokha district, and Merangkong, Khar, Mongchen and Aonokpu areas in Mokokchung district. Nagaland coal is typically the 'Tertiary coal' which was formed during the Oligocene period of the Tertiary Era (15 to 60 million years old). The Oligocene coal deposits occur in pericratonic downwarps in the 'belt of Schuppen' over the northern flank of the Naga-Patkai range and extend over the states of Nagaland, Assam and Arunachal Pradesh (Biswas *et al*., 1994; Mishra and Ghosh, 1996). In Nagaland coal excavation is done by the primitive mining method commonly known as 'rat-hole' mining and the open cast mining. In rat-hole mining, the forest land is initially cleared by felling trees and removing the ground vegetation, followed by burrowing pits ranging from 10 to 60 m^2 which are dug vertically into the ground to reach the coal seam. Thereafter, tunnels are made horizontal following the trace of the seam for extraction process, which is then carried manually by using a bamboo conical basket or a wheel barrow. While in Open cast method the operation is processed by first manually clearing a very large area of land by the local laborers using handmade tools; later, the vegetation of the forest are felled completely followed by employing mechanic tractors to strip off the mountain or excavate the plains. The extracted coals are taken out and dumped at nearby un-mined areas; from there it is carried to the larger collecting point or station usually near a highway for its trade and transportation. For many communities in the frontier, coal is the most accessible and controllable resource, particularly given the methods of extraction common at the local level (McDuie-Ra and Kikon, 2016). In Nagaland, the state government imposed the ban on coal mining in an attempt to capture control of coal extraction and trade and partly over concern for the environment. However, local communities over the years have opposed the bans, and

in some areas resumed mining under the authority of tribal councils and civil society. McDuie-Ra and Kikon, (2016) politicised three main arguments that contributes to understanding coal mining and communities in frontier regions with respect to Nagaland. First, the majority of the coal mining activity has been initiated and managed by members of tribal communities rather than profit-driven outsiders. Second, in contrast to other contexts in India where large state or private enterprises seek to modify the law to enable coal extraction, in Nagaland it has been communities that resent and challenge state and national laws being applied to their lands. Third, the right to extract coal is connected to the right of tribal communities to determine what happens on their lands based on Article 371 (A). In recent years the intensive scale of coal mining, and the concerns related to environmental degradation began to surface out indicated by activities such as deforestation, pollution of rivers and other water bodies, contamination of agricultural lands and the loss of biodiversity as a whole. All these occurrences conjointly threaten the ecological function and poses serious challenges to the sustaining forest habitats of Changki, Nagaland. Therefore, the present study compelled the urgent need to assess the ecological status of the coal mine affected areas and formulate management strategies that can improve the forest health.

1.2 REVIEW OF LITERATURE

1.2.1 Coal mining and the environment

Coal is predominantly mined from the earth surface and this often causes damage to nearby ecosystems (Mishra and Das, 2017). The industry is considerably one of the most environmental deteriorating sector, as it is the largest anthropogenic source of carbon dioxide emission to the environment which affects the climatic conditions (Ritchie and Roser, 2018). It is reported that coal industry produced 14.4 gigatonnes (Gt) of CO_2 in 2018, which is 40% of the total fossil fuel emissions and over 25% of total global greenhouse gas emissions (Resilience, 2020). The coal-mining operations either by underground or open-cut mining is the most recognizable and demonstrable environmental problem since it modifies or alter the physical, chemical and biological parameters of the environment that surrounds the mining area and it has far reaching influence on the ecological unit (Halim *et al*., 2013; Howladar *et al*., 2014). During mining, the overlying soil is removed and the fragmented rock is heaped in the form of overburden dumps (Ghosh, 2002). The left over dumps occupy large amount

of land, which loses its original soil qualities and gets degraded (Barpanda *et al*., 2001). The dump materials consist of generally loose rocks, muds, coarse to fine particles of metals which become highly prone to being carried away by wind and water. The materials get spread over the surrounding affecting the fertile land, vegetation and wildlife and disturbed their natural habitat. It has also been studied that overburden dump top materials are usually deficient in major nutrients (Makdoh and Kayang, 2015; Talukdar *et al*., 2016) and plantation do not thrive well. But the physicochemical properties of overburden dump materials are site specific and differ from one dump to another dump due to different geological deposit of rocks (Lovesan *et al*., 1998). Coal mining tends to have notable consequences on the environment, the severity depends on whether the mine is working or abandoned, the mining methods used, and the geological conditions (Bell *et al*., 2001). The impact of coal industry on the environment includes various issues such as water and air pollution, land degradation and unconventional waste management inflicted by mining activities. Along with the atmospheric pollution, usage of coal also add up hundreds of millions of tons of solid waste products yearly, which includes fly ash (USEPA, 2017) bottom ash and flue-gas desulfurization sludge, that comprises elements including arsenic, mercury, thorium, uranium, and other heavy metals. The destruction of vegetative cover by activities such as stockpiling of topsoil, construction of roads and soil hauling followed by coal excavating increase the accessibility of dust around mining operations. Air quality is also degraded by the dust accumulated in the area, which in-turn has a detrimental impact on the vegetation, and directly piles up complication on the health of mine workers and nearby residents (Resilience, 2020).

1.2.2 Soil status in coal mining affected area

Mining activities are associated with removal of fertile organic top soil layer which are enriched with biomass of vegetation cover hence has environmental consequences (Goswami, 2015) which can change the previous terrain and landform. Due to the long time dumping of coal gangue, hazardous substances are leached into the soil and result in soil pollution. Cui *et al*. (2004) demonstrated that the enrichment factor of heavy metal in the soil around the gangue is proportional to the history of coal mining. Nutrient element such as nitrogen, phosphorus, potassium among other in soil can easily move into the water-log and catchments (Lei *et al*., 2009) which deprive the normal functions of the soil. Affected soil are

usually low in moisture due to lack of stable soil structure, higher stone content and lack of organic matter (Maiti, 2007) which can increase bulk density too. Moisture content in mine affected soil is a fluctuating parameter which is influenced by the time of sampling, height of dump, stone content, amount of organic carbon, and the texture and thickness of litter layers on the soil surface (Donahue, 1990). The absence of vegetation on dump materials may also contribute to high bulk density in the mining site and bulk density is negatively correlated with age of overburden spoils as reported by Sadhu *et al*. (2012). It decreases with the increase in age of overburden spoils due to accumulation of organic matter in the dump samples (Leelavathi *et al*., 2009). Heavy metals are generally present in excess amount in coal mining affected soils and can alter or deteriorate soil strata. For instance, given the chemistry of lead in soil, the USEPA (1986) suggests that the uneven distribution of lead in ecosystems can displace other metals from the binding sites on the organic matter which may hinder the chemical breakdown of inorganic soil fragments. According to Li *et al*. (2013) the vertical variations of trace elements in different coal seams indicate the concentrations of most trace elements in coals that are significantly related with depositional environments. Mined soils have physical, chemical and biological deficiency or toxicity that may inhibit optimal plant growth (Bradshaw, 1997). The mined lands have low pH, resulting in the leaching of aluminum, soluble iron and zinc ions that may cause toxicity to plants including low organic matter and soil microbes (Gould and Liberta, 1981). Mishra and Das (2017) reported that the trace factors contained in coal are a large group of various pollutants with a number of health and environmental effects which disturbs the ecosystem and endangers human health as well. The release of mining waste into the surrounding soil can cause intense destruction of ecosystems, which in some cases may not be fully restored or rehabilitated (Halim *et al*., 2013) and the toxic contamination by heavy metals (As, Ni, Co, Cu, Cd, Zn and Mn) in the soil and vegetation of mining area are often beyond the desirable limits which can deteriorates the environment (Herawati *et al.*, 2000; Razo *et al.*, 2004).

1.2.3 Effect of coal mining on water quality status

Major impacts of coal mining are generally associated with changes in water chemistry, including changes in pH and concentrations of potentially toxic elements (Rathore *et al*., 1993). As acidity increases in water due to mine waste, there is a correlated increase in the solvency of metals associated with coal and other minerals. Secondary minerals may be

dissolved directly by hydrogen ions or catalytically by iron ions, resulting in an increased metal load in the drainage system (Plumlee *et al*., 1993). Coal mine drainage ranges widely in composition from acid to alkali, typically with high concentration of heavy metals like, Fe, Mn, Cu, Ni, which can fatally degrade the aquatic habitat and the quality of water supplies because of toxicity, corrosion, encrustation and other effects from dissolved constituents which alter the physical, chemical and biological nature of the receiving water body (Halim *et al*., 2013). Depending on the type of coal and surrounding rock, a number of metals may be present in the solution including Fe, As, Mn, Cu, Al, among many others (Moore *et al*., 2005). Coal mining operations expose relatively large areas of rock to the action of the environment, with the result that abnormal quantities of water soluble minerals may contaminate the drainage from the mine, including the local surface drainage system. In many mines, the rate of water percolation, even in critical summer, is heavy and needs to be pumped out to the surface basically as a mine drainage operation (Singh, 1988). Mining activities significantly cause mineralisation of mine waters as a result of interaction of water with various weatherable minerals present in the geochemical regime. Water cloudiness (turbidity) and sediment content (suspended solids) are visually observed (Singh, 1988). Pollution of both surface water and groundwater is becoming rampant due to coal mining activity which leaves a mark disturbing the physico-chemical like free CO_2, alkalinity, BOD, DO, chloride, turbidity, electrical conductivity and total hardness as well as the geochemical water cycle in nature. During the initial period, the release of obnoxious substances from coal mining activities like ash, oil, phosphorus, ammonia, urea and organic acid contaminates the surface water quality of the mining regions (Reza and Singh, 2010) and on later period the water bodies are affected by acid mine drainages. Ash disposal from coal burning in landfills and settling in ponds can influence adjacent aquatic ecosystems directly, through inputs of ash basin effluent and surface runoff, and indirectly through seepage and groundwater contamination. Mine water contains very high amount of dissolved solids and hence corrosive in character particularly due to sulphate and chloride contents (BIS, 2004). They also significantly decrease dissolved oxygen level, bed permeability and cause particle entrapment within the periphyton matrix (Quinn *et al*., 1992).

1.2.4 Coal mining and its impact on vegetation

The unscientific mining of fuel poses a serious threat to the environment, resulting in the reduction of forest cover, erosion of soil in a greater scale, pollution of air, water and land and reduction in biodiversity. Denudation of forest cover in large scale, loss of biodiversity and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining (Gupta *et al*., 2002). Vegetation is an important part of the environment but may be subjected to disturbance in areas close to coal mines and this result in a slowing of the rate of biomass growth caused by fading of vegetation cover (Swer and Singh, 2004). Simultaneously, carbon stored in vegetation is also constantly released, weakening vegetation ability to act as a carbon sink; while the biggest impact on the carbon imbalance of vegetation near coal mines may be attributed to a reduced ability to absorb atmospheric CO_2 (Huang *et al*., 2015). Mining caused massive damage to landscapes and biological communities of the earth (Down, 1974). According to Bussler *et al*. (1984) the use of machinery in mining process destroys root system in the ground which affects the vegetation cover. Mined areas have disturbed vegetation distribution as a study on plant diversity by Sarma *et al.* (2010) shows that Shannon diversity index for tree and shrub species were low in mined areas as compared to that of the unmined forest; disturbance during the mining reduces the chances of regeneration of species, thereby, reducing the number of species in the mined areas. Changes in the health of vegetation may also act as vital markers for a disturbed mined land (Zuo *et al*., 2014). Natural plant communities gets disturbed and the habitats become impoverished due to mining, resulting in fewer plant growth and vegetation deprivation while very few adaptable species flourished in the area like *Setaria viridis, Euphorbia supina* and *Carex brevior* which serves as an indicator species in mining areas (Shaw and Diane, 1989).

1.2.5 International status

Mining may be responsible for approximately 20% of deforestation in developing countries on a global scale (Bahrami *et al.*, 2010). Evidence suggests that coal mining is one of the factors contributing to the rapid loss of lakes (8.9% decline from 1987 to 2010) on the Mongolian Plateau (Tao *et al*., 2015); coal mining activities have also exposed the vulnerable plateau to ecological hazards, as a result, observers believe extensive vegetation degradation has generally been a likely consequence of mining activities (Zhang *et al*., 2009;

Woodworth, 2015). Wiryono and Siahaan (2013) compared the species composition of understory vegetation growing naturally in coal mined land planted with *Gmelina arborea* in Central Bengkulu, Indonesia, with that of unreclaimed coal mined land and of natural forests and found that the species composition of understory vegetation in reclaimed mined land had high similarity with that of abandoned mined land but was totally different from that of natural forests. Coal mining seriously jeopardizes the mining area's ecological environment, with the potential to cause a wide range of consequences such as surface subsidence, land desertification, soil degradation, surface and groundwater pollution, vegetation destruction, ecosystem degradation, diminished biodiversity, landscape damage, and crop failures (Fan *et al*., 2003). Sahoo *et al*. (2016) pointed out that soils of mining areas are often characterized by low organic matter content, low fertility, poor physical, chemical and biological properties, limiting their capability for sustainable vegetation growth. Coal mining activities are relevantly known to affect the local or native vegetation from the following perspectives: mining activities cause surface subsidence and changes the surface micro topography that alter the growth environment of vegetation's roots (He, 2003); burning of gangue hill and underground coal fire causes large areas of vegetation to fade or die (Zhang *et al*., 2007); soil physical and chemical properties change which hinders nutrient absorption by vegetation (Hu *et al*., 2012; Sun *et al*., 2008) increase in pollution level and declining levels of groundwater hinder water absorption by vegetation (Wang *et al*., 2008). In many regions of the world, coal mining is a threat to the resource quality and quantity of both the surface and ground water (Khan *et al*., 2005). Global reports by Sams *et al*. (2000) states that acid mined drainage discharging from deep mines and surface mines usually results in elevated concentrations of acidity, iron, manganese, aluminum and sulfate in receiving streams and rivers. The accumulation of salts from mining sites caused river water alkalinity and sodicity affects while the remaining water creates acute transpiration and evaporation disturbing the aquatic habitat (Keller *et al*., 1998). Naicker *et al*. (2003) reported the groundwater in the mining district of Johannesburg, South Africa, is heavily contaminated and acidified as a result of oxidation of pyrite contained in the mine dumps and has elevated concentrations of heavy metals. According to Lei *et al*. (2009) in arid mining areas, western part of China, underground water level decreased sharply. Corbetted (1977) reported that the disturbed areas yields hard water of the calcium-sulfate or calcium-magnesium-sulfate type

which is low in pH, high in iron and aluminum and which contains trace elements. Taylor *et al.* (2002) found higher concentrations of Al, Cu, and Zn in the mining-impacted Dee river (Australia) than the normal allowable level as defined by the Australian and New Zealand Environment Conservation Council guidelines. Olias *et al.* (2004) investigated seasonal variations in the water quality of the Odiel River (South West Spain), reporting the presence of various metals and categorizing them in order of concentration as Zn followed by Fe, Mn, Cu, Pb, As and Cd. Espana *et al*. (2005) investigated the physico-chemical properties of water in 64 discharges from 25 different mines in Odiel river watershed, Spain and reported very acidic pH in the range of 1.4 to 4, extremely high sulphates and high metal concentrations primarily Fe, Al and Zn. Valente and Gomes (2007) characterized the acid mine drainage (AMD) streams with very low pH values (pH<3), high metal solubility, presence of iron colloids that aggravate water turbidity and created insufficiency of inorganic carbon and phosphorus, resulting in stress condition. Gemici (2008) reported a seasonal variation in the water quality of an abandoned mine (Alasehir, Turkey) as very acidic, with a pH value of 2.55 in the arid season and 2.70 in the wet season and sulphate levels were significantly higher than the WHO drinking water guidelines. Luis *et al*. (2009) studied the impact of acid mine drainage water and sediments on diatoms in streams surrounding mining areas in Lousal and Aljustrel in Portugal and also reported high concentrations of As, Fe, Mn, Pb and Zn in water as well as in sediments and their solubility increased with acidity. Bitzer (2012) investigated on the physico-chemical characteristics of stream water in correlation to toxicity in mining influenced streams of West Virginia and reported high inter-relationship. James *et al*. (2000) investigated the effects of coal mine drainage on stream quality in the Allegheny and Monongahela river basins and of the seven sites, they reported significant elevation trend of sulphate concentration in the Dunkard and Stonycreek river.

1.2.6 National status

In India, various workers like Rathore and Wright (1993), Sikdar *et al*. (2004), Ghose (2004) and Singh *et al*. (2010) have reported regarding the effects of mining on the landscape. Rai *et al*. (2010) selected the overburden dump site at different mining areas under Jharia coalfields (JCF) for experimenting the physico-chemical characteristics and found that the samples collected from the coal mining areas were poor in organic carbon, available nitrogen and available phosphorus due to lower amount of microbial activities

while bulk densities were in range not suitable for plantation purposes without addition of fertilizers and pH of all the sampling sites is slightly acidic in nature. The loss of available nutrients (NPK), exchangeable cation (Ca, Mg, Na, K) in native soil's indicate that open cast mining alters soil quality (Sadhu *et al*., 2012). Ladwani *et al*. (2012) have work out the concentrations of heavy metals (Cd, Cr, Co, Cu, Mn, Ni, Pb and Zn) in soils near lignite coal mine located at Surat (Gujarat) and their toxicity was used to assess the risk of the heavy metals in contaminated soils. Soils around the mine were found to be polluted with Cd, Cr, Co, Cu, Mn, Ni, Pb and Zn while the geo-accumulation index values revealed that Cu, Pb and Ni are significantly accumulated in the study area. Pandey (2014) reported the pollution load index derived from contamination factor indicated that the sites near coal mining areas are most polluted. Trivedi (2000) estimated the heavy metal in the Gomti river water at Lucknow and reported the presence of copper, zinc and chromium. Tiwary (2001) further reported the acid mine drainage associated problem in the water bodies from various coal fields of India such as the Western Coalfield Limited, Northern Coal field Limited and North Eastern Coal field Limited and water from those coal fields contained very high toxic level of sulphate, Fe and Mn Nigam *et al*. (2015) studied the physicochemical characteristics of mine water in opencast mine at Chirimiri district, Chhattisgarh and found that the quality of the water is rated 'good' only some of the parameters like turbidity, calcium, fluoride and total hardness are slightly greater than the permissible value. Sahoo *et al*. (2016) have studied the physicochemical parameter of water quality of Talcher area (Odisha) and the data indicates the degradation of water quality which was due to intensive mine waste dumping. Singh *et al*. (2010) qualitatively assessed the mine water from the Raniganj coalfield and reported the pH of the mine water ranged from 6.5 to 8.8, the anion chemistry was dominated by sulphate. On an average, chloride and nitrate contributed 10 and 19% of the total anionic balance, while the cation chemistry was dominated by Mg^{2+} and Ca^{2+}. Moreover, concentrations of some trace metals (Fe, Cr, and Ni) were found to be above the levels recommended for drinking water. Chatterjee *et al*. (2010) assessed groundwater quality in a coal mine-dominated area in Dhanbad district, Jharkand, India using an integrated analysis of physicochemical parameters and concluded that, despite the mining and heavy industry, the water quality is predominantly good to excellent. Tiwary and Singh (2016) have studied the impact of open cast coal mining on plants and they observed stunted

growth as well as poor morphological aspects like height, length and leaf and flower size in plants under this area compared to normal vegetation. They also reported that un-sustained coal mining has resulted into almost complete denudation of the vegetation cover of study site due to removal of top soil and it has also been observed that many of the plant species are disappearing due to unsustainable mining activities.

1.2.7 Regional status

In Northeastern India, Singh and Rawat (1985) reported the mine drainages to be highly acidic and contain trace elements which are highly undesirable for drinking purposes. Akram and Khan (2014) reported on water quality affected by coal mining in Jaintia Hills, Meghalaya, and demonstrated that coal mining has increased the toxicity level to such an extent that the water is completely unfit for agriculture and human consumption and even highly toxic to the native flora and fauna. The degraded water comprised of high concentrations of sulphate ions, toxic heavy metals, high biological oxygen demand (BOD) and high electrical conductivity. Ghose (2004) stated the changes in soil fertility due to open cast mining operations in Eastern coalfields and reported surface mining cause more pollution as they produce large amounts of waste in comparison of the underground mines. Makdoh and Kayang (2015) studied the soil physico-chemical properties of five coal mine spoils in chronosequence and an unmined site in coal mining areas of Khliehriat, East Jaintia Hills, Meghalaya. Their study revealed that the overburden soils were poor in nutrient but rich in heavy metals, where higher concentrations were recorded in the summer season than in the dry season. Talukdar *et al*. (2016) studied on soil quality parameters of Simsang river, Meghalaya affected by acid mine drainage and observed that the soil quality in most affected areas have relatively low pH, low nutrients (NPK) and reduce organic carbon. As reported by Chabukdhara and Singh (2016) the northeast Indian coals have unusual physicochemical characteristics like high sulfur, volatile matter and vitrinite content, and low ash content as well as many environmental sensitive organic and mineral bound elements such as Fe, Mg, Bi, Al, V, Cu, Cd, Ni, Pb and Mn remain enriched in these coals. A study conducted by Sarma (2005), indicates that due to extensive coal mining, large areas in Meghalaya district has turned into degraded land, creating unfavourable habitat condition for plant growth. The number of tree, shrub and herb species got reduces due to mining activities, compared to the unmined areas while the high importance value of *Pinus kesiya* in mining areas suggests its

ability to grow in the disturbed environments. Sarma *et al*. (2010) studied and analyze the impact of coal mining on plant diversity and tree population structure and reported low diversity and unstable growth in the mining proximity and also noted that majority of species showed contiguous distribution pattern. Akram and Khan (2014) did a comparative analysis and observed that dense forest is transformed into open forest, scrubland and quarries due to the extension of mining areas. Various studies have been conducted on vegetation composition and soil properties of mining areas by several workers in different parts India as well as in the north eastern states (Chabukdhara and Singh, 2016; Talukdar *et al*., 2016) and most studies depicted on the deteriorating consequences of mining activities.

1.3 ORIGIN OF THE RESEARCH PROBLEM

Association of coal mining operation in the locality and the revenues, undoubtedly has brought wealth and employment opportunities, but concurrently has led to extensive environmental disruption and disarray of ecosystem protection norms in the community. Environmental problems exhibited through unscientific mining and non-green practical methods have been felt severely due to the region's fragile ecosystems and rich biological and cultural diversity. In addition, a vast area has become physically disfigured due to forest fragmentation, haphazard dumping of overburden dumps, caving in of the ground and subsidence of forested land. The environment stresses associated with mining have severely affected the Changki village biodiversity. For instance, large scale denudation of forest cover, decrease in wildlife fauna and flora, pollution of air, scarcity of water, degradation of water and soil in agricultural lands are seemingly associated due to coal excavation. Alongside with coal mining, various activities such as shifting cultivation (Jhum), plantations, sand mining and stone quarries are highly prevalent in the region. All this practices have accelerated both on-site and off-site degradation due to soil erosion, nutrient loss, disruption in watershed hydrology and habitat loss. The long decade anthropogenic threat on the Changki forested region with no evaluation on the environmental quality calls for an urgent need to protect the tropical forest habitats by assessing its ecological status. Although various studies has been conducted in coal mining regions of the world to assess their ecological impacts, there is a perceptible lack of research to monitor the coal mining effects on the environmental quality on Tropical forest, though it is often regarded as the

most environmentally degrading activity in developing countries. This lack of knowledge is especially evident for India, and in particular Nagaland. Hence the proposed research work entitled **"*Ecological studies on the affected and non-affected forest in coal mining areas of Changki in Mokokchung district, Nagaland"*** has been taken up with a view to explore the impact of coal mining on the soil, water and vegetation conditions prevailing in the area.

The following hypotheses were raised to effectively justify the effect of coal mining in a Northern tropical semi-deciduous forest in Nagaland.

(a) Coal mining reduces forest soil quality.

(b) Coal mine drainages deteriorate Tsurang river water quality.

(c) Coal mining activities decreases vegetation diversity.

(d) Coal mining activities escalates heavy metals accumulation in soil, water and bioaccumulation in dominant plants.

1.4 SCOPE OF THE STUDY

The comprehensive study is first of its kind in Changki coal mining areas of Nagaland, which will provide information about the ecological characteristics of the affected and the unaffected forest and assist in future monitoring for formulating conservation strategies. The database on the phyto-diversity of the mining affected and non-affected forest will reflect the biodiversity status of the area and raise awareness. Similarly, studies on the spatio-temporal variability of soil and water physicochemical properties will provide insightful knowledge in identifying the key factors affecting the environmental quality. Detection of heavy metals present in the river water, soil and dominant vegetation will give us information about the toxic elements which may hamper the ecosystem or even harm the local inhabitants. In addition, forests not only sustain biodiversity and ecological values but also provide homes to indigenous people, serve as pharmacopeia of natural products, provide crucial ecosystem services and play an important role in the ethnicity and socio-cultural life of the Naga tribal, so it is crucial to understand the impacts of anthropogenic activities on forest ecosystem and employ ways to counter their effects. The findings will initiate necessary steps to reiterate tribal community norms in conserving forests to the upcoming younger generations, improve their knowledge for identifying important ecological species of special concern and enable different stakeholders to take appropriate

decisions and measures for sustainable forest management. Overall, the current research will provide a comprehensive assessment on the environmental quality in this region and will be helpful for regulating measures in regards to pollution control and environmental monitoring for Nagaland state government and tribal bodies.

OBJECTIVES OF THE STUDY

1. To compare vegetation diversity between the Coal mining affected forest (CMAF) and Non-affected forest (NAF).
2. To determine the soil physicochemical characteristics of CMAF and NAF.
3. To estimate the water physicochemical properties of Tsurang river.
4. To detect heavy metals from dominant plants, soil and water samples.

The thesis as a whole is organized as follows:

Chapter 1: Introduction and review of literature

Chapter 2: Materials and methods

Chapter 3: Vegetation diversity of coal mine affected and non-affected forest at Changki

Chapter 4: Soil physicochemical properties and quality status of coal mine affected and non-affected forest

Chapter 5: Spatio-temporal variation of water physicochemical properties and quality status of Tsurang river

Chapter 6: Heavy metals accumulation on coal mining affected and non-affected forest soil, Tsurang river water and bioaccumulation on some dominant plant species

References

Appendices

CHAPTER-2

MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY SITES

Nagaland lies in the Indo-Burma biodiversity hotspot region of Northeastern India and covers a geographical area of 16,579 km^2, extending from $25^0 6'$ N to $27^0 4'$ N latitude and $93^0 20'$ E to $95^0 15'$ E longitude. It is bounded by the neighboring states of Arunachal Pradesh and Myanmar in the east, Manipur in the south and Assam in the north-west. Agriculture covers over 70% of the state's economy and other significant economic activities includes forestry, tourism and miscellaneous cottage industries. About one-sixth of the state is under tropical and sub-tropical evergreen forests including palms, bamboo, timber and mahogany forests (DEFCC, 2018). Mokokchung covers an area of 1,615 km^2 and has a northern tropical semi evergreen forest with high plant diversity, contributing to the state flora (DEFCC, 2018). The designated study area "Changki" a 'Coal mining village' is located in the south-western part of Mokokchung and is surrounded by the villages Khar at the east, Longtho in the north and Chungtia at the south. The geographical coordinates i.e. latitude and longitude of Changki Village is $26^0$25'9.95"N and $94^0$23'16.78"E respectively. For decades (Since 1990s), unregulated coal mines owned by community and private enterprise have been taking place in the forest, adjoining hill slopes and plains of Changki. Coal mining was initiated in this region by the Ao Nagas in collaborations with major stakeholders from Assam and other neighbouring states for over 25-30 years. The vicinity of the village holds considerable loads of tertiary coal and the exposures are found along the roads, rivers, hill slopes, forests, valleys and in the paddy fields. There are 17 significant active coal mining sites

jointly called as the Changki coalfields in and around the Changki village. The present evaluation for soil and vegetation quantification was carried out in two Northern tropical semi-deciduous forests. The Non-affected forest (NAF) which is a community protected forest is geographically located at $26^0$24′40″N and $94^0$23′31″E at an altitude of 598 m above msl while the Coal mining-affected forest (CMAF) lies at $26^0$26′18″N and $94^0$22′48″E at an altitude of 248 m above msl **(Plate-I)**. The Changki coal fields are active mines operated for over 30 years covering an area of approximately 52,000 m^2 and annually on average, 250 tons of overburdened mine spoils are dumped at the CMAF. For experimental purposes in CMAF site, the secondary footprint area categorized by Frelich (2019) over a length of 200 meters from the main coal field was selected and considered as the disturbed forest. Apart from coal mining, other anthropogenic activities along the stretch of CMAF belt includes stone quarries, plantation, agriculture, collection of fodder for livestock, foraging and the passage of national highway "Mokokchung-Mariani Road (NH 702D)". The NAF sampling sites has no anthropogenic activities for over 5 km in all directions (North, West, South and East) and was considered as a "control site" limited only to the effects of environmental factors such as the climatic conditions, physiographic and seasonal changes of the region. On visual observation, the CMAF site has low vegetation, soil erosion, small open patches of degraded lands, mine drainages including streams passing through the forest, overburden dumps from coal mines scattered in the southern side of the forest with no signs of wildlife. On the otherhand, the NAF site has diverse vegetation and thick outgrowth of forest cover with wildlife activities. The Tsurang is one of the major river of Mokokchung district affected by coal mine drainages, agriculture activities and domestic household waste. It has few small tributaries from neighbouring district of Wokha; however, in Mokokchung district, its main tributaries arise from Mangkolemba division passing through the Tsurangkong range (Naga foothills) adjoining Changki and Longtho. The river stretches 45–50 km in Mokokchung till it reaches the neighboring state of Assam where it is named "Bhogdoi Nodi." The present study was conducted over a length of 22–26 km. On visual observation, the River water is yellowish to brownish, muddy, pungent odour, carrying forest litters and other solid sewages during the rainy seasons. The water color gradually becomes clearer during the dry winter months and the water level decreases upto an extent where the river bed can be viewed. The landuse/landcover (LULC) map of the study area is shown in **Fig. 2.1.1** and **Fig. 2.1.2** while the features of Tsurang river sampling stations, their

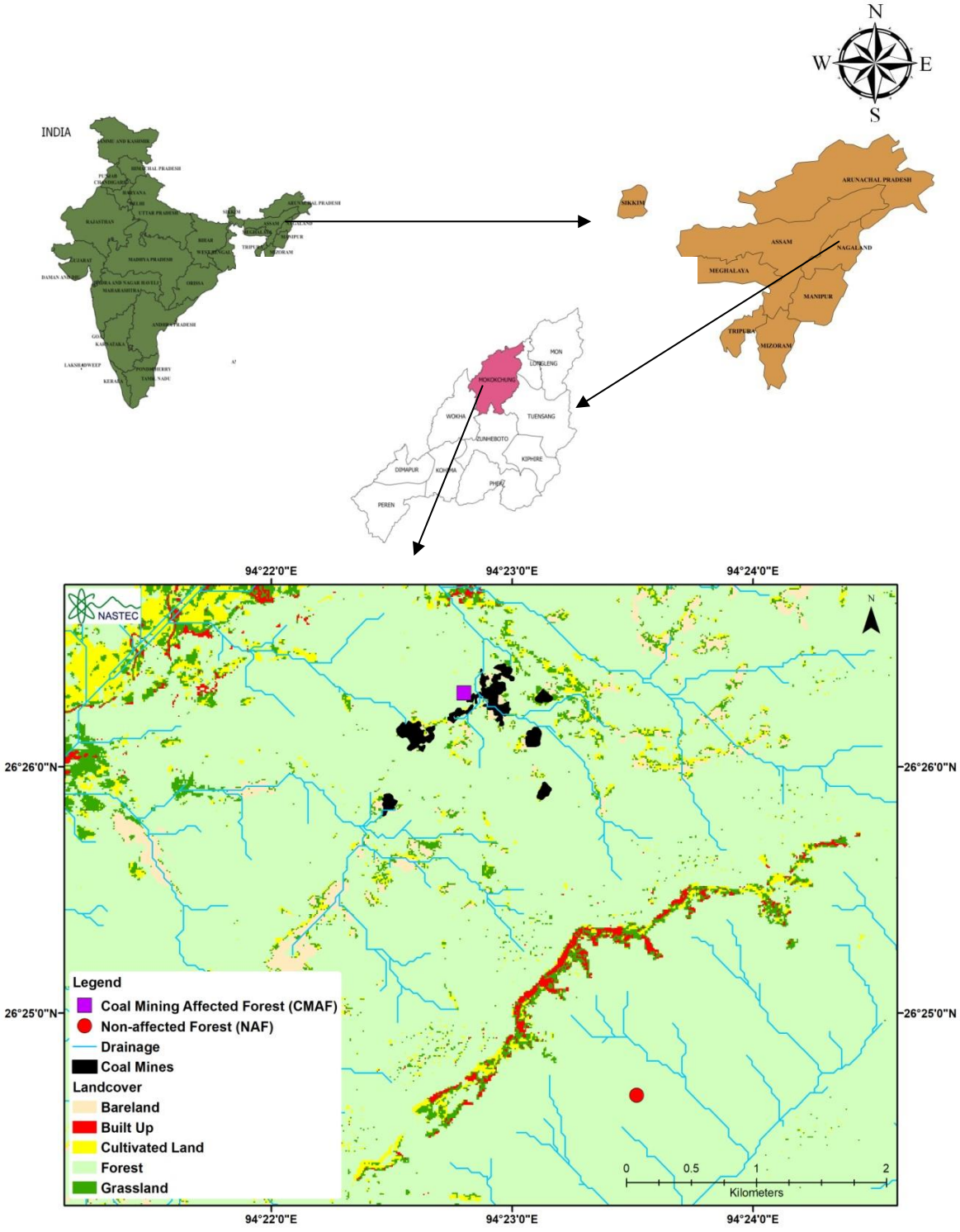


Fig. 2.1: Landuse/landcover map of Coal mining affected forest (CMAF) and Non-affected forest (NAF) at Changki, Mokokchung, Nagaland (Source: Remote Sensing Centre, Nagaland Science and Technology Council, Department of Science and Technology)

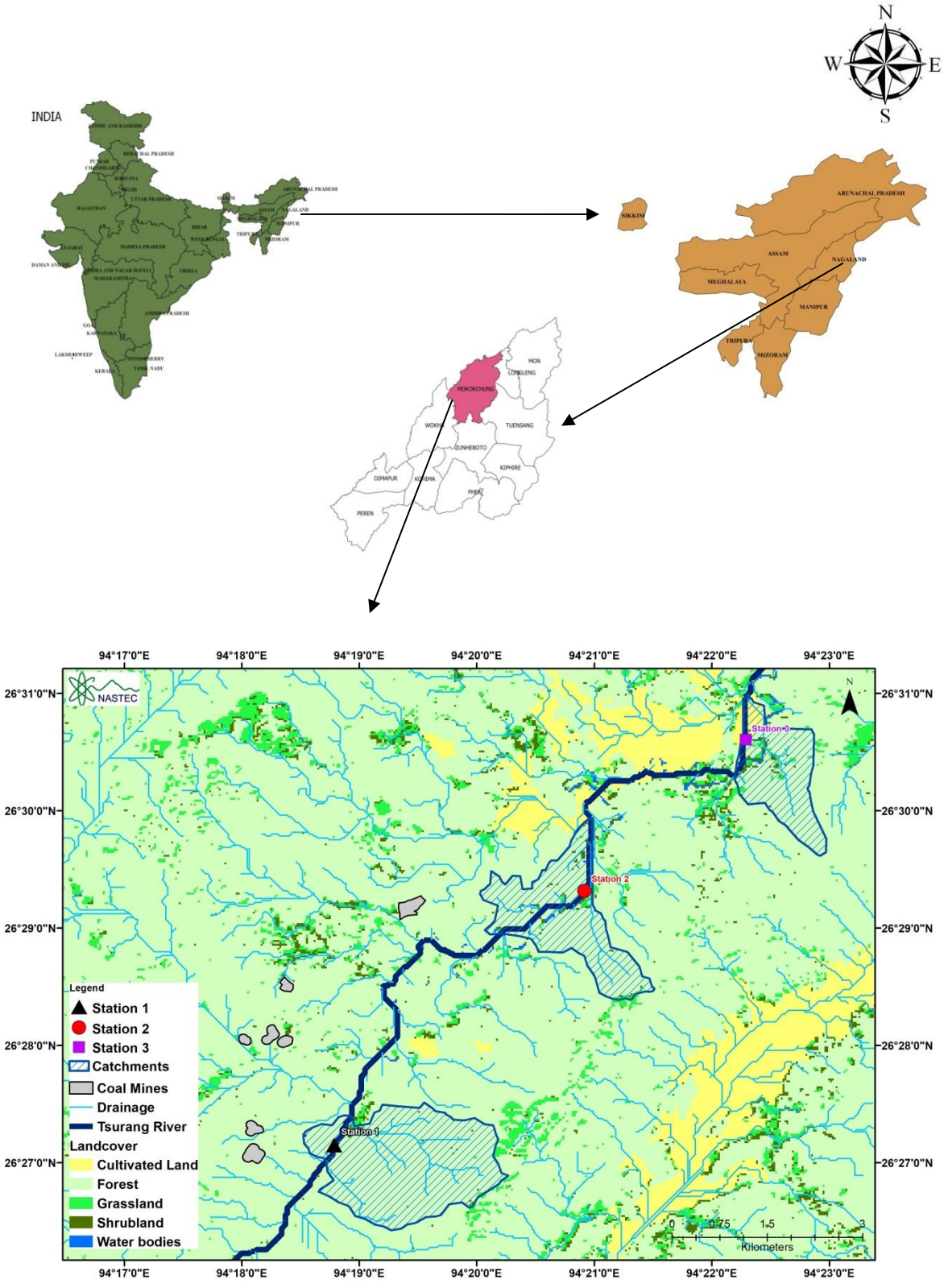


Fig. 2.2: Landuse/landcover map along the sampling stations of Tsurang river, Mokokchung, Nagaland (Source: Remote Sensing Centre, Nagaland Science and Technology Council, Department of Science and Technology)

coordinates and elevations are presented in **Table 2.1**. **Plate-II**, **III** and **IV** shows coal mining activities in Changki, the three sampling stations of Tsurang river and coal mine drainages respectively.

Table 2.1: Characteristic features of the sampling station, their coordinates and elevation along Tsurang river

Sampling station	Station code	Characteristics of sampling station	Coordinates	Elevation (msl)
Station 1	S1	Upstream, the station has terrain covered by semi-deciduous forest, coal mines and plantations.	$26^0$27′09″N 94°18′47″E	199 m
Station 2	S2	Midstream, the landmass at this station has plantations, coal mines and sand mining activities.	$26^0$29′19″N 94°20′55″E	181 m
Station 3	S3	Downstream, the station is confined with agricultural fields and recreational spots.	$26^0$30′34″N $94^0$22′26″E	174 m

2.2 CLIMATIC FEATURES OF THE STUDY AREA

The state has a subtropical to warm temperate climate and experienced the south-west monsoon. The maximum temperature is observed during the summer months (21 to 36°C) while in winter, temperature generally drops from 21 to 4°C. Monsoon seasons start from May till the end of September with June, July and August experiencing the highest rainfall. Annual average rainfall ranges from 1,800 to 2,500 millimeters (70–100 inches). Frost is common at high elevations and strong northwest wind blows across the state during the months of February and March. The Ombrothermic diagram of the study area (Mokokchung district) during the study period i.e. 2018 and 2019 are depicted in **Fig. 2.3**.

A. Plant diversity assessment

The phytosociological studies of herbs, shrubs and trees from the CMAF and NAF were conducted during the period of January to December, 2019. In each site, from a one-hectare area (1-ha) plot, the Nested quadrat sampling method was applied to acquire the utmost representative composition of the samples. An area of 1 × 1 m^2 (60 quadrats), 5 × 5 m^2 (50 quadrats) and 10 × 10 m^2 (25 quadrats) plots for herbs, shrubs and trees were

Plate - I: An overview of coal mining affected forest and community forest at Changki

Coal mining affected forest

Changki community forest (Non-affected forest)

Plate –II: Coal mining activities at Changki

Open cast mining

Rat hole mining

Coal Miners

Plate – III: An overview of the sampling stations of Tsurang river

Station 1

Station 2

Station 3

Plate – IV : Coal mine drainages and overburden dumps

Coal mine drainages

Overburden dumps/waste of coal mining

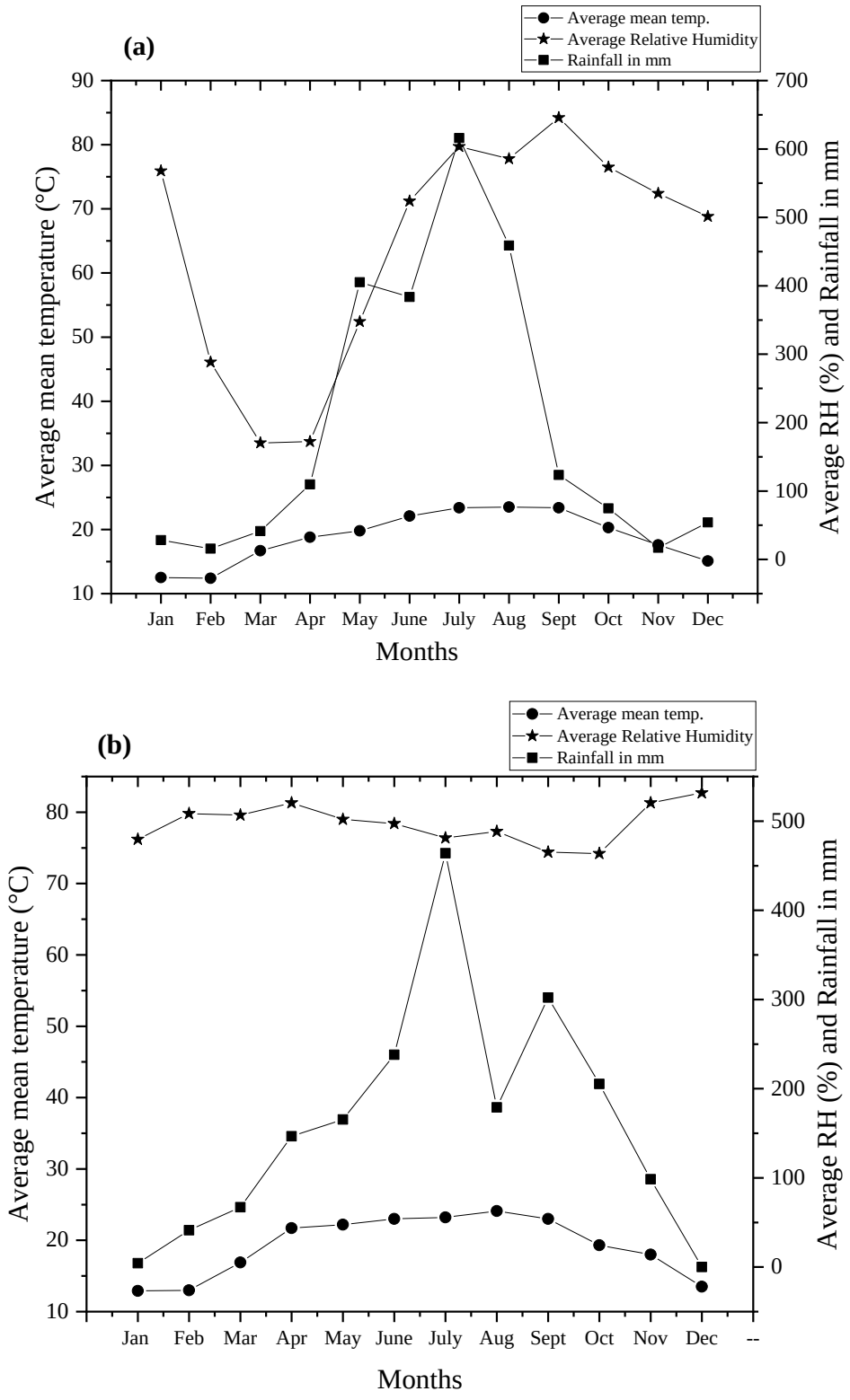


Fig. 2.3: Ombrothermic diagram of Mokokchung district for the period a) 2018 and b) 2019 (Source: Soil and Water Conservation Department, Govt. of Nagaland)

demarcated and subdivided following Misra, (1968). The tree population structure was considered for eight girth classes: 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80 and 81-90 cm (the highest girth class of trees in the study area falls under 81-90 cm) and measured at breast height (dbh at 1.37 m above ground level) while the diameter for shrub (10 cm above ground) and herb (base of stem) were recorded from the main plant stem using diameter tape and a screw gauge (Pande *et al*., 1988). The representative taxa collected during the field survey were processed for herbarium following Jain and Rao (1977) and identified with the help of standard literature and regional floras (Bentham and Hooker, 1862-1883; Prain, 1903; Kanjilal *et al*., 1934; Kanjilal *et al*., 1936; Kanjilal *et al*., 1938; Kanjilal *et al*., 1940; Bor, 1940; Bennet, 1987; Dey, 2018). The voucher specimens with each accession number were then scanned for digital herbarium using Epson DS-60000, later deposited in the Department of Botany, Nagaland University, Lumami Campus.

1. Quantitative analysis

To estimate the phytosociological characters like density, frequency and abundance, standard methods formulated by Curtis and Mclntosh (1950) was used.

Density

Density determines the numerical strength of species in a community and gives the idea on the degree of competition.

$$Density = \frac{Total\ number\ of\ individual\ of\ a\ species}{Total\ number\ of\ quadrates\ studied}$$

Relative density (R.D)

It denotes the numerical strength of a species in a community to the total number of individuals of all the species. RD is expressed as:

$$Relative\ density\ (\%) = \frac{Density\ of\ a\ species}{Sum\ of\ density\ of\ all\ species} \times 100$$

Frequency (FQ)

Degree of dispersion or distribution of individual species in a given area and is expressed in terms of percentage.

$$Frequency\ (\%) = \frac{Total\ number\ of\ quadrates\ in\ which\ the\ species\ occur}{Total\ number\ of\ quadrates\ studied} \times 100$$

Relative frequency (R.F)

The degree of dispersion of individual species in an area in relation to the number of all the species that occurred.

$$\textit{Relative frequency}\ (\%) = \frac{Frequency\ of\ a\ species}{Sum\ of\ frequency\ of\ all\ the\ species} \times\ 100$$

Abundance

It represents the number of individuals of different species in the community per unit area.

$$Abundance = \frac{Total\ no.\ of\ individuals\ of\ a\ species}{Total\ no.of\ quadrats\ in\ which\ the\ species\ occured}$$

Relative dominance (R. DOM)

It is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area. Relative dominance is determined by the value of the basal cover.

$$\textit{Relative dominance}\ (\%) = \frac{Total\ basal\ area\ of\ a\ species}{Total\ basal\ area\ of\ all\ the\ species} \times 100$$

The Basal area was calculated by using the formula:

$$Basal\ area = \frac{C^2}{4\pi}$$

Where, C = Girth at breast height

2. Important Value Index (IVI)

The index is used to determine the importance of each species in the community structure. IVI for each species was calculated by summing the Relative frequency (RF), Relative density (RD) and Relative dominance (R. DOM) values following Curtis (1959) as IVI = R. DOM + R.D + R.F.

Abundance to Frequency ratio (A/F) of each species was calculated to study the population dispersion pattern. The values for determining dispersion range pattern were categorized as: regular ($<$0.025), random (0.025-0.05), contiguous (0.05-1.00) and clump ($>$1.00) proposed by Cottam and Curtis (1956).

3. Measurement of various biodiversity indices

The phytosociological datas were enumerated and calculated using various biodiversity indices for each sites. A diversity index is a statistical representations of

biodiversity that reflects how many different types (such as species) are there in a dataset (a community), and that can simultaneously take into account the relations among the individuals distributed in different aspects. The following are the indices used for the measurement of biodiversity:

Shannon-Wiener Index (Shannon and Wiener, 1963) assumes all species in a sample are represented and are very susceptible to abundance. The abundance of certain species in a sample significantly affects the index. The value ranges from 1 to 4.5 and values higher than 3 are typically considered more diverse (Barajas-Gea, 2005). It is calculated using the formula as:

$H' = - \sum(ni/N) \log (ni/N)$

ni = Total number of individuals of a species.

N = Total number of individuals of all species

Simpson's Diversity Index (Simpson, 1949) is a measurement of diversity which takes into account the number of species present, as well as the relative abundance of each species.

$D = \frac{\sum ni\ (ni-1)}{N(N-1)}$

Simpson's index of diversity = 1 – D

Margalef's Richness Index (Margalef, 1958) represents the mean number of species present in a community.

R = S-1 / In N

Where, S = Total number of species

Evenness Index given by Pielou (1969) measures the relative abundance of different species that make up the richness of an area. Its value ranges between 0 and 1, with 1 indicating a complete evenness of species distribution.

$E = H' / \text{In } S$

Sorensen Similarity Index (Sorensen, 1948) measures the similarity between the species in a community. It is expressed as:

S = 2C / A+B

Sorensen dissimilarity index = 1 - S

Where, S = Similarity index

A = Number of species in one community or site

B = Number of species in the other community or site

C = Number of species common to both the sites

B. Soil physicochemical parameter analysis

Soil samples were collected from each site within an area of 100 × 100 m^2, in the second week of every month from September 2018 to August 2019. Later, the monthly data were categorized into four seasonal mean values *viz*., winter (November, December and January), spring (February, March and April), summer (May, June and July) and autumn (August, September and October) based on the climatic conditions of Nagaland (IMD, 2017) and used for the study. Soils were sampled using a sampling corer (area of 10 cm^2) from three layers depth (0-10 cm, 10-20 cm, and 20-30 cm), collected in airtight polythene bags, and were taken to the laboratory. Unwanted debris, forest litters, stones, and gravels were removed from the samples; after that, it was air-dried at room temperature and grounded into fine particles that could pass through a 2-mm nylon sieve. Apart from soil moisture, temperature and bulk density, the other parameters were analyzed using air-dried soil samples. Soil temperature was measured on the spot by using digital soil thermometer. Parameters such as pH and electrical conductivity (EC) were measured by digital pH and electrical conductivity meter (1:5 w/v, distilled water), soil moisture using the gravimetric method (Misra, 1968), Soil texture by pipette method proposed by Piper (1942), bulk density (BD) using core method (Allen, 1989), organic carbon (OC) was determined using $K_2Cr_2O_7$ wet oxidation method (Walkley and Black's, 1934), Total nitrogen (TN) was estimated through sulphuric acid digestion, followed by distillation and titration (Kjeldahl, 1883) and available nitrogen (AN) by the $KMnO_4$ oxidation method following Anderson and Ingram (1993), Available phosphorus (AP) following Bray's no. 1 extract method (Bray and Kurtz, 1945) using UV-Vis spectrophotometer, potassium (K) using flame photometer (Photometric method) following Jackson (1973) and cation exchange capacity (CEC) was determined following Bower *et al*. (1952). A brief description on the analysis of the physical and chemical soil parameters are described below:

1. Soil pH and Electrical conductivity:

10 gm of soil sample was taken in a conical flask and 50 ml of distilled water was added. The mixture was shaken continuously for 30 minutes. The supernatant is than

collected in a beaker, the pH and EC were noted using a digital meter (HM Digital pH-200 and LMCM-20).

2. Soil moisture:

For estimating soil moisture, 50 gm of freshly collected soil samples were weighted and kept in an oven at 105°C for 24 hrs.

$$\text{Soil moisture content (\%)} = \frac{Weight\ of\ the\ oven\ dried\ soil}{Weight\ of\ the\ fresh\ soil\ sample} \times 100$$

3. Bulk density:

Soil core samplers were used for measuring 10 × 10 cm (Diameter × Height) soil bulk density. The samples were dried in the oven for 24 hrs at 105°C and then calculated using the formula:

$$\text{Bulk density (gm/cm}^3\text{)} = \frac{Mass\ of\ the\ oven\ dried\ sample}{Volume\ of\ the\ soil\ core\ sampler}$$

4. Soil porosity:

Dried soil sample weighing 25 gm was taken from each soil layer and 50 ml of water is added in a measuring cylinder, kept it for a 20 seconds. The rise in the volume of water was measured and the particle density and soil porosity was calculated from the obtained value with the given formula:

$$\text{Particle density (gm/cm}^3\text{)} = \frac{Mass\ of\ dried\ soil\ sample}{Volume\ of\ soil\ solid}$$

$$\text{Soil porosity (\%)} = 1 - \frac{Bulk\ density}{Particle\ density} \times 100$$

5. Soil texture:

20 gm of the dried soil samples were taken in a 500 ml graduated cylinder. 10 ml of distilled water is added along with 50 ml of sodium hexametaphosphate (dispersing agent). The mixture is stirred continuously for 5 minutes and the volume is filled upto 500 ml, inverted several times to further resuspend the soil particles. After shaking, at 48 sec, 25 ml of the aliquot from the upper 10 cm is removed with the help of a pipette. A mark is made on the pipette at 10 cm from the tip. The aliquot was transferred to an evaporating dish and placed in an oven at 105°C. This dish was labelled as "Silt + Clay". The second 25 ml aliquot was taken after 40 min from the upper 5 cm of the suspension. The pipette was marked 5 cm above tip and placed in the oven at 105°C. After 24 hrs, the evaporating

dishes were removed from the oven, cooled and weight. The net weight of the first evaporating dish as combined silt and clay in 1/20 of the soil-water suspension was recorded. The net weight of the second is assumed to be 1/20 of the clay. The percentage composition of sand, silt and clay are calculated using the following:

Clay (%) = (20 × dry mass of the second aliquot / total mass of the soil taken) × 100

Silt (%) = (20 × [dry mass of first aliquot – dry mass of the second aliquot] / total mass of the soil taken) × 100

Sand (%) = 100 – (silt % + clay %)

6. Soil organic carbon:

Air dried soil sample weighing 1 gm was taken in a conical flask. 10 ml of $K_2Cr_2O_7$ solution and 20 ml of conc. H_2SO_4 was added and allowed to react for 30 minutes. After which 200 ml of distilled water and 10 ml of phosphoric acid is added. Further, 1 ml of diphenylamine indicator (solution turns darkish blue on addition of this indicator) is added and finally titrated against 1N ferrous ammonium sulphate (FAS), the dark bluish solution changes to green colour (endpoint).

Organic carbon (%) = $\frac{V1-V2}{W} \times 0.003 \times 100$

Where, V_1 = ml of 1N $K_2Cr_2O_7$

V_2 = ml of FAS used in titration till the end point

W = Weight of soil sample taken

7. Phosphorus:

Reagent A = 17.14 gm of Ammonium molybdate A.R. + 0.392 gm potassium antimonyl tartrate A.R. + 200 ml Sulphuric acid + 850 ml deionized water.

Reagent B = 0.53 gm of L-Ascorbc acid A.R. + 5 ml of deionized water + 70 ml of reagent A.

Dispense 7 ml of Bray extracting solution (2.22 g of Ammonium fluoride + 5 ml Conc. Hcl) and add 1 gm of air-dried soil in a centrifuge tube. Shake vigorously for 1 minute. Transfer the tubes to the centrifuge and spin at 6000 rpm for 5 minutes. Dispense 0.50 ml of the supernatant plus 2.0 ml reagent B in a colorimeter tube and let it stand for 30 minutes. Prepare a standard solution from the 2.50 mg/l phosphorus solution (0.05, 0.10, 0.20, 0.30, 0.40 and 0.50 mg/l). Now, set instrument zero and measure the absorbance of

the standards and samples at 882 nm wavelength. Plot the phosphorus concentration against absorbance.

Available phosphorus (kg/ha) = $\frac{Phosphorus\ concentration \times Dilution\ factor \times 2.24 \times aliquot\ used}{Sample\ weight}$

8. Potassium:

In a 150 ml Erlenmeyer flask 50 gm of air dried soil sample and 25 ml of ammonium acetate (pH = 7.0) solutions were added. After which it is placed in a mechanical shaker for 5 min and filtered through Whatman No. 1 filter paper. Using flame photometer, the extracted sample solution was recorded after adjusting to zero with the blank. For the standard curve, 0, 5, 10, 15, 20 and 25 ppm of the working K solution was prepared and the readings were recorded. The concentrations of each of the given sample were calculated by plotting against the standard curve.

Available K (kg/ha) = $\frac{R \times Volume\ of\ extract \times 2.24}{weight\ of\ the\ soil\ taken}$

Where R is the ppm of K in the extract obtained from the standard curve

9. Total Nitrogen:

1 gm of the soil sample is digested by adding 10 ml of conc. H_2SO_4 and 3-4 gm of catalyst mixture (5:1 potassium sulphate and copper sulphate) in the Kelplus – KES 20 LR AL digestion System. The temperature is increased gradually to 420 °C for digestion to take place (1 to ½ hour). This results in the formation of a green colour indicating the digestion is completed. The sample is allowed to cool and 40-50 ml of distilled water is added to undergo further distillation process. In the distillation process, the sample tube is loaded in the distillation unit. A conical flask mixed with 25 ml of Boric acid and methyl orange indicator is placed at the receiving end to collect the liquid ammonia. 40 % of alkali is added to the sample tube until a dark brown colour appears and this process takes place for about 9 minutes. After this process, the conical flask at the receiving end is titrated against 0.1N HCl.

Nitrogen (%) = $\frac{14.01 \times 0.1 \times (TV - BV) \times 100}{W \times 1000}$

Where, 14.01 = molecular weight of ammonia

0.1N = normality of titrating solution

TV = titration value of the sample

BV = titration value of the blank

W = weight of the soil sample taken

10. Available Nitrogen:

Air dried soil sample weighing 5 gm was placed in the Kelplus digestion tube. 20 ml of distilled water and 25 ml of 0.32% $KMNO_4$ are added to the tube, shake thoroughly, and fitted in the distillation unit. 25 ml of 2.5% NaOH solution was added through the distillation unit. At the receiving end of the distillation unit, 25 ml of 2.5 % boric acid with mixed indicator (0.3 gm of Bromogresol green + 0.2 gm of methyl red + 400 ml of 95% ethanol) was placed in a conical flask to receive the released liquid ammonia. The collected distillate was then titrated against 0.02N H_2SO_4.

Available Nitrogen (Kg/ha) = $\frac{14 \times (\text{Normality of the acid}) \times (\text{titrant value reading}) \times 2.24 \times 106}{\text{Sample weight} \times 1000}$

11. Cation Exchange Capacity:

Take 4.5 gm of soil sample, put it in a 40 ml centrifuge tube and add 33 ml Sodium acetate trihydrate. Shake for 5 min and centrifuge at 300 rpm until supernatant liquid is clear. Decant the supernatant as completely as possible and discard. Repeat with 33 ml portion of 1 N Sodium acetate trihydrate for four times, discarding the supernatant liquid each time. Then add 33 ml 95% ethanol, stopper tube, shake for 5 minutes and centrifuge until the supernatant is clear and decant. Wash the sample with 33 ml portion 95% ethanol for 3 times, discarding the supernatant liquid each time. Replace the adsorbed sodium from the sample with 33 ml portions 1N Ammonium acetate solution for three times. Each time shake for 5 minutes and centrifuge until supernatant liquid is clear. Decant the three supernatant liquids into a 100 ml volumetric flask, bring to volume with 1 N Ammonium acetate solution and mix well. Run a series of suitable Na standards; Dilute 2, 4, 6 and 8 ml of 250 ppm Na solution. Add 1 N Ammonium acetate (pH 7.0) to each flask with distilled water to 100 ml marked, for obtaining 0, 5, 10, 15 and 20 ppm Na solution. Measure the samples and take the emission readings by a Flame photometer.

CEC (meq/100g) = $\frac{meq}{L} Na\ (from\ calibration\ curve) \times \frac{Total\ volume\ of\ the\ extract\ (ml)}{Weight\ of\ soil} \times \frac{100}{1000} \times 20$

Statistical analyses

The seasonal mean values (± SD) from the three soil depth (0-10, 10-20 and 20-30 cm) were taken to estimate the seasonal difference among the soil physicochemical parameters

of each site by analysis of variance (one-way ANOVA) at the $p < 0.05$ level. Pearson correlation coefficient was used to determine the significant correlations between the soil physicochemical parameters. Both the statistics were performed using statistical software SPSS (Build 1.0.0.1447).

Soil quality index (SQI) evaluation

SQI value was calculated using additive and weighted methods following Andrews *et al*. (2003) and Marzaioli *et al*. (2010). Three main steps were involved in finding the SQI, which required: the selection of a minimum data set (MDS) of parameter among the measured parameters that could best represent the soil function; followed by scores assigned to the MDS parameters according to their performance of soil function; and finally integrating these scores to determine the index of soil quality. MDS was determined using Principal component analysis (PCA), which was run on the normalized data matrix using the inbuilt R function "princomp" in Rstudio (RStudio Team, 2020). PCA was plotted using "fviz_pca_biplot" function of "factoextra package" (Kassambara and Mundt, 2020). The principal components having a very high eigenvalue (>1) along with the variables having higher factor loading are assumed to be variables that can better represent the attribute of the system. Here, only those principal components with eigenvalues greater than 1 (Mandal *et al*., 2008) were selected and along with the criterion that it should explain a minimum of 5% of the variation in the data (Nabiollahi *et al*., 2017). For each principal component considered, variables having very high factor loading with absolute values within 10% of the highest factor loading are regarded as highly weighted factors and thus were retained for MDS. To reduce the redundancy among the highly weighted variables, given that more than one factor are present for a single principal component, Pearson's correlation coefficients among the highly weighted variables are required to determine those redundant variables and to be eliminated from the MDS (Andrews *et al*., 2002; Guo *et al*., 2018; Yu *et al*., 2018). The variable with the highest factor loading was selected, whereas all the other highly correlated variables were recognized to be redundant, and thus only one variable was considered for the MDS.

The SQI (Additive and Weighted) values were calculated for each observation using the following equations:

$$\text{SQI(Additive)} = \sum_{i=1}^{n} Si/n \quad (1)$$

$$\text{SQI(Weighted)} = \sum_{i=1}^{n} Wi\,Si \quad (2)$$

Where *n* is the number of parameters included in MDS, *Si* is the score for the variable in the MDS, and *Wi* is the weighing factor derived from the PCA results.

A linear scoring method (Andrews *et al*., 2002) was followed to calculate the values of *S* for each observation in the MDS. The parameters were qualitatively grouped into "good" or "bad." A "good" parameter was considered to improve the soil quality; whereas, a "bad" parameter was considered to deteriorate the soil quality. Parameters identified as good for the soil are placed as "more is better." Observation having the highest observed value is assigned to have a score of 1. For all the corresponding observations, the *S* values are calculated as the ratio of the observed value over the highest observation value. Similarly, parameters identified as bad for the soil are tagged as "less is better"; the lowest loaded value was assigned a score of 1, and the *S* values for all the corresponding observations were calculated as the ratio of the lowest value over the observed value of samples for each variable (Guo *et al*., 2018; Sharma *et al*., 2005).

C. Estimation of Tsurang river water physicochemical parameters

Monthly water samples were collected at three stations (approximately 7 km apart) from Tsurang River for a period of one year (September, 2018 to August, 2019) and later the monthly datas were categorized into seasonal values covering the four seasons *viz*., Winter, Spring, Summer and Autumn. The glasswares utilized were pre-treated by washing with dilute HCl (10%), later rinsed with distilled water and then oven dried at 50°C in a dust free room. Furthermore, at the sampling points the containers were rinsed with relevant samples, filled in Tarsons bottles, corked tightly and taken to the laboratory to estimate the physicochemical parameters. The flow rate of five (5) coal mine drainages (D) entering the Tsurang river was estimated seasonally by a digital flow meter (Water Sparks, DFM01) to check their inter-relation with the Water Quality Index (WQI).

Seventeen (17) physicochemical parameters of water were selected for the present study, namely pH, water temperature (WT), free CO_2, turbidity, electrical conductivity (EC), total dissolved solids (TDS), sulphate (SO_4^{2-}), total alkalinity (TA), total hardness (TH), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrate (NO_3^-), potassium (K), inorganic phosphorus (PO_4^{3-}), dissolved oxygen (DO) and biological oxygen demand (BOD) for generating the water quality status of Tsurang river. Physicochemical parameters such as pH, WT and TDS were measured at the sampling spot using HM

digital meter pH-200, thermometer and ERMA TDS-035, while turbidity was analyzed with the help of Nephelometer. All the parameters were estimated following standard protocols given by Trivedi and Goel (1986) and APHA (2005). The standards given by Indian Council of Medical Research (ICMR, 1975), Bureau of Indian Standard (BIS, 2012) and World Health Organization (WHO, 2017) were taken into consideration to determine the permissible limit of drinking water.

1. Chloride

Silver nitrate reacts with chloride to form a soluble white precipitate of AgCl. At the endpoint when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate of reddish-brown color. Take 50 ml of the sample in a conical flask and add 2 ml of 5% K_2CrO_4 solution and titrate with 0.02N $AgNO_3$ until a persistent red tinge appears.

Calculation:

$$Cl^- \text{ (mg/l)} = \frac{\text{Volume of } AgNO_3 \text{ used } \times 1000 \times 35.5}{\text{Volume of water sample used}}$$

2. Total Hardness

50 ml of water samples was taken in a conical flask and 1 ml of buffer solution (a mixture of NH_4Cl and EDTA) was added. A pinch of Eriochrome Black T was further put into the sample solution until the solution turns red wine and is titrated with EDTA solution (0.01M). The endpoint color changes to blue.

Calculation:

$$\text{Hardness as } CaCO_3 \text{ (mg/l)} = \frac{\text{ml of EDTA used} \times 1000}{\text{ml of water sample used}}$$

3. Total alkalinity

Take 100 ml of water sample in a conical flask and add 2 drops of phenolphthalein indicator. With this, the color of the sample changes to pink and is titrated against 0.1N HCl until the endpoint color changes to colorless.

$$\text{Total alkalinity as } CaCO_3 \text{ (mg/l)} = \frac{\text{ml of HCl used} \times 1000 \times 50}{\text{ml of water sample used}}$$

4. Calcium

Take 50 ml of water sample; add 2 ml of 1N NaOH solution and a pinch of murexide indicator. At this point, the color develops into a pink which is then titrated against 0.01M EDTA solution until the pink color changes to purple.

Calculation:

$$Ca^{2+}\ (mg/l) = \frac{\text{Volume of EDTA used } \times 400.8}{\text{Volume of water sample used}}$$

5. Magnesium

Calcium and magnesium form a complex of wine-red color with Eriochrome Black T at pH 10. EDTA has got a strong affinity for Ca^{2+} and Mg^{2+}; the former complex is broken down and a new complex of blue color is formed. The value of Mg^{2+} is then obtained by substracting the value of calcium ion from the total Ca^{2+} and Mg^{2+}.

Calculation:

$$Mg^{2+}\ (mg/l) = \frac{Y - X\ \times 400.8}{\text{Volume of water sample used} \times 1.645}$$

Where, Y = EDTA used in harness determination for the same volume of the water sample.

X = EDTA used in calcium determination for the same volume of the water sample.

6. Free CO_2

Take 100 ml of the sample in a conical flask and add 3-5 drops of phenolpthalein indicator. The solution is then titrated with 0.05N NaOH solution until the endpoint turns pink.

Calculation:

$$\text{Free } CO_2\ (mg/l) = \frac{\text{ml of NaOH used} \times 44\ \times 1000}{\text{ml of water sample used}}$$

7. Dissolved Oxygen

Water samples are collected in 125 ml BOD bottles and immediately fixed with 1 ml each of manganous sulphate and alkali iodide solution. On addition, brown precipitates are formed indicating the presence of oxygen. Once this is confirmed, 2 ml of H_2SO_4 is added and thoroughly mixed till brown precipitate are dissolved. From it, 50 ml of the sample is taken in a conical flask and then titrated with 0.025N sodium thiosulphate till a straw yellow color appears. Few drops of starch solution are added to the sample and titrate further until the blue color disappears (colorless).

Calculation:

$$\text{DO (mg/l)} = \frac{\text{ml of sodium thiosulphate used} \times 8 \times 1000}{\text{ml of water sample used}}$$

8. Biological Oxygen Demand

BOD is the measures of degradable organic matter present in the water sample and can be defined as the amount of oxygen required by the microorganism to stabilized the biologically degradable organic matter under aerobic conditions. BOD measures the difference in the oxygen concentration of the water sample after incubating it for 5 days at 20°C.

Calculation:

BOD (mg/l) = (DO_0 – DO_5)

Where, DO_0 = initial dissolved oxygen value

DO_5 = final dissolved oxygen value after 5 days

9. Nitrate

On addition of brucine, nitrate present in the water sample reacts to produce a yellow color. The intensity of the yellow color is then measured at 410 nm. The reaction is highly dependent upon the heat generated during the test. However, it can be controlled by carrying out the reaction for a fixed time at a constant fixed temperature. Take 10 ml of sample in a 50 ml test tube, adjust the pH to 7.0 and add 10 ml of H_2SO_4. Another 0.5 ml of brucine reagent is added and the tube is placed in a hot water bath for about 20 minutes. After this, the contents are then allowed to cool in a cold water bath, and readings are taken at 410 nm. For blank and standard solutions similar procedure is followed.

10. Inorganic phosphorus

Phosphate in water reacts with ammonium molybdate and form a complex heteropoly acid (molybdophosphoric acid), which eventually gets reduced to a complex of blue color in the presence of $SnCl_2$. The absorption of light by this blue color is then measured at 690 nm to estimate the concentration of phosphates. In a conical flask, 100 ml of the water is taken, 2 ml of ammonium molybdate along with 5 drops of $SnCl_2$ solution are added to the sample and mixed thoroughly. A blue color appears on the addition of all the above reagents and the reading is taken at 690 nm. For the reading of blank and standard solution, a similar amount of reagents and procedures are followed.

11. Sulphate

The measurement of sulphate ion is based on the logic that on addition of barium sulphates, it tends to precipitate into a colloidal form of uniform size. This tendency is further enhanced in the presence of sodium chloride, hydrochloric acid and glycerol. The absorbance of barium sulphates formed is measured by spectrophotometer at 420 nm and the sulphates ion concentration is determined by comparison of the reading with a standard curve.

In a 100 ml standard volumetric flask, 25 ml of the water sample is added. In it, 5 ml of the conditioning reagents is poured in and make up the volume to 100 ml mark using distilled water. The solution is mix thoroughly and then adds a pinch of Barium chloride. The sample readings are taken at 420 nm after 4 minutes.

12. Potassium

The potassium present in the water sample was determined by a flame photometer. The characteristics radiation for potassium is 768 nm and the intensity of the emitted flame is read on a scale by using a filter for this wavelength. The characteristic flame produced in the process is due to the excitation of electrons when the sample with potassium is sprayed into the flame. The intensity of this characteristics radiation is directly proportional to the concentration of potassium in the water sample analysed.

In a 100 ml volumetric flask the water samples are diluted and observed the readings using potassium filter at 768 nm. To calibrate the flame photometer, a standard calibration curve is prepared from the standard potassium solution in the range of 0-10 mg/l against which the concentration of potassium in the water sample is estimated.

K (mg/l) = (mg/l of K in diluted aliquot) + dilution factor

ANOVA statistical analyses

One-way ANOVA followed by Tukey Post-hoc test ($p < 0.05$) were performed using the statistical software SPSS (Build 1.0.0.1447) to estimate the seasonal water physicochemical parameter significant differences at the three sampling stations.

Water Quality Index (WQI) calculation

In total, 13 physicochemical water parameters *viz.*, pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), sulphate (SO_4^{2-}), total alkalinity (TA),

total hardness (TH), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrate (NO_3^-), dissolved oxygen (DO) and biological oxygen demand (BOD) were selected to generate the overall water quality index (WQI) of Tsurang River. As recommended by Dunette (1979) these water quality variables shows the evidence of organic and inorganic pollutions from different land use system, discharge from residential or industrial areas including mining activities. Moreover, all these parameters have their standard limits set by Bureau of Indian Standards (BIS, 2012) and Indian Council of Medical Research (ICMR, 1975) making it more convenient to quantify the water quality.

The Weighted Arithmetic Index (WAI) method calculates the water quality based on the degree of suitability by applying commonly measured water quality variables inferred with the aim of giving a simple numeric expression. WAI method developed by Brown *et al*. (1970) to estimate the WQI is given in the following equation:

$$WQI = \sum Q_n W_n / \sum W_n \quad (1)$$

where Q_n = the quality rating of n^{th} water quality parameter, W_n = the unit weight of n^{th} water quality parameter.

The quality rating (Q_n) for each parameter was calculated using the following equation:

$$Q_n = 100\,[(V_n - V_i)/(V_s - V_i)] \quad (2)$$

Where, V_n = Estimated value of the n^{th} water parameters at a given sampling station, V_i = ideal value of the parameter are taken as zero for the drinking water [$V_i = 0$, except for pH ($V_i = 7$) and DO ($V_i = 14.6$ mg/l)], V_s = standard permissible value (BIS/ICMR) for the n^{th} water quality parameter.

The index is classified to easily monitor data which involves the assigning of 'unit weight (W_n) to estimate the WQI from the selected physicochemical parameter taken into study.

Unit weight (W_n) was calculated using the formula:

$$W_n = k / V_s \quad (3)$$

Where, k = constant of proportionality and it is calculated using the equation

$$k = [1/\sum 1/V_s] \quad (4)$$

Where $\sum(1/V_s) = 1/V_s$ (pH) + $1/V_s$ (Turbidity) + $1/V_s$ (Electrical Conductivity) + $1/V_s$ (Total Dissolved Solids) + $1/V_s$ (Total Hardness) + $1/V_s$ (Total Alkalinity) + $1/V_s$ (Calcium) + $1/V_s$ (Magnesium) + $1/V_s$ (Chloride) + $1/V_s$ (Nitrate) + $1/V_s$ (Sulphate) + $1/V_s$ (Dissolved Oxygen) + $1/V_s$ (Biological Oxygen Demand)

The WQI range, status and its probable usage are presented in **Table 2.2**.

Table 2.2: Water Quality Index (WQI) range, status and probable usage of water sample (Brown *et al*., 1972)

WQI range	Water quality status (WQS)	Probable usage
0-25	Excellent water quality	Drinking, irrigation and industrial purpose
26-50	Good water quality	Drinking, irrigation and industrial purpose
51-75	Poor water quality	Irrigation and industrial purpose
76-100	Very poor water quality	For irrigation purpose
Above 100	Unsuitable for drinking purpose	Proper treatment required for any kind of usage

D. Heavy metal analysis

1. Collection and analysis of soil, water and plant samples

Random soil sampling (5 samples) followed by composite mixture from a depth of 0-30 cm were collected from CMAF and NAF of Changki. Later, unwanted debris, forest litters, stones and gravels were removed from the sample, thereafter air-dried and grounded into fine particles that could pass through a 2.0 mm sieve. Elements such as Zinc (Zn), Cadmium (Cd), Copper (Cu), Nickel (Ni), Lead (Pb), Chromium (Cr), Antimony (Sb), Mercury (Hg), Barium (Ba) and Arsenic (As) were tested to comparatively assess the differences between CMAF and NAF soil. The pollution status of CMAF soil was also estimated from the analysed heavy metals considering NAF as the 'control site'. Tsurang river water was sampled from three sampling stations to determine Zinc (Zn), Manganese (Mn), Cadmium (Cd), Nickel (Ni), Lead (Pb), Chromium (Cr), Antimony (Sb), Barium (Ba) and Arsenic (As). The plant species for heavy metal bioaccumulation analysis were selected after the phytosociological studies and the dominant species based on CMAF site (*Melastoma malabathricum, Dicranopteris linearis, Chromolaena odorata, Pteridium esculentum* and *Thysanolaena latifolia*) were examined. For comparative estimation their counterparts from NAF site were also selected for heavy metal quantification. The shoots (stem, leaves) of each selected plant species were taken to the laboratory, rinsed with distilled water, air-dried in a dust free

room, grinded and digested for the detection of five heavy metals *viz*., Zinc (Zn), Cadmium (Cd), Copper (Cu), Nickel (Ni) and Lead (Pb). The samples were analysed following IS (1992; 2001 and 2005); APHA (1992) and ISO (1998) which were determined quantitatively using Perkin Elmer, Atomic Absorption Spectrometer (AAS) AAnalyst – 700. Triplicates readings were taken for all the parameters and elements analysed and the mean value were used for the study.

2. Detection of heavy metals in water

Brief process and procedures for detecting heavy metals are discussed below:

Arsenic

35 ml of sample were pipetted into a clean generator bottle with addition of 5 ml concentrated hydrochloric acid, 2 ml potassium iodide solution, 8 drops of stannous chloride which were mixed thoroughly and allowed to rest for 15 minutes for reduction of arsenic to the trivalent state. Now 4 ml of silver diethyl dithiocarbamate reagent were pipetted into absorber tubes with 3 gm of zinc to generator and connected to the scrubber-absorber assembly immediately and rest for 30 minutes for complete evaluation of arsine. The generator was warmed slightly to ensure that all arsine is released. The solution is than poured from absorber directly into 1 cm cell and absorbance is measured at 535 nm, using reagent blank as reference, followed by treating the portions of standard solutions containing 0, 1, 2, 5, 10 µg/l arsenic. Later, the plot absorbance versus concentration of arsenic in the standard was estimated.

Barium

Caesium-lanthanum solution amounting to 5 ml was taken to a clean dry 50 ml standard volumetric flask and diluted to 50 ml with the sample or sample aliquot solution. The standard and sample solutions were aspirated and the nitrous oxide-acetylene flame was processed for Barium determinations. Volume of barium stock solution added (ml) are 0, 0.25, 1.0, 1.5, 5.0 concentration (µg/l). Calculate the concentration of each metal ion reference to the calibration curves obtained by plotting concentrations of the standard solutions versus the corresponding absorbance readings at 553 nm.

Antimony

In a 125 ml Erlenmeyer flask, 50 ml aliquot was transferred, along with 5 ml of sulphuric acid and evaporated to fumes of SO_3, followed by cooling the flask with

addition of 10 drops 70% perchloric acid and again evaporated to white fumes. The digested sample were cooled in ice-bath for 30 min, and slowly 5 ml pre-cooled 6 N hydrochloric acid was added with the help of pipette and stand in ice-bath for 15 min, with an addition of 8 ml pre-cooled 3N phosphoric acid. (Until colour is extracted into benzene, perform subsequent operations as quickly as possible, colour is stable in benzene after several hours). Immediately 5 ml precooled Rhodamine B solution is added, shaked vigorously and transferred to pre-cooled 125 ml separator. Now 10 ml pre-cooled benzene is pipetted into separator, shaked vigorously for 1 min, aqueous layer was discarded and benzene layer (red if antimony is present) was transferred into a test tube till water settle. Rinse 1 cm cell with extract, fill the cell, and absorption was read at 565 nm against benzene blank taken through entire determination. 0, 2, 4, 6, 8 and 10 ml antimony working standard solutions was pipetted into 125 ml Erlenmeyer flask with 5 ml sulphuric acid to each. The plot absorption against µg of antimony was derived and calculated the µg (or mg) of antimony from the graph corresponding to the observed absorption value.

Chromium

The aliquot sample 50 ml was transferred to a 250 ml beaker and dilute to 100 ml with water. Later, blank and standard solution in the manner of 0, 2, 4, 6, 8 and 10 ml was prepared. The pH of the sample and standard solutions was adjusted to 2.5 with hydrochloric acid and transferred quantitatively to a 200 ml volumetric flask with 2.5 ml of ammonium pyrrolidine dithiocarbamate solution and mixed. 10 ml methyl isobutyl ketone was added, shaked vigorously for 1 min and water was added until the ketone layer is in the neck of the flask. The ketone layer was aspirated and the record readings of standards within the range of detection and samples against blank were estimated. The calibration curve were prepared from the average of each standard and read the sample concentration at 553 nm.

Nickel

In a 500 ml volumetric flask, 20 ml of nickel solution were placed that contain 10 mg/l of nickel, 0.5 ml of nitric acid and filled to the mark with distilled water, this is solution S. Four calibration solutions were prepared by diluting solution S with distilled water to cover the ranges of concentrations of nickel from 0 to 200 ug/l. Each calibration solution was acidified by adding the same nitric acid which has been added to preserve

the samples. The volume added is such that the concentrations of nitric acid are the same in the sample and in the calibration solutions. By reference to the calibration graph, the concentrations corresponding to the absorbance at 553 nm were determined for the test portion and of the blank.

Lead

To 100 ml portion of the sample, 0.5 ml of nitric acid, 5 ml of concentrated hydrochloric acid were added, heated to reduce the volume to 20 ml in a well-ventilated hood. Later, the sample was cooled, filtered, make up to 100 ml in a standard flask, aspirate the sample solution and measured the absorbance at 283.3 nm. A reagent blank and sufficient standards containing 1.0, 2.5, 5.0, 7.5 and 10 mg/1 of lead by diluting suitable volume of the standard solution with nitric acid (1:499) were prepared and the absorbance were measured. A standard calibration graph was constructed by plotting the absorbance versus mg of lead concentration of each standard and concentration of the sample from the graph was noted.

Zinc

For total zinc, 1 ml of concentrated hydrochloric acid was added to 50 ml of the sample and boiled for 5 minutes. The solution was cooled and adjusted to pH 7 with sodium hydroxide solution. 10 ml of this solution was taken in an Erlenmeyer flask and 0.5 g of sodium ascorbate, 1 ml of cyanide solution, 5 ml of buffer solution, 3 ml of zincon solution and 1 ml of chlorohexanone solution in the above order were added with a marked up solution to 500 ml. A reagent blank was prepared by treating 50 ml of double distilled water and optical density of the sample solution at 620 nm were measured against the reagent blank containing added zinc. 50 ml portions of standard solutions containing 0.02, 0.05, 0.1, 0.5, 1.0 and 5.0 mg/l of zinc was treated as above and the absorbance was measured. The absorbance versus milligram of zinc for the standards were plotted to get a calibration graph and later the concentration of zinc in the sample from the calibration graph were noted.

Cadmium

To 100 ml portion of the sample 5 ml of concentrated hydrochloric acid was added and evaporated to 20 ml. The solution was cooled and filtered and make up to 100 ml in a standard flask. The sample solution were aspirated and measured at the absorbance of 228.8 nm. A reagent blank was prepared and a series of 100 ml standards

containing 0.0, 0.05, 0.1, 0.5, 1 and 2 mg/l of cadmium by diluting a suitable volume of the standard solution with dilute nitric acid were prepared and absorbance measured. A standard calibration graph was constructed by plotting the absorbance versus cadmium concentration (mg/l) of each standard and the concentration of the sample from the graph was recorded.

Manganese

To a 300 ml conical flask of borosilicate glass a suitable volume of the sample was added mixed with 4 ml of dilute sulphuric acid and evaporated to fumes. To the solution while heating, hydrogen peroxide-nitric acid mixture was added in few drops at a time, to completely remove any organic matter. Later cooled, and10 ml of stabilized distilled water was added and evaporated to fumes. 50 ml of stabilized distilled water is also added with 2 ml of the phosphoric acid and 0.2 g of potassium periodate, bringing to boil for 1 hour. The solution is than cooled to room temperature, transferred to a Nessler tube, with an adjustment of the volume to 50 ml with stabilized distilled water. Into seven 300 ml conical flasks measured by means of a burette, 0, 1.0, 2.0, 4.0, 6.0, 8.0 and 10 ml of standard manganese solution were prepared, the standards were treated as described above for the sample. The absorbance of the known sample using spectrometer at a wavelength of 450 nm was than recorded.

Copper

50 ml of the sample were transferred to a 125 ml separating funnel with 5 ml of hydroxylamine-hydrochloride solution, 10 ml of sodium citrate solution, 10 ml of neocuproine solution and shaked well. 20 ml of chloroform were also added, shaked for 1 minute and allowed the aqueous and chloroform layers to separate. The chloroform layer was collected in a dry flask and the process was repeated with separate 20 ml aliquot of chloroform. Now, the extracts were mixed and diluted to 50 ml with isopropyl alcohol. A reagent blank was prepared by treating 50 ml of double distilled water in the same way as described above. Optical density was measured for the sample solution at 457 nm against the reagent blank. For standard solutions, 0.05, 0.1, 0.5, 1.0, 5.0 mg/l of copper were prepared. The absorbance versus copper concentration for the standards was recorded to get a calibration graph and the concentration of copper in the sample from the calibration graph was noted.

Mercury

An amount of 50 ml of the sample was transferred by graduated cylinder to the reaction vessel of the accessory, and 3 ml of 100 g/l stannous chloride solution was added. A standard solution of 0, 2, 6, 10 and 20 µg/l was also prepared. Now the calculation for the concentration of mercury in each sample at absorbance of 253 nm by reference to the calibration curve obtained through plotting concentrations of the standard solutions versus the corresponding peak heights were recorded.

3. Detection of heavy metals in soil and plant

Absorbance wavelength: Cadmium-228.8 nm, Chromium-357.9 nm, Copper-324.8 nm, Lead-217 nm, Nickel-232 nm, Zinc-213.9 nm, Mercury-300 nm, Antimony-565 nm, Barium-553 nm and Arsenic-535nm.

Preparation of stock and standard solutions of individual elements

Cadmium solutions

Cadmium, stock solution corresponding to 1000 mg/l of cadmium:

1 gm of cadmium metal (minimum purity 99.5%) was diluted in a covered 250 ml glass beaker with 40 ml of nitric acid by adding 100 ml of water, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Cadmium, standard solution corresponding to 20 mg/l of cadmium:

An estimated 20 ml of the stock cadmium solution was pipetted into a 1000 ml volumetric flask with 20 ml of nitric acid and filled to the mark with distilled water.

Chromium solutions

Chromium stock solution corresponding to 1000 mg/l of chromium:

Dissolve 2.8290 gm of potassium dichromate, dried at 130°C for 24 h, in a covered 400 ml glass beaker with 40 ml of distilled water; 5 ml of sulphuric acid was added, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Chromium standard solution corresponding to 20 mg/l of chromium:

20 ml of the stock chromium solution was taken into a 1000 ml volumetric flask, mixed with 20 ml of nitric acid and filled to the mark with distilled water.

Copper solutions

Copper stock solution corresponding to 1000 mg/l of copper:

Weight of 1 gm copper metal (minimum purity 99.5%) was dissolved in a covered 250 ml glass beaker filled with 40 ml of nitric acid which was diluted by adding 100 ml distilled water, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Copper standard solution corresponding to 20 mg/l of copper:

20 ml of the stock copper solution was pipetted into a 1000 ml volumetric flask, 20 ml of nitric acid was added and filled to the mark with distilled water.

Lead solutions

Lead, stock solution corresponding to 1000 mg/l of lead:

An approximate weight of 1 gm lead metal (minimum purity 99.5%) was dissolved in a covered 250 ml glass beaker with 40 ml of nitric acid mixed with 100 ml of distilled water, later boiled to expel nitrous fumes, cooled, transferred into a 1000 ml volumetric flask and finally filled to the mark with distilled water.

Lead standard solution corresponding to 20 mg/l of lead:

20 ml of the stock lead solution was pipetted into a 1000 ml volumetric flask mixed with 20 ml of nitric acid and filled to the mark with distilled water.

Nickel solutions

Nickel stock solution corresponding to 1000 mg/l of nickel:

1 gm of nickel metal (minimum purity 99.5%) was dissolve in a covered 250 ml glass beaker filled with 10 ml of hydrochloric acid and 10 ml of nitric acid. The solution was added with 100 ml of distilled water, later boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Nickel, standard solution corresponding to 20 mg/l of nickel:

An amount of 20 ml of the stock nickel solution was pipetted into a 1000 ml volumetric flask with an addition of 20 ml of nitric acid and later filled to the mark with distilled water.

Zinc solutions

Zinc stock solution corresponding to 1000 mg/l of zinc:

An estimated 1 gm of zinc metal (minimum purity 99.5%) was dissolve in a covered 250 ml glass beaker with 40 ml of nitric acid. 100 ml of distilled water was added into the

solution, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Zinc standard solution corresponding to 20 mg/l of zinc:

20 ml of the stock zinc solution was taken into a 1000 ml volumetric flask with 20 ml of nitric acid and filled to the mark with distilled water.

Mercury solutions

Mercury stock solution corresponding to 1000 mg/l of mercury:

An approximate weight of 1 gm mercury metal (minimum purity 99.5%) was dissolved in a covered 250 ml glass beaker with 40 ml of nitric acid, diluted with 100 ml of water, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and later filled to the mark with distilled water.

Mercury standard solution corresponding to 20 mg/l of mercury:

Mercury stock solution of 20 ml was taken into a 1000 ml volumetric flask with 20 ml of nitric acid and filled to the mark with distilled water.

Antimony solutions

Antimony, stock solution corresponding to 1000 mg/l of antimony:

An estimated weight of 1 gm antimony metal (minimum purity 99.5 %) was dissolved in a covered 250 ml glass beaker with 40 ml of nitric acid. Later, 100 ml distilled water was added, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Antimony standard solution corresponding to 20 mg/l of antimony:

20 ml of the stock antimony solution was pipetted into a 1000 ml volumetric flask with 20 ml of nitric acid and fill to the mark with distilled water.

Barium solutions

Barium stock solution corresponding to 1000 mg/l of barium:

1 gm of barium metal (minimum purity 99.5 %) was dissolved in a covered 250 ml glass beaker with 10 ml of hydrochloric acid and 10 ml of nitric acid. Later 100 ml of distilled water was added, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Barium, standard solution corresponding to 20 mg/l of barium:

An amount of 20 ml of the stock barium solution was taken into a 1000 ml volumetric flask with 20 ml of nitric acid and later filled to the mark with distilled water.

Arsenic solutions

Arsenic stock solution corresponding to 1000 mg/l of arsenic:

1 gm of arsenic metal (minimum purity 99.5 %) was dissolved in a covered 250 ml glass beaker with 40 ml of nitric acid. Measured amount of 100 ml distilled water was added, boiled to expel nitrous fumes, cooled, transferred to a 1000 ml volumetric flask and filled to the mark with distilled water.

Arsenic standard solution corresponding to 20 mg/l of copper:

Stock arsenic solution of 20 ml was taken into a 1000 ml volumetric flask with 20 ml of nitric acid and filled to the mark with distilled water.

Digestion of heavy metals

The Nitric-hydrochloric acid digestion (1:3) method formulated by Ang and Lee (2005) was used for the digestion of soil and plant samples. Samples were weighed (0.5g) and placed in a 100 ml Poly tetrafluoroethylene (PTFE) beaker. 9 ml of the freshly prepared acid mixture of 65% HNO_3 and 37% HCl were added to the samples. Then, the mixture was boiled gently over a hot water bath at 95°C for a time period of 4–5 hrs (or until the sample had completely dissolved).

Blank test

A blank test was carried out at the same time as the extraction with aqua regia using cleaned quartz sand instead of the samples and followed the same procedure, using the same quantities of all the reagents for determination.

Preparation of the calibration solutions

Before each batch of determinations, 20 mg/l element standard solution was prepared for at least five calibration solutions covering the range of concentrations to be determined.

Cadmium, Zinc and Mercury calibration solutions

1 ml, 2 ml, 4 ml, 6 ml, 8 ml, 10 ml of the metal standard solution was pipetted into a series of 100 ml volumetric flasks. To each flask 21 ml of hydrochloric acid, 7 ml of nitric acid was added and diluted to the mark with distilled water and mixed well. These solutions correspond to the metal concentrations of 0.2 mg/l, 0.4 mg/l, 0.8 mg/l, 1.2 mg/l, 1.6 mg/l and 2.0 mg/l, respectively.

Chromium, Copper, Lead, Nickel, Barium, Antimony and Arsenic calibration solutions

5 ml, 10 ml, 20 ml, 30 ml and 40 ml portions of the metal standard solution was pipetted into a series of 100 ml volumetric flasks. To each flask, 21 ml of hydrochloric acid and 7 ml of nitric acid was added, than diluted to the mark with distilled water and mixed well. These solutions correspond to the metal concentrations of 1 mg/l, 2 mg/l, 4 mg/l, 6 mg/l and 8 mg/l, respectively.

Plotting calibration graphs

A graph for each element was plotted with the concentrations of the calibration solutions (from which has been subtracted the blank calibration reading for the solution), in milligrams per litre, as abscissa, and the corresponding absorbance values as ordinate.

Determination of test portion

The blank test solution and the test portion (digested sample) were aspirated separately, and the absorbance was measured for that element.

Calculation

By reference to the calibration graph obtained, the concentration of the element corresponding to the absorbance of the test portion and of the blank test solution were determined. The metal content of the element in the sample was calculated using the following equation:

$W_{(M)} = (R-r).f.V/m$

Where,

$W_{(M)}$ = is the mass fraction of the element M in the sample, in milligrams per kilogram

R = is the concentration of the element, in milligrams per litre, corresponding to the absorbance of the test portion

r = is the concentration of the element, in milligrams per litre, corresponding to the absorbance of the blank test solution.

f = is the dilution factor of the diluted test portion, if applicable

V = is the volume, of the test portion taken for the analysis

m = mass of the sample taken

E. Soil pollution indices

The heavy metal concentration in soil extracts were calculated on the basis of dry weight (mg/kg) and the indices of soil pollution were determined by the following methods:

1. Single pollution index (PI)

PI determines a specific heavy metal representing the highest threat for a soil environment. The PI equation, as defined by Lacutusu (2000), was used for the derivation of the contamination factors.

$$PI = \frac{Cn}{GB}$$

Where Cn is the content of heavy metal in CMAF soil, and GB is the geochemical background value taken from NAF.

2. Pollution load index (PLI)

The total assessment of the degree of contamination in soil is estimated using PLI. It is calculated as a geometric average of PI based on the following formula given by Thomilson *et al*. (1980).

$$PLI = [PI_1 \times PI_2 \times PI_3 \times ……..\times PI_n]^{1/n}$$

Where n is the number of analyzed heavy metals, and PI is the calculated values for the single pollution index.

3. Nemerow integrated pollution index (NIPI)

The NIPI assesses the overall pollution integrity of the area and is calculated as formulated by Nemerow (1985).

$$NIPI = [0.5 \times (I_{mean}^2 + I_{\max}^2)]^{1/2}$$

Where I_{mean} is the average concentration of all pollution indices considered, and $I_{\max}$ is the maximum pollution index.

Soil pollution models and their classification schemes utilized in the study are shown in **Table 2.3**.

Table 2.3: Soil pollution status models and the classification schemes utilized in the study

Single Pollution Index/ Contamination Index		**Pollution Load Index**		**Nemerow Integrated Pollution Index**	
< 0.1	Very slight contamination	>0 PLI ≤1	Unpolluted to moderately polluted	≤0.7	Safe
0.1 – 0.25	Slight contamination	>1 PLI ≤2	Moderately polluted	>0.7 NIPI≤ 1	Precaution
0.26 – 0.5	Moderate contamination	>2 PLI ≤3	Moderately to highly polluted	>1 NIP ≤2	Slightly polluted
0.51 – 0.75	Severe contamination	>3 PLI ≤4	Highly polluted	>2 NIP ≤3	Moderately polluted
0.76 – 1.0	Very severe contamination	≥5	Very highly polluted	> 3	Heavily polluted
1.1 – 2.0	Slight pollution	-	-	-	-
2.1 – 4.0	Moderate pollution	-	-	-	-
4.1 – 8.0	Severe pollution	-	-	-	-
8.1 – 16	Very severe pollution	-	-	-	-
>16	Excessive pollution	-	-	-	-

CHAPTER - 3

VEGETATION DIVERSITY OF COAL MINING AFFECTED AND NON-AFFECTED FOREST AT CHANGKI

3.1 INTRODUCTION

Tropical forest covers approximately 44% of the earth's land surface (FAO, 2015). It sustains the most species-diverse terrestrial ecosystems and serves as a storehouse for the biological and genetic diversity, along with more than half of the world's life form thriving under these forests (May and Stumpf, 2000; Keenan *et al*., 2015). The species diversity is an essential component of a forest as it represents the overall forest health and offers valuable knowledge that serves as the primary information for the conservation and protection of the ecosystem (Roy *et al*., 2004; Sharma and Kant, 2014). Plant composition, diversity and their spatial distribution in a forest ecosystem are largely influenced by the geographical location of the region, soil, climate, regeneration pattern of species (Sarkar and Devi, 2014; Siregar *et al*., 2019) niche requirement and disturbances (Huang *et al*., 2003). Over the years, vegetation cover under natural forests has been rapidly declining worldwide, particularly in tropical areas and secondary forests are rising in dominance (Devi *et al*., 2018). In South and Southeast Asia, the net forest loss was estimated to be around 25% higher between 2010 and 2015 compared to the 1990's (Keenan *et al*., 2015). It is estimated that an alarming percent of 0.8 – 2% of these forests gradually disappear per year (Sagar *et al*., 2003). Vast area of forest cover are impaired by multiple anthropogenic actions such as clearing of forest for agricultural land, industrial built-ups, dams, highways and extensive mining. Environmental factors

including soil erosion, heavy rain, lightning, forest fire and other harsh climatic condition can also alter the composition of the standing forest structure. However primary causes of forest destruction are attributed mainly to man-made sources. Therefore, it is critical to understand the human impact on the ecosystem to prioritize the conservation of tropical forests (Devi *et al*., 2018). External anthropogenic pressures alter the soil, water and air quality and affect the environmental gradient of the individual plant species and their population via various mechanisms of reaction, and thus influence the plant community structure. As such by the selection pressures of the environment, the plant community structure of an area tends to become established. The superimposition of severe pressures on the plant community sometimes occurs to allow feedback mechanisms to operate for the selection of resistant and dominant species (Pandey *et al*., 2014). Coal mining is an environmental degrading activity that initially involves clearing of a large area of forest which gradually changes the forest landscape affecting the forest ecosystem while the repercussion effect of it stays for decades spreading over a vast area of land. In India, workers such as Singh *et al*. (1994), Sarma *et al*. (2010), Sarma and Barik (2011) and Pandey *et al*. (2014) reported the negative effects of coal mining on plant community structure which resulted in the loss of species, reduction in forest cover and alteration of the landscape.

Northeast India is a part of the Indo-Burma mega biodiversity hotspot which includes an immense variety of plant species and is one of the richest in terms of biological wealth and endemism in the Indian subcontinent (Tynsong and Tiwari, 2011). However, the primary forest of this region are disappearing at an alarming rate due to a number of human activities including shifting cultivation, deforestation, forest fragmentation (Upadhaya *et al*., 2003), coal mining (Rai, 2002; Barik *et al*., 2006: Sarma and Barik, 2011) and urbanization. Quantitative plant diversity studies in northeast Indian forests are very limited and mainly confined to the tropical forests of Arunachal Pradesh (Bhuyan *et al*., 2003), Meghalaya (Kumar, 2006; Upadhaya *et al*., 2003), lowland primary and secondary moist deciduous forests of Tripura (Majumdar, 2012), subtropical forests of Manipur (Khumbongmayum *et al*., 2005), tropical forest stands of Mizoram (Singh *et al*., 2015) and Nagaland (Ao *et al*., 2020; Ao *et al*., 2021). In concern with the growing awareness and need for biodiversity conservation, quantification of plant species distribution and its abundance is vital. However, Northeast India and in particular Nagaland, when compared to the rest of the country is understudied. One major challenging factor and hurdle for enthusiast researchers or scientist could be the

topography of the area itself, which are often not easily accessible, as most states in this part of the country have a hilly terrain resulting in a cost and time-intensive study (Nohro and Jayakumar, 2020). Quantitative analysis of plants in the Coal mining affected forest (CMAF) and Non-affected forest (NAF) will provide baseline information on the effects of anthropogenic disturbance on forest plant species distribution and diversity.

3.2 RESULTS

3.2.1 Trees composition, distribution and diversity in the CMAF and NAF

A total of 769 tree individuals belonging to 60 genera, 64 species and 37 taxonomically well-represented families from the two forests were enumerated. The tree species richness was higher at NAF (44) compared to CMAF (36) **(Table 3.1)**. At NAF, a total of 421 tree individuals representing 44 genera constituting 29 families were identified whereas at CMAF, a total of 348 individual trees belonging to 36 genera and 12 families were recorded.

Table 3.1: Composition of trees at Coal mining-affected forest (CMAF) and Non-affected forest (NAF) of Changki

Accession no.	Species name	Family	NAF	CMAF
NU-KS-1	*Artocarpus lakoocha* Roxb.	Moraceae	+	Δ
NU-KS-2	*Abarema clypearia* (Jack) Kosterm	Fabaceae	+	Δ
NU-KS-3	*Alstonia scholaris* R. Br.	Apocynaceae	+	+
NU-KS-4	*Albizia chinensis* (Osbeck) Merr.	Fabaceae	Δ	+
NU-KS-5	*Aporosa octandra* (Buch.-Ham ex D. Don)	Phyllanthaceae	+	+
NU-KS-6	*Brassaiopsis mitis* C. B. Clarke	Araliaceae	+	Δ
NU-KS-7	*Balakata baccata* (Roxb.) Esser	Euphorbiaceae	+	Δ
NU-KS-8	*Bridelia tomentosa* Blume	Phyllanthaceae	+	+
NU-KS-9	*Bauhinia variegata* (L.) Benth	Fabaceae	Δ	+
NU-KS-10	*Bambusa pallida* Munro	Poaceae	Δ	+
NU-KS-11	*Callicarpa arborea* Roxb.	Lamiaceae	Δ	+
NU-KS-12	*Cassia fistula* L.	Fabaceae	Δ	+
NU-KS-13	*Castanopsis indica* (Roxb. Ex Lindl.)	Fagaceae	+	Δ
NU-KS-14	*Colona flovibunda* (Kurz) Craib	Malvaceae	+	+
NU-KS-15	*Canarium strictum*. Roxb.	Burseraceae	+	+
NU-KS-16	*Croton persimilis* Mull. Arg.	Euphorbiaceae	+	+
NU-KS-17	*Casearia graveolens* Dalzell	Salicaceae	+	Δ
NU-KS-18	*Choerospondias axillaris* Roxb.	Anacardiaceae	+	Δ
NU-KS-19	*Diospyros stricta* Roxb.	Ebenaceae	+	Δ
NU-KS-20	*Dalbergia retusa* Hemsl.	Fabaceae	Δ	+
NU-KS-21	*Dendrocalamus giganteus* Munro	Poaceae	Δ	+
NU-KS-22	*Dalhousiea bracteata* (Roxb.) Benth.	Fabaceae	Δ	+
NU-KS-23	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	Lythraceae	Δ	+
NU-KS-24	*Engelhardia spicata* Lechan ex Blume var.	Junglandaceae	+	Δ
NU-KS-25	*Erythrina stricta Roxb.*	Fabaceae	Δ	+
NU-KS-26	*Ficus obscura* Blume	Moraceae	Δ	+
NU-KS-27	*Ficus nervosa* B. Heyne ex Roth	Moraceae	+	+

NU-KS-28	*Gmelina arborea* Roxb.	Verbenaceae	Δ	+
NU-KS-29	*Gnetum gnemon* L.	Gnetaceae	+	Δ
NU-KS-30	*Garuga pinnata* Roxb.	Burseraceae	+	Δ
NU-KS-31	*Grewia abutilifolia* W. Vent ex Juss	Tiliaceae	+	+
NU-KS-32	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	+	Δ
NU-KS-33	*Litsea monopetala* (Roxb. ex Baker)	Lauraceae	+	+
NU-KS-34	*Lithocarpus dealbata* (Hoof. f. & Thomson ex Miq.)	Fagaceae	+	Δ
NU-KS-35	*Litsea glutinosa* (Lour.) C. B. Rob.	Lauraceae	+	Δ
NU-KS-36	*Litsea cubeba* (Lour.) Pers.	Lauraceae	+	Δ
NU-KS-37	*Macaranga denticulata* (Blume) Mull. Arg.	Euphorbiaceae	+	Δ
NU-KS-38	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	Δ	+
NU-KS-39	*Mitragyna rotundifolia* (Roxb.) kuntze	Rubiaceae	Δ	+
NU-KS-40	*Mallotus ferrugineous* (Roxb.) Muell. Arg.	Euphorbiaceae	Δ	+
NU-KS-41	*Meliosma pinnata* (Roxb.)	Sabiaceae	+	Δ
NU-KS-42	*Mesua ferrea* L.	Calophyllaceae	+	+
NU-KS-43	*Micromelum integerrimum* Buch.-Ham.ex Colebr	Rutaceae	+	Δ
NU-KS-44	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	+	Δ
NU-KS-45	*Maesa indica* (Roxb.) A. DC.	Primulaceae	Δ	+
NU-KS-46	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	+	Δ
NU-KS-47	*Phoebe lanceolata* (Nees) Nees	Lauraceae	+	+
NU-KS-48	*Phyllanthus emblica* L.	Euphorbiaceae	+	Δ
NU-KS-49	*Quercus serrata* Murray	Fagaceae	Δ	+
NU-KS-50	*Rhus semialata* Murray	Anacardiaceae	+	Δ
NU-KS-51	*Saurauia armata* Kurz	Actinidiaceae	+	+
NU-KS-52	*Sapium baccatum* Roxb.	Euphorbiaceae	+	Δ
NU-KS-53	*Schima wallichii* (DC.) Korth	Theaceae	Δ	+
NU-KS-54	*Styrax serrulatus* Roxb.	Styracaceae	+	+
NU-KS-55	*Syzygium syzygioides* (Miq.) Merr. & L. M Perry	Myrtaceae	+	+
NU-KS-56	*Stixis suaveolens* (Roxb.) Pierre	Caprifoliaceae	+	Δ
NU-KS-57	*Sterculia* sp.	Malvaceae	+	Δ
NU-KS-58	*Toxicodendron succedanea* L.	Anacardiaceae	+	Δ
NU-KS-59	*Trema orientalis* L. Blume	Cannabaceae	+	+
NU-KS-60	*Toona ciliata* M. Roem.	Meliaceae	Δ	+
NU-KS-61	*Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	+	+
NU-KS-62	*Vitex altissima* L. fil.	Lamiaceae	+	Δ
NU-KS-63	*Wendlandia tinctoria* (Roxb.) DC.	Rubiaceae	Δ	+
NU-KS-64	*Wrightia arborea* (Dennst.) D. J. Mabberley	Apocynaceae	+	Δ

At CMAF, *Terminalia myriocarpa* had the highest IVI (22.98) followed by *Phoebe lanceolata* (17.83), while *Ficus obscura* imparted the lowest IVI (2.03) (**Fig. 3.1**). Based on the IVI obtained in NAF, *Terminalia myriocarpa* contributed the highest IVI (15.7) followed by *Litsea monopetala* (14.78) (**Fig. 3.2**). The family Euphorbiaceae occupied the highest (5) number of species followed by Anacardiaceae (4), Lauraceae (4), Apocynaceae (2), Phyllanthaceae (2), Fagaceae (2), Malvaceae (2) and Burseraceae (2) in NAF. In CMAF, Fabaceae (7) dominated the forest followed by Euphorbiaceae (3), Phyllanthaceae (2), Poaceae (2), Moraceae (2), Rubiaceae (2) and Lauraceae (2). The rest of the families in both the forest have 1 species each. It was observed that the family

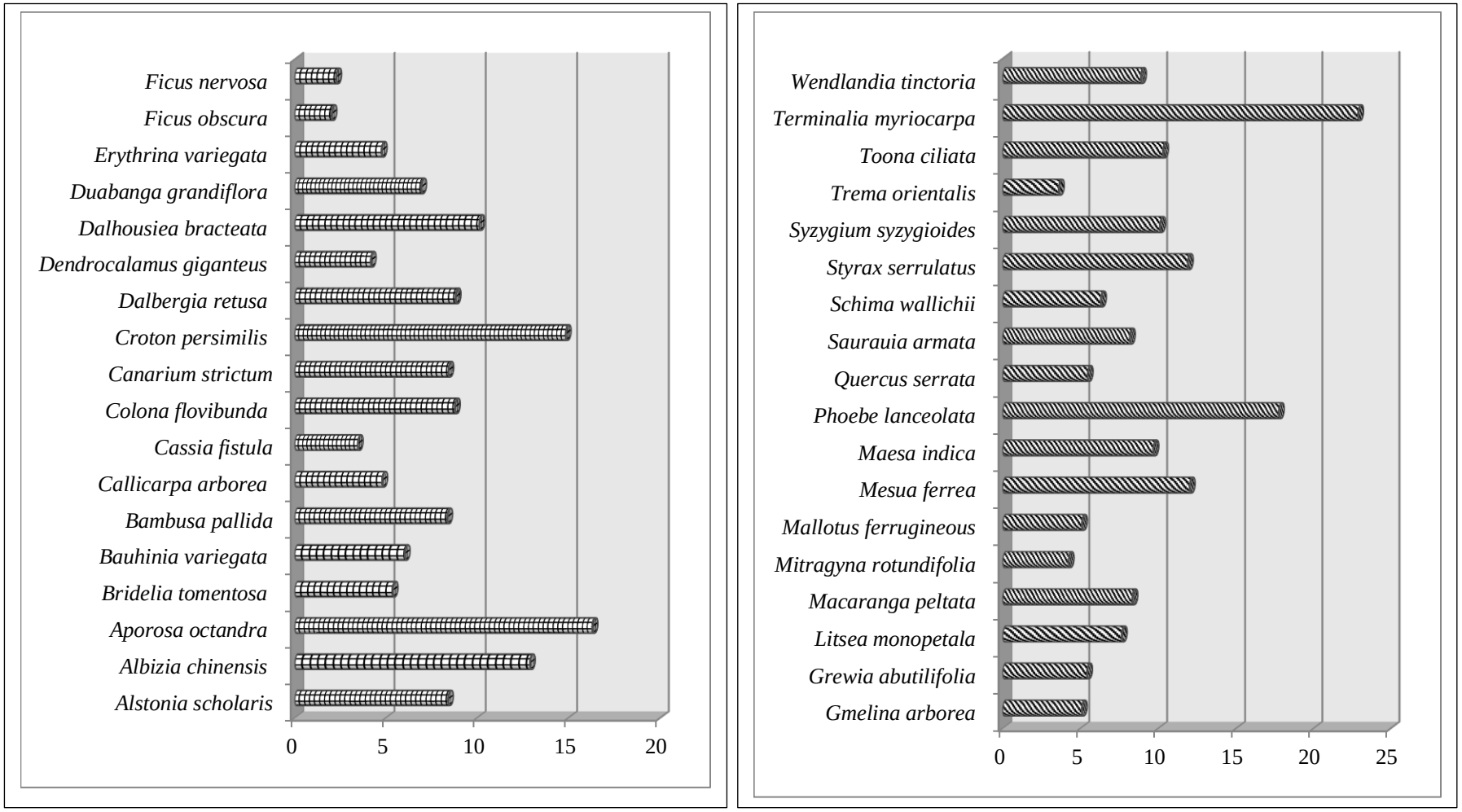


Fig. 3.1: Important value index (IVI) of CMAF trees

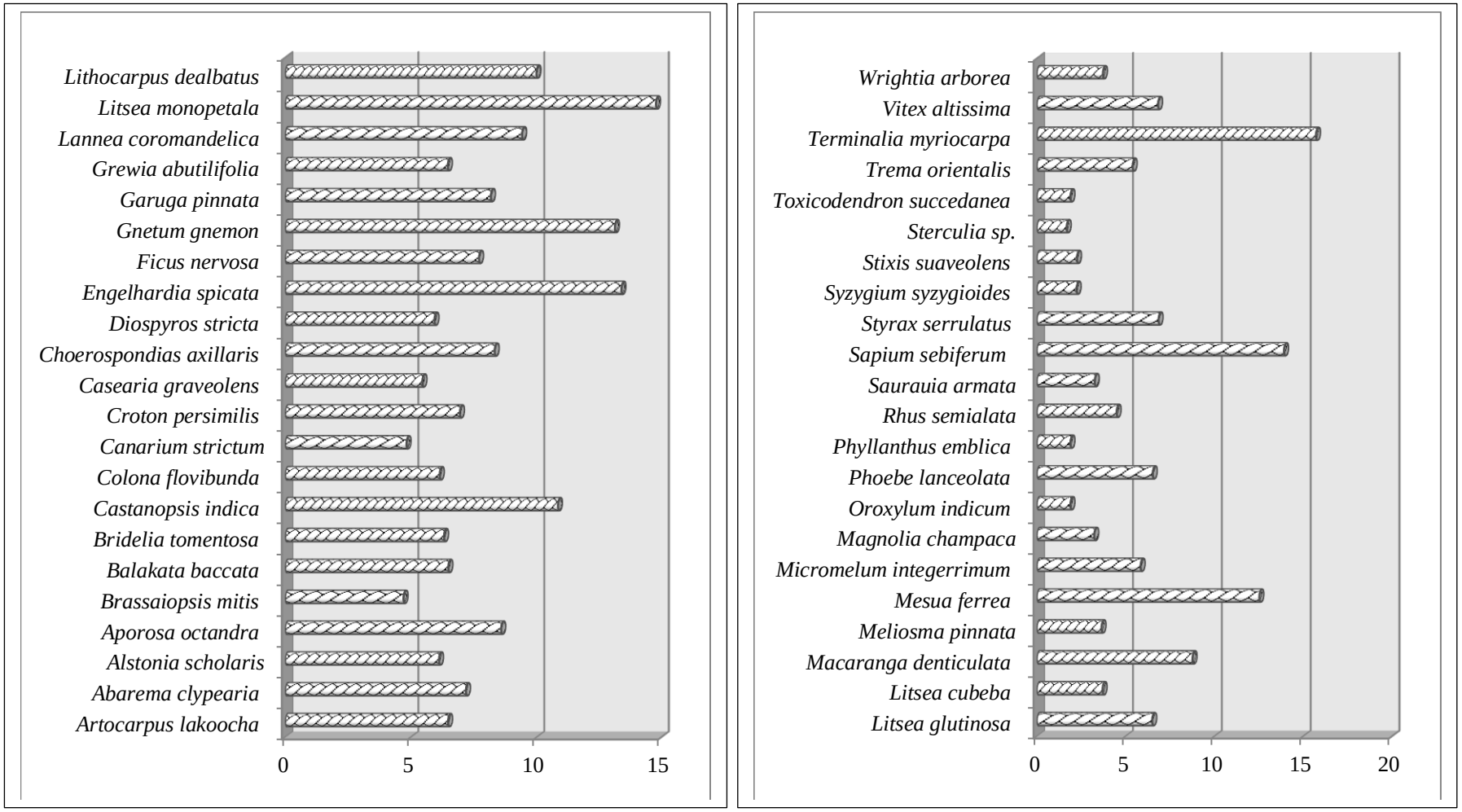


Fig. 3.2: Important value index (IVI) of NAF trees

Table 3.2: Quantitative analysis of trees at Coal mining-affected forest (CMAF) of Changki

Scientific name	FQ	Abundance	Density/ha	BA (m^2/ha)	R.F	R.DOM	R.D	IVI	A/F ratio
Alstonia scholaris	12	1.33	16	16.610	2.255	4.694	1.149	8.41	0.11
Albizzia chinensis	16	1.5	24	39.571	3.007	11.182	1.724	12.90	0.09
Aporosa octandra	32	3.88	124	8.038	6.015	2.271	8.908	16.32	0.12
Bridelia tomentosa	16	1.5	24	1.32665	3.007	0.374	1.724	5.38	0.09
Bauhinia variegate	8	1	8	8.038	1.503	2.271	0.574	6.04	0.13
Bambusa pallida	8	10	80	2.268	1.503	0.641	5.747	8.37	1.25
Callicarpa arborea	12	1.67	20	3.799	2.255	1.073	1.436	4.81	0.14
Cassia fistula	8	1	8	7.543	1.503	2.131	0.574	3.47	0.13
Croton persimiilis	24	5.5	132	2.543	4.511	0.718	9.482	14.86	0.23
Colona floribunda	16	3.25	52	4.152	3.007	1.173	3.735	8.79	0.20
Canarium strictum	12	1.67	20	9.616	2.255	2.717	1.436	8.43	0.14
Dalbergia retusa	24	2	48	1.766	4.511	0.499	3.448	8.83	0.08
Dendrocalamus giganteus	4	6	24	3.461	0.751	0.978	1.724	4.18	1.5
Dalhousiea bracteata	28	2.14	60	1.130	5.263	0.319	4.310	10.13	0.08
Duabanga grandiflora	12	1.67	20	30.175	2.255	8.527	1.436	6.94	0.14
Erythrina variegate	8	1.5	12	7.543	1.503	2.131	0.862	4.78	0.19
Ficus nervosa	4	1	4	2.543	0.751	0.718	0.287	2.29	0.25
Ficus obscura	4	1	4	2.009	0.751	0.5679	0.287	2.03	0.25
Gmelina arborea	12	1.67	20	8.038	2.255	2.271	1.436	5.09	0.14
Grewia abutifolia	16	1.25	20	2.009	3.007	0.567	1.436	5.43	0.08
Litsea monopetala	8	2	16	20.417	1.503	5.769	1.149	7.66	0.25
Macaranga peltata	16	2	32	7.543	3.007	2.131	2.298	8.34	0.13
Mesua ferrea	12	1	12	20.417	2.255	5.769	0.862	12.02	0.08
Mitragyna rotundifolia	12	1.67	20	2.268	2.255	0.641	1.436	4.25	0.14
Mallotus ferrugineous	12	2	24	5.306	2.255	1.499	1.724	5.10	0.17

Maesa indica	20	3.6	72	1.538	3.759	0.434	5.172	9.69	0.18
Phoebe lanceolata	28	3.29	92	16.610	5.263	4.694	6.609	17.75	0.12
Quercus serrata	8	2	16	13.847	1.503	3.913	1.149	5.47	0.25
Saurauia armata	20	2	40	4.152	3.759	1.173	2.873	8.18	0.1
Schima wallichii	8	1.5	12	8.038	1.503	2.271	0.862	6.32	0.19
Styrax serrulatus	16	6.25	100	3.461	3.007	0.978	7.183	11.90	0.39
Syzygium syzygioides	24	2.17	52	3.799	4.511	1.073	3.735	10.12	0.09
Toona ciliata	16	1.5	24	22.050	3.007	6.231	1.724	10.31	0.09
Terminalia myriocarpa	28	3.57	100	52.783	5.263	14.916	7.183	22.90	0.13
Trema orientalis	8	1	8	6.601	1.503	1.865	0.574	3.62	0.13
Wendlandia tinctoria	20	2.6	52	2.833	3.759	0.800	3.735	8.89	0.13

Table 3.3: Quantitative analysis of trees at Non-affected forest (NAF) of Changki

Scientific name	FQ	Abundance	Density/ha	BA (m^2/ha)	R.F	R.DOM	R.D	IVI	A/F ratio
Artocarpus lakoocha	16	2	32	10.746	2.500	2.462	1.900	6.47	0.13
Abarema clypearia	20	2.8	56	4.521	3.125	1.035	3.325	7.18	0.14
Alstonia scholaris	12	1.33	16	22.890	1.875	5.244	0.950	6.11	0.11
Aporosa octandra	24	2.67	64	4.152	3.75	0.951	3.800	8.58	0.11
Brassaiopsis mitis	12	2.67	32	2.543	1.875	0.582	1.900	4.70	0.22
Balakata baccata	16	1.5	24	9.616	2.500	2.203	1.425	6.48	0.09
Bridelia tomentosa	16	3.5	56	1.326	2.500	0.303	3.325	6.31	0.22
Castanopsis indica	20	4.2	84	13.195	3.125	3.023	4.988	10.84	0.21
Colona flovibunda	16	2.25	36	4.152	2.500	0.951	2.137	6.14	0.14
Canarium strictum	4	3	12	13.195	0.625	3.023	0.712	4.82	0.75
Croton persimilis	16	4	64	1.766	2.500	0.404	3.800	6.94	0.25
Casearia graveolens	12	1.67	20	6.601	1.875	1.512	1.187	5.45	0.14
Choerospondias axillaris	12	1.33	16	41.832	1.875	9.584	0.950	8.32	0.11

Diospyros stricta	16	2.75	44	2.268	2.500	0.519	2.612	5.93	0.17
Engelhardia spicata	20	3.8	76	30.175	3.125	6.913	4.513	13.39	0.19
Ficus nervosa	20	1.4	28	8.038	3.125	1.841	1.662	7.70	0.07
Gnetum gnemon	28	4.71	132	2.543	4.375	0.582	7.838	13.13	0.17
Garuga pinnata	12	3.67	44	13.195	1.875	3.023	2.612	8.17	0.31
Grewia abutifolia	20	2.2	44	2.009	3.125	0.460	2.612	6.46	0.11
Lannea coromandelica	16	2	32	13.847	2.500	3.172	1.900	9.41	0.13
Litsea monopetala	32	2.88	92	22.890	5	5.244	5.463	14.78	0.09
Lithocarpus dealbatus	24	2.33	56	8.038	3.750	1.841	3.325	9.98	0.10
Litsea cubeba	8	2	16	4.152	1.250	0.951	0.950	3.70	0.25
Litsea glutinosa	16	3	48	3.461	2.50	0.793	2.850	6.49	0.19
Macaranga denticulata	16	2.5	40	10.746	2.50	2.462	2.375	8.76	0.16
Magnolia champaca	8	1	8	4.152	1.250	0.951	0.475	3.23	0.13
Meliosma pinnata	8	3.5	28	2.009	1.250	0.460	1.662	3.64	0.44
Mesua ferrae	20	2.4	48	26.407	3.125	6.050	2.850	12.52	0.12
Micromelum integerrium	20	2	40	0.949	3.125	0.217	2.375	5.84	0.1
Oroxylum indicum	4	3	12	1.538	0.625	0.352	0.712	1.89	0.75
Phoebe lanceolata	8	2	16	29.209	1.250	6.692	0.950	6.52	0.25
Phyllanthus emblica	4	3	12	1.538	0.625	0.352	0.712	1.89	0.75
Rhus semialata	12	3	36	1.326	1.875	0.303	2.137	4.49	0.25
Saurauia armata	8	2.5	20	5.722	1.25	1.311	1.187	3.26	0.31
Sapium baccatum	28	2.43	68	15.197	4.375	3.482	4.038	13.91	0.09
Stixis suaveolens	4	3	12	4.521	0.625	1.035	0.712	2.26	0.75
Styrax serrulatus	16	3	48	4.152	2.500	0.951	2.850	6.85	0.19
Syzygium syzygioides	4	1	4	3.799	0.625	0.870	0.237	2.24	0.25
Stecularia sp.	4	1	4	2.268	0.625	0.519	0.237	1.68	0.25
Toxicodendron succedanea	4	3	12	1.538	0.625	0.352	0.712	1.89	0.75
Trema orientalis	12	3	36	10.173	1.875	2.330	2.137	5.39	0.25

Terminalia myriocarpa	28	2.71	76	51.503	4.375	11.800	4.513	15.71	0.10
Vitex ultissima	12	2.33	28	9.074	1.875	2.079	1.662	6.82	0.19
Wrightia arborea	12	1	12	3.461	1.875	0.793	0.712	3.72	0.08

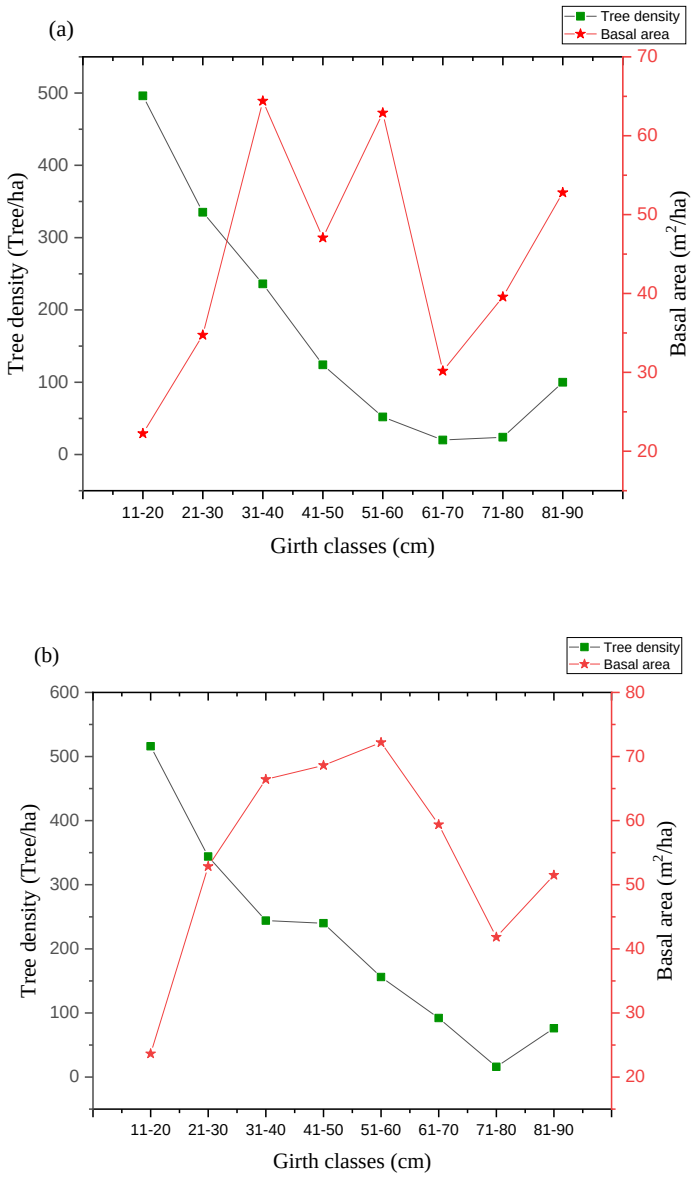


Fig. 3.3: Tree density (tree/ha) and basal area (m^2/ha) distribution graph based on girth classes: a) Coal mining-affected forest (CMAF) b) Non-affected forest (NAF).

Araliaceae, Salicaceae, Ebenaceae, Junglandaceae, Gnetaceae, Sabiaceae, Rutaceae, Magnoliaceae, Bignoniaceae and Caprifoliaceae were absent in CMAF but present in NAF. While the family Poaceae, Lythraceae, Verbenaceae, Rubiaceae, Primulaceae, Theaceae and Meliaceae were present in CMAF but absent in NAF. In terms of dominance, *Terminalia myriocarpa*, *Mesua ferrae* and *Lannea coromandelica* were found to be the most dominant tree species at NAF while *Aporosa octandra*, *Croton persimilis*, *Terminalia myriocarpa* and *Styrax serrulatus* dominated the CMAF. **Table 3.2** and **Table 3.3** shows the comprehensive quantification of trees in CMAF and NAF. The CMAF and NAF tree basal area range from 1.13 to 52.78 m^2/ha and 0.94 to 51.50

m^2/ha respectively. In both the forest, *Terminalia myriocarpa* contributed the highest basal area cover. In CMAF, *Croton persimilis* had the highest density of 132 individual/ha followed by *Aporosa octandra* (124 individual/ha), *Styrax serrulatus* (100 individual/ha) and *Terminalia myriocarpa* (100 individual/ha). In NAF, *Gnetum gnemon* (132 individual/ha) contributed the maximum species density followed by *Litsea monopetala* (92 individual/ha) and *Castanopsis indica* (84 individual/ha). The total tree density cover in CMAF and NAF was 1392 trees/ha and 1684 trees/ha respectively. In both the sites, the lower girth classes 11-20>21-30>31-40 cm represented higher number of individuals and density/ha while the middle girth classes 31-40>41-50>51-60 cm covers maximum basal area/ha (**Fig. 3.3**). The A/F ratio ranged from 0.07 to 0.75 at NAF and 0.07 to 1.5 at CMAF. The species in the two sites followed the contiguous pattern of distribution except for *Bambusa pallida* and *Dendrocalamus giganteus* in CMAF showing a clumped pattern of distribution. Shannon-Wiener index showed that NAF (1.55) has higher diversity than CMAF (1.40) which was also observed in the Simpson's diversity index at NAF (0.97) and CMAF (0.95). A Margalef index of 5.98 and 7.11 while species evenness of 0.39 and 0.41 was recorded in CMAF and NAF **(Table 3.10)**. Sorenson's index shows a low similarity (40%) and higher dissimilarity (60%) between the tree species of NAF and CMAF **(Table 3. 11)**. Some of the tree species found in the study area are shown in **Plate-V**.

3.2.2 Shrubs composition, distribution and diversity in the CMAF and NAF

The shrub species richness was higher at NAF (22) compared to CMAF (13). At NAF, a total of 291 shrubs comprising 21 genera and 12 families were recorded whereas, in CMAF, a total of 239 shrubs belonging to 12 genera and 9 families were identified **(Table 3.4)**. *Mussaenda roxburghii* contributed the highest IVI (19.85) followed by *Schefflera bengalensis* (18.84) and *Morinda augustifolia* (18.47) at NAF. Whereas in CMAF, *Melastoma malabathricum* had the highest IVI (44.50) followed by *Cassia hirsuta* (36.69) and *Mussaendra roxburghii* (33.03) (**Fig. 3.4**). At NAF, Rubiaceae (5) presented the maximum number of species followed by Fabaceae (4), Lamiaceae (3), Melastomataceae (2), Primulaceae (1), Phyllanthaceae (1), Capparaceae (1), Asteraceae (1), Acanthaceae (1), Urticaceae (1), Caprifoliaceae (1) and Araliaceae (1). Rubiaceae (3) dominated CMAF followed by the family Fabaceae (2), Melastomataceae (2),

Plate – V: Some of the tree species found in the study area at Changki

Phoebe lanceolata (Nees) Nees

Rhus semialata Murray

Cassia fistula L.

Castanopsis indica (Roxb. ex Lindl.)

Choerospondias axillaris Roxb.

Litsea cubeba (Lour.) Pers.

Lannea coromandelica (Houtt.) Merr.

Colona floribunda (Kurz) Craib

Micromelum integerrimum Buch.-Ham.ex Colebr.

Mesua ferrea L.

Callicarpa arborea Roxb.

Bridelia tomentosa Blume

Saurauia armata Kurz

Schima wallichii (DC.) Korth

Stixis suaveolens (Roxb.) Pierre

Syzygium syzygioides (Miq.) Merr. & L. M Perry

Terminalia myriocarpa Van Heurck & Mull.

Toona ciliata M. Roem.

Diospyros stricta Roxb.

Duabanga grandiflora (Roxb. ex DC.) Walp.

Engelhardia spicata Lechan ex Blume var. Spicata

Erythrina stricta Roxb.

Garuga pinnata Roxb.

Grewia abutilifolia W. Vent ex Juss.

Abarema clypearia (Jack) Kosterm.

Albizia chinensis (Osbeck.) Merr.

Alstonia scholaris R. Br.

Balakata baccata (Roxb.) Esser.

Bambusa pallida Munro

Bauhinia variegata (L.) Benth.

Table 3.4: Composition of shrubs at Coal mining-affected forest (CMAF) and Non-affected forest (NAF) of Changki

Accession no.	Species name	Families	NAF	CMAF
NU-KS-65	*Acacia pennata* (L.) Willd.	Fabaceae	+	+
NU-KS-66	*Ardesia* sp.	Primulaceae	+	Δ
NU-KS-67	*Breynia retusa* (Dennst.) Alston	Phyllanthaceae	Δ	+
NU-KS-68	*Clerodendrum coleobrookianum* Walp.	Lamiaceae	+	Δ
NU-KS-69	*Clerodendrum infortunatum* L.	Lamiaceae	Δ	+
NU-KS-70	*Cassia hirsuta* L.	Fabaceae	Δ	+
NU-KS-71	*Capparis acutifolia* J.F. Macbr.	Capparaceae	+	Δ
NU-KS-72	*Flueggea virosa* (Roxb. Ex Willd.)	Phyllanthaceae	+	Δ
NU-KS-73	*Holmskioldia sanguine* Retz.	Lamiaceae	+	Δ
NU-KS-74	*Inula cappa (*Buch.-Ham. *ex* D.Don*)* DC.	Asteraceae	+	Δ
NU-KS-75	*Ixora acuminata* Roxb.	Rubiaceae	+	Δ
NU-KS-76	*Leea indica* (Burm. f.) Merr.	Vitaceae	Δ	+
NU-KS-77	*Lantana camara* L.	Verbenaceae	Δ	+
NU-KS-78	*Melastoma malabathricum* L.	Melastomataceae	+	+
NU-KS-79	*Millettia pachycarpa* Benth.	Fabaceae	+	Δ
NU-KS-80	*Morinda angustifolia* Roxb.	Rubiaceae	+	+
NU-KS-81	*Mussaenda glabra* Vahl	Rubiaceae	+	+
NU-KS-82	*Mussaenda roxburghii* Hook. f.	Rubiaceae	+	+
NU-KS-83	*Mycetia longifolia* (Wall.) Kuntze	Rubiaceae	+	Δ
NU-KS-84	*Osbeckia stellata* Buch. Ham. ex Ker Gawl.	Melastomataceae	+	+
NU-KS-85	*Pterolobium hexapetalum* (Roth)Santapau & Wagh	Fabaceae	+	Δ
NU-KS-86	*Phlogacanthus thyrsiflorus* Nees	Acanthaceae	+	Δ
NU-KS-87	*Premna pinguis* C.B. Clarke	Lamiaceae	+	Δ
NU-KS-88	*Sarcochlamys pulcherrima* Gaud.	Urticaceae	+	Δ
NU-KS-89	*Sambucus hookeri* Rehder	Caprifoliaceae	+	+
NU-KS-90	*Schefflera bengalensis* Gamble	Araliaceae	+	Δ
NU-KS-91	*Solanum torvum* Dunal.	Solanaceae	Δ	+
NU-KS-92	*Tephrosia candida* (Roxb.) DC.	Fabaceae	+	Δ

Phyllanthaceae (1), Lamiaceae (1), Vitaceae (1), Caprifoliaceae (1), Solanaceae (1) and Verbenaceae (1). Some of the family like Primulaceae, Capparaceae, Asteraceae, Acanthaceae, Urticaceae and Araliaceae were present in NAF but not in CMAF while Vitaceae and Solanaceae were present in CMAF but absent in NAF. **Table 3.5** and **Table 3.6** shows the comprehensive quantification of shrubs in CMAF and NAF. The shrub basal area of CMAF ranges from 0.11 to 0.72 m^2/ha. *Breynia retusa* occupies the lowest basal area cover and *Clerodendrum infortunatum* had the highest basal area. In NAF, the basal area ranges from 0.13 to 1.17 m^2/ha. The basal area of *Tephrosia candida* was lowest while *Pterolobium hexapetalum* constituted the highest basal area cover. The total

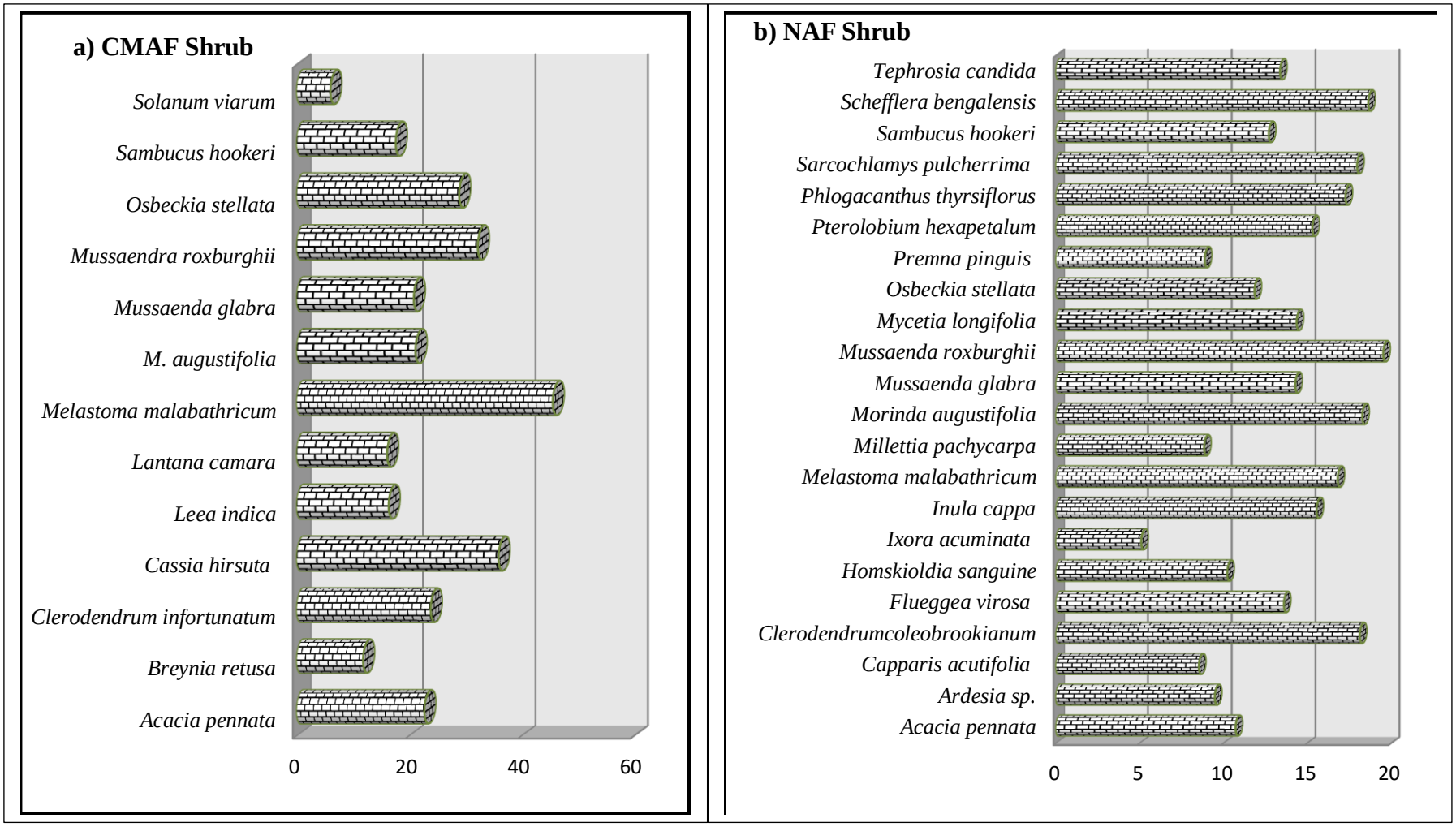


Fig. 3.4: Important value index (IVI) of a) CMAF and b) NAF shrub

Table 3.5: Quantitative analysis of shrubs at Coal mining-affected forest (CMAF) of Changki

Scientific name	FQ	Abundance	Density/ha	BA (m^2/ha)	R.F	R.DOM	R.D	IVI	A/F ratio
Acacia pennata	16	1.62	104	0.453	8.421	8.931	5.439	22.79	0.10
Breynia retusa	12	1.33	64	0.113	6.315	2.232	3.347	11.90	0.11
Clerodendrum infortunatum	12	1.33	64	0.723	6.315	14.250	3.347	23.91	0.11
Cassia hirsuta	30	2.6	312	0.196	15.789	3.865	16.317	35.97	0.09
Leea indica	8	2.25	72	0.429	4.210	8.467	3.765	16.44	0.28
Lantana camara	6	4.67	112	0.362	3.157	7.149	5.857	16.17	0.78
Melastoma malabathricum	26	3.80	392	0.580	13.684	11.436	20.502	45.62	0.14
M. augustifolia	8	2	64	0.693	4.210	13.662	3.347	21.22	0.25
Mussaenda glabra	20	1.7	136	0.166	10.526	3.271	7.112	20.91	0.09
Mussaendra roxburghii	24	3.08	296	0.212	12.631	4.181	15.481	32.29	0.13
Osbeckia stellata	20	2.8	224	0.341	10.526	6.735	11.715	28.98	0.14
Sambucus hookeri	4	3	48	0.664	2.105	13.087	2.510	17.70	0.75
Solanum viarum	4	1.5	24	0.138	2.105	2.727	1.255	6.088	0.38

Table 3.6: Quantitative analysis of shrubs at Non-affected forest (NAF) of Changki

Scientific name	FQ	Abundance	Density/ha	BA (m^2/ha)	R.F	R.DOM	R.D	IVI	A/F ratio
Acacia pennata	6	2.33	56	0.553	3	5.341	2.405	10.75	0.39
Ardesia sp.	8	1.75	56	0.321	4	3.100	2.405	9.51	0.22
Capparis acutifolia	4	2.5	40	0.502	2	4.845	1.718	8.56	0.63
Clerodendrum coleobrookianum	10	3.6	144	0.723	5	6.977	6.185	18.16	0.36
Flueggea virosa	10	2.2	88	0.502	5	4.845	3.780	13.63	0.22

Homskioldia sanguine	10	2.2	88	0.151	5	1.465	3.780	10.25	0.22
Ixora acuminata	4	2	32	0.180	2	1.744	1.374	5.12	0.5
Inula cappa	12	2.5	120	0.453	6	4.372	5.154	15.58	0.21
Melastoma malabathricum	12	2.67	128	0.553	6	5.341	5.498	16.84	0.22
Millettia pachycarpa	6	4	96	0.180	3	1.744	4.123	8.87	0.67
Morinda augustifolia	8	3.5	112	0.984	4	9.496	4.810	18.31	0.44
Mussaenda glabra	14	2.43	136	0.151	7	1.465	5.841	14.31	0.17
Mussaenda roxburghii	14	3	168	0.553	7	5.341	7.216	19.56	0.21
Mycetia longifolia	12	3	144	0.228	6	2.207	6.185	14.39	0.25
Osbeckia stellata	10	2.2	88	0.321	5	3.100	3.780	11.88	0.22
Premna pinguis	4	3	48	0.502	2	4.845	2.061	8.91	0.75
Pterolobium hexapetalum	4	3	48	1.168	2	11.268	2.061	15.33	0.75
Phlogacanthus thyrsiflorus	12	4.33	208	0.246	6	2.374	8.934	17.31	0.36
Sarcochlamys pulcherrima	14	3.29	184	0.321	7	3.100	7.903	18.00	0.23
Sambucus hookeri	6	2.67	64	0.723	3	6.977	2.749	12.73	0.44
Schefflera bengalensis	8	4.25	136	0.915	4	8.830	5.841	18.67	0.53
Tephrosia candida	12	3	144	0.125	6	1.211	6.185	13.40	0.25

shrub density in CMAF (1912 shrub/ha) was considerably lower than NAF (2328 shrub/ha). *Melastoma malabathricum* (392 individual/ha) contributed the highest density followed by *Cassia hirsuta* (312 individual/ha) and *Mussaenda roxburghii* (296 individual/ha) in CMAF. While in NAF, *Phlogacanthus thyrsiflorus* contributed the highest density (208 individual/ha) followed by *Sarcochlamys pulcherrima* (184 individual/ha) and *Mussaenda roxburghii* (168 individual/ha). Contiguous pattern of distribution was observed in both the sites which ranged from 0.17 to 0.75 (NAF) and 0.08 to 0.78 (CMAF). In NAF and CMAF, the Shannon-Wiener index was 1.30 and 0.99 while Simpson's diversity value was 0.95 and 0.88 respectively **(Table 3.10)**. The evenness index value of 0.43 and 0.37 and Margalef index of 3.70 and 2.37 were recorded in NAF and CMAF. A Sorenson's index between the shrubs of the two forests shows a similarity of 40% and a dissimilarity of 60% **(Table 3.11)**. Some of the shrub species identified are given in **Plate-VI**.

3.2.3 Herbs composition, distribution and diversity in the CMAF and NAF

An absolute total of 2730 individual herbs belonging to 83 genera, constituting 88 species and 46 families were recorded from the two forests. In NAF, the species richness accounts for 62 species which was comparatively higher than CMAF (54) **(Table 3.7)**. NAF had a total of 1440 individual herbs representing 58 genera and 37 families whereas CMAF had a total of 1290 individual herbs belonging to 51 genera and 30 families. **Table 3.8** and **Table 3.9** presents the comprehensive quantification of herbs in CMAF and NAF site. In NAF, *Chromolaena odorata* contributed the highest IVI (15.57) followed by *Pteridium esculentum* (13.29) and *Alpinia malaccensis* (9.82). At CMAF, *Chromolaena odorata* had the highest IVI (31.86) followed by *Pteridium esculentum* (29.01) and *Thysanolaena latifolia* (24.53) (**Fig. 3.5**). Poaceae (6) dominated the NAF followed by Zingiberaceae (5) Cyperaceae (4), Acanthaceae (4) and Asteraceae (3). In CMAF, Poaceae occupied the maximum (10) number of families followed by Asteraceae (9) and Cyperaceae (4). It was observed that the NAF herb families such as Araceae, Zingiberaceae, Begoniaceae, Adiantaceae, Fabaceae, Balsaminaceae, Hypoxidaceae, Urticaceae, Selaginellaceae, Marantaceae, Asparagaceae, Melastomataceae, Chloranthaceae, Linderniaceae, Smilacaceae, Urticaceae and Araliaceae were absent in CMAF whereas Thelypteridaceae, Cryophyllaceae, Euphorbiaceae, Ranuculaceae and Phyllanthaceae were present in CMAF but not in NAF. Basal area cover in CMAF ranges from 0.07 to 2.54 m^2/ha with the lowest cover by *Cyperus iria* and *Drymaria cordata* and

Plate - VI: Some of the shrub species found in the study area at Changki

Clerodendrum infortunatum L.

Melastoma malabathricum L.

Mussaenda roxburghii Hook. f.

Leea indica (Burm. f.) Merr.

Inula cappa (Buch.-Ham. ex D.Don) DC.

Ixora acuminata Roxb.

Mycetia longifolia (Wall.) Kuntze

Tephrosia candida (Roxb.)DC.

Osbeckia stellata Buch. Ham. ex Ker Gawl.

Premna pinguis C.B. Clarke

Schefflera bengalensis Gamble

Phlogacanthus thyrsiflorus Nees

the highest by *Pteridium esculentum*. The NAF basal area ranges from 0.07 to 3.14 m^2/ha. Basal area cover of *Cheilanthes tenuifolia, Eragrostis amabilis, Kyllinga brevifolia, Odontosoria chinensis, Torenia violacea* were recorded minimum and *Alpinia malaccensis* as maximum. In CMAF, *Chromolaena odorata* (30833 individual/ha) contributed the highest density followed by *Dicranopteris linearis* (23000 individual/ha) and *Thysanolaena latifolia* (16833 individual/ha). The NAF density stand of *Chromolaena odorata* (24000 individual/ha) was recorded maximum followed by *Strobilanthus coloratus* (14666 individual/ha) and *Dicranopteris linearis* (13500 individual/ha).

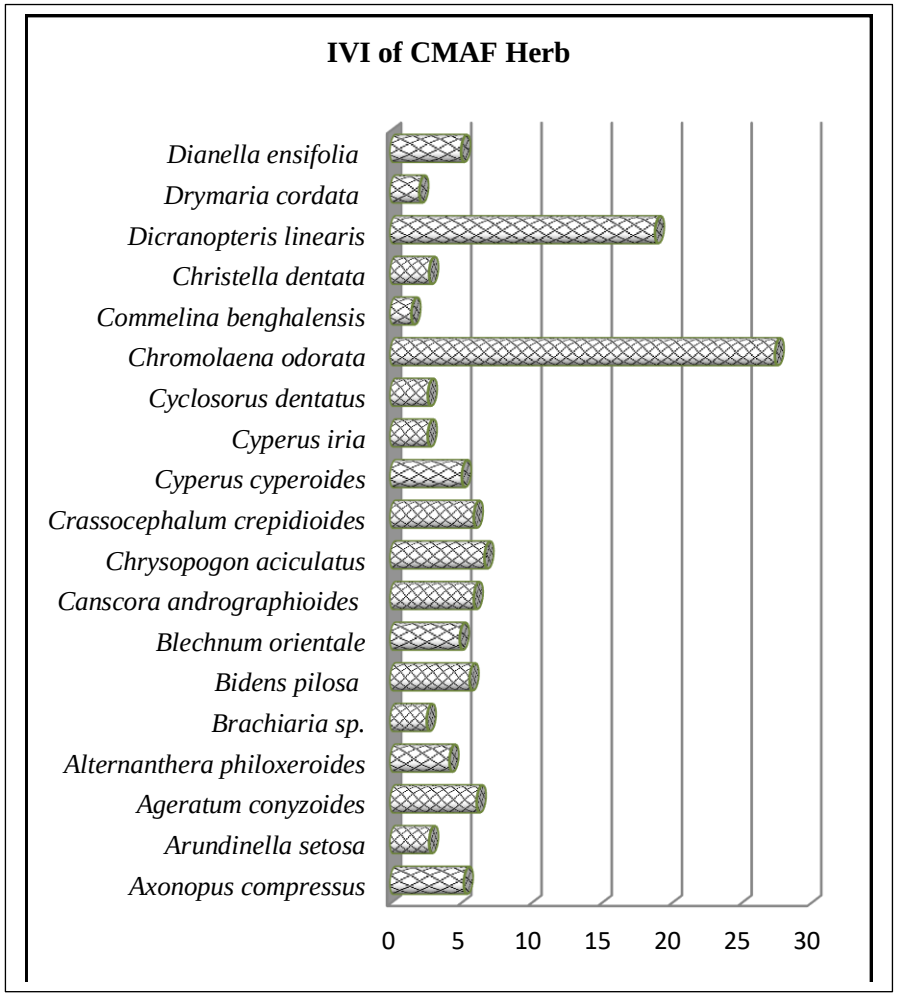
Table 3.7: Composition of herbs at Coal mining-affected forest (CMAF) and Non-affected forest (NAF) of Changki

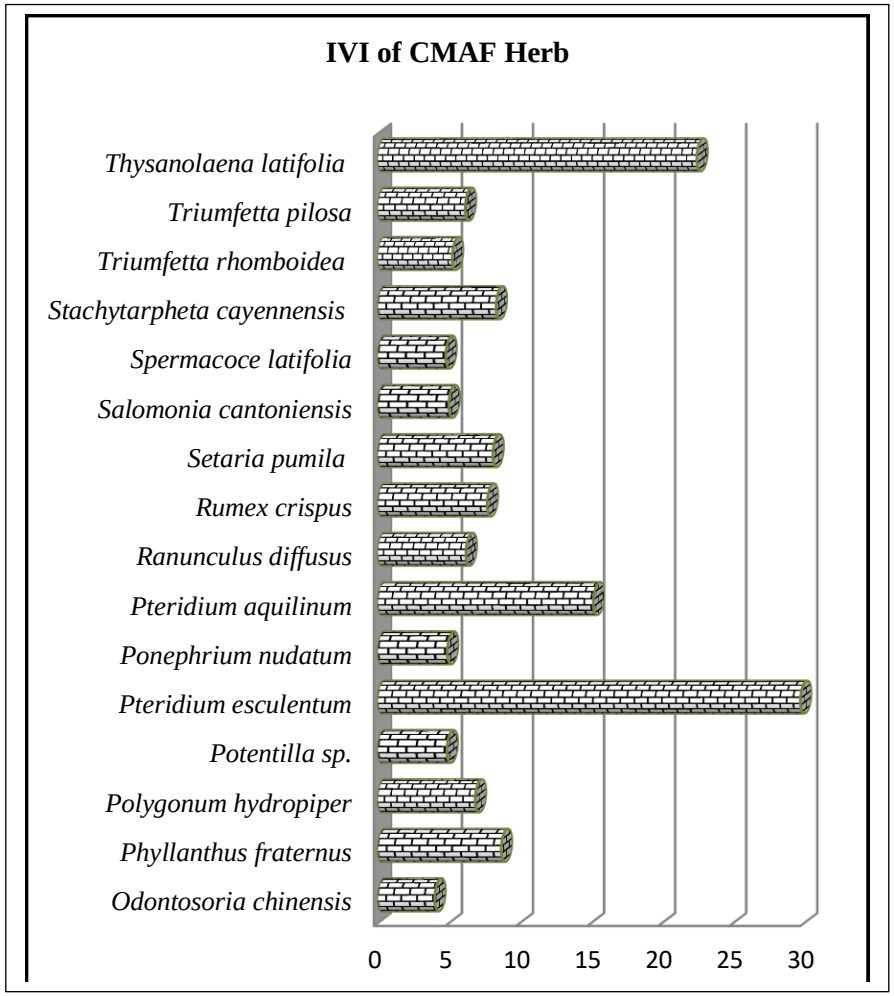
Accession no.	Species name	Family	NAF	CMAF
NU-KS-93	*Axonopus compressus* (Sw.) P. Beauv.	Poaceae	Δ	+
NU-KS-94	*Amorphophallus bulbifer* (Roxb.) Blume	Araceae	+	Δ
NU-KS-95	*Arundinella setosa* Trin.	Poaceae	Δ	+
NU-KS-96	*Ageratum conyzoides* L.	Asteraceae	Δ	+
NU-KS-97	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Δ	+
NU-KS-98	*Alpinia malaccensis* (Burm. f.) Rosc	Zingiberaceae	+	Δ
NU-KS-99	*Ageratina riparia* (Regel) R. M. King & H. Rob.	Compositae	+	Δ
NU-KS-100	*Brachiaria* sp.	Poaceae	Δ	+
NU-KS-101	*Bidens pilosa* Linn. var. Radiata	Asteraceae	Δ	+
NU-KS-102	*Begonia palmate* D. Don	Begoniaceae	+	Δ
NU-KS-103	*Blechnum orientale* L.	Blechnaceae	+	+
NU-KS-104	*Canscora andrographioides* Griff.	Gentianaceae	+	+
NU-KS-105	*Carex baccans* Nees	Cyperaceae	+	Δ
NU-KS-106	*Chrysopogon aciculatus* (Retz.) Trin	Poaceae	+	+
NU-KS-107	*Crassocephalum crepidioides* (Benth.) S. Moore	Asteraceae	+	+
NU-KS-108	*Cyperus cyperoides* (L.) Kuntze	Cyperaceae	+	+
NU-KS-109	*Cyperus iria* L.	Cyperaceae	Δ	+
NU-KS-110	*Cyperus flavescens* L.	Cyperaceae	+	Δ
NU-KS-111	*Cyclosorus dentatus* (Forssk.) Ching	Thelypteridaceae	Δ	+
NU-KS-112	*Chromolaena odorata* (L.) R. M. King & H. Rob.	Asteraceae	+	+
NU-KS-113	*Commelina benghalensis* L.	Commelinaceae	Δ	+
NU-KS-114	*Christella dentate* (Forssk.) Brownsy & Jermy	Thelypteridaceae	Δ	+
NU-KS-115	*Cheilanthes tenuifolia* (Burm. f.)	Adiantaceae	+	Δ
NU-KS-116	*Cucurma augustifolia* Roxb.	Zingiberaceae	+	Δ
NU-KS-117	*Curculigo capitulata* (Lour.) Kuntze	Hypoxidaceae	+	Δ
NU-KS-118	*Curculigo orchioides* Gaertn.	Hypoxidaceae	+	Δ
NU-KS-119	*Dicranopteris linearis* (Burm. fil.) Underw.	Gleicheniaceae	+	+

NU-KS-120	*Drymaria cordata* L.	Caryophyllaceae	Δ	+
NU-KS-121	*Dicliptera chinensis* (L.) Juss.	Acanthaceae	+	Δ
NU-KS-122	*Dianella ensifolia* (L.) DC.	Asphodelaceae	+	+
NU-KS-123	*Desmodium triquetrum* DC.	Fabaceae	+	Δ
NU-KS-124	*Digitaria setigera* Roth	Poaceae	Δ	+
NU-KS-125	*Eclipta prostrate* (L.) L.	Asteraceae	+	Δ
NU-KS-126	*Eupatorium adenophorum* Spreng.	Asteraceae	Δ	+
NU-KS-127	*Erigeron linifolius* Willd.	Compositae	Δ	+
NU-KS-128	*Euphorbia hirta* L.	Euphorbiaceae	Δ	+
NU-KS-129	*Eleusine indica* (L.) Gaertn.	Poaceae	Δ	+
NU-KS-130	*Eragrostis amabilis* (L.) Wight & Arn.	Poaceae	+	Δ
NU-KS-131	*Fimbristylis dichotoma* (L.) Vahl	Cyperaceae	Δ	+
NU-KS-132	*Floscopa scandens* Lour.	Commelinaceae	+	Δ
NU-KS-133	*Galinsoga parviflora* Cav.	Asteraceae	Δ	+
NU-KS-134	*Gomphostemma parviflorum* Wall. ex Benth.	Lamiaceae	+	Δ
NU-KS-135	*Gomphrena celosioides* Mart.	Amaranthaceae	+	Δ
NU-KS-136	*Helichrysum luteoalbum* (L.) Rchb.	Asteraceae	Δ	+
NU-KS-137	*Hydrocotyle javanica* Thunb.	Araliaceae	+	+
NU-KS-138	*Hypoestes phyllostachya* Baker	Acanthaceae	+	+
NU-KS-139	*Hedychium gardnerianum* Roscoe	Zingiberaceae	+	Δ
NU-KS-140	*Imperata cylindrica* (L.) Raeusch	Poaceae	+	+
NU-KS-141	*Impatiens latiflora* Hook. F. & Th.	Balsaminaceae	+	Δ
NU-KS-142	*Justicia gendarussa* Burm. fil.	Acanthaceae	+	Δ
NU-KS-143	*Kyllinga brevifolia* Rottb.	Cyperaceae	+	+
NU-KS-144	*Kaempferia rotunda* L.	Zingiberaceae	+	Δ
NU-KS-145	*Lindernia crustacea* (L.) F. Muell.	Linderniaceae	+	+
NU-KS-146	*Leucas aspera* (Willd.) Link	Lamiaceae	Δ	+
NU-KS-147	*Laportea crenulata* Gaud.	Urticaceae	+	Δ
NU-KS-148	*Ludwigia perennis* L.	Onagraceae	+	+
NU-KS-149	*Lygodium flexuosum* (L.) Sw.	Lygodiaceae	+	+
NU-KS-150	*Lycopodium cernuum* L.	Selaginellaceae	+	Δ
NU-KS-151	*Mimosa pudica* L.	Mimosaceae	+	+
NU-KS-152	*Mitracarpus hirtus* (L.) DC.	Rubiaceae	+	+
NU-KS-153	*Melinis repens* (Willd.) Zizka	Poaceae	+	+
NU-KS-154	*Meistera koenigii* (J. F. Gmel.) Skornick. & M. F. Newman	Zingiberaceae	+	Δ
NU-KS-155	*Odontosoria chinensis* (L.) J. Sm.	Lindsaeaceae	+	+
NU-KS-156	*Phyllanthus fraternus* G. L. webster	Phyllanthaceae	Δ	+
NU-KS-157	*Polygonum hydropiper* L.	Polygonaceae	+	+
NU-KS-158	*Potentilla* sp.	Rosaceae	+	+
NU-KS-159	*Pteridium esculentum* G. Forst Cockayne	Dennstaedtiaceae	+	+
NU-KS-160	*Ponephrium* nudatum (Roxb. Ex Griff) Holtt. Blumea	Thelypteridaceae	Δ	+
NU-KS-161	*Pteridium aquilinum* (L.) Kuhn.	Polypodiaceae	+	+
NU-KS-162	*Phrynium pubinerve* Blume	Marantaceae	+	Δ
NU-KS-163	*Peliosanthes teta* Andrews	Asparagaceae	+	Δ
NU-KS-164	*Pouzolzia hirta* Hassk.	Urticaceae	+	Δ

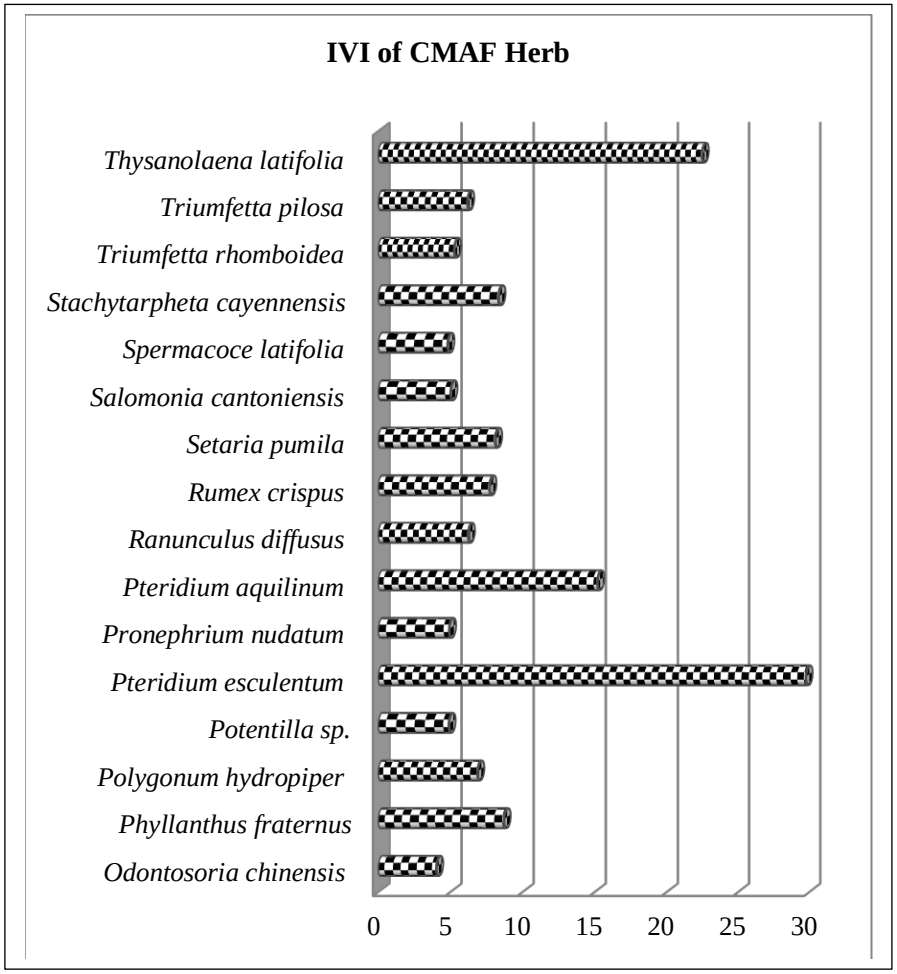
NU-KS-165	*Ranunculus diffusus* DC.	Ranunculaceae	Δ	+
NU-KS-166	*Rumex crispus* L.	Polygonaceae	Δ	+
NU-KS-167	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae	Δ	+
NU-KS-168	*Salomonia cantoniensis* Lour.	Malvaceae	Δ	+
NU-KS-169	*Spermacoce latifolia* Aubl.	Rubiaceae	+	+
NU-KS-170	*Stachytarpheta cayennensis* (Rich.) Vahl	Verbenaceae	+	+
NU-KS-171	*Sellaginella involvens* (Sw.) Spring	Selaginellaceae	+	Δ
NU-KS-172	*Sonerilla khasiana* C. B. Clarke	Melastomataceae	+	Δ
NU-KS-173	*Strobilanthes coloratus* Nees	Acanthaceae	+	Δ
NU-KS-174	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae	+	Δ
NU-KS-175	*Sarcandra glabra* (Thunb.)	Chloranthaceae	+	Δ
NU-KS-176	*Smilax perfoliata* Lour	Smilacaceae	+	Δ
NU-KS-177	*Triumfetta rhomboidea* Jacq.	Malvaceae	+	+
NU-KS-178	*Triumfetta pilosa* Wall.	Malvaceae	+	+
NU-KS-179	*Torenia violacea* (Blanco) Pennell	Linderniaceae	+	Δ
NU-KS-180	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda.	Poaceae	+	+

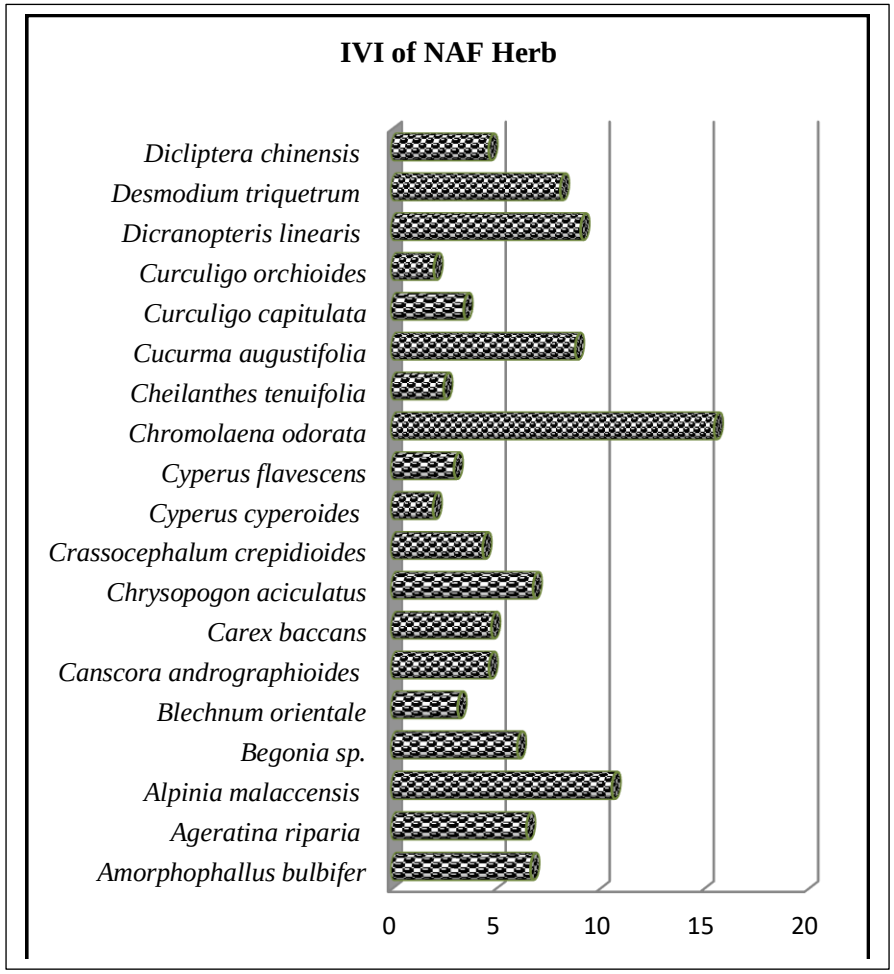
The A/F ratio ranged from 0.35 to 5.7 (NAF) and 0.34 to 5.4 (CMAF) which constituted the contiguous and clump pattern of distribution. Shannon-Wiener index showed that the diversity value in NAF (1.61) was higher than CMAF (1.34). The NAF and CMAF Simpson's diversity value was 0.97 and 0.92 while species evenness was 0.39 and 0.34 respectively **(Table 3.10)**. A Margalef index value of 7.40 and 8.40 was recorded in CMAF and NAF. Sorenson's index shows a similarity of 48% and a dissimilarity of 52% between the two forests **(Table 3.11)**. Some of the shrub species collected from the study area are presented in **Plate-VII**.


IVI of CMAF Herb
Dianella ensifolia
Drymaria cordata
Dicranopteris linearis
Christella dentata
Commelina benghalensis
Chromolaena odorata
Cyclosorus dentatus
Cyperus iria
Cyperus cyperoides
Crassocephalum crepidioides
Chrysopogon aciculatus
Canscora andrographioides
Blechnum orientale
Bidens pilosa
Brachiaria sp.
Alternanthera philoxeroides
Ageratum conyzoides
Arundinella setosa
Axonopus compressus
0
5
10
15
20
25
30


IVI of CMAF Herb
Thysanolaena latifolia
Triumfetta pilosa
Triumfetta rhomboidea
Stachytarpheta cayennensis
Spermacoce latifolia
Salomonia cantoniensis
Setaria pumila
Rumex crispus
Ranunculus diffusus
Pteridium aquilinum
Ponephrium nudatum
Pteridium esculentum
Potentilla sp.
Polygonum hydropiper
Phyllanthus fraternus
Odontosoria chinensis
0
5
10
15
20
25
30

Cont…


IVI of CMAF Herb
Thysanolaena latifolia
Triumfetta pilosa
Triumfetta rhomboidea
Stachytarpheta cayennensis
Spermacoce latifolia
Salomonia cantoniensis
Setaria pumila
Rumex crispus
Ranunculus diffusus
Pteridium aquilinum
Pronephrium nudatum
Pteridium esculentum
Potentilla sp.
Polygonum hydropiper
Phyllanthus fraternus
Odontosoria chinensis
0
5
10
15
20
25
30


IVI of NAF Herb
Dicliptera chinensis
Desmodium triquetrum
Dicranopteris linearis
Curculigo orchioides
Curculigo capitulata
Cucurma augustifolia
Cheilanthes tenuifolia
Chromolaena odorata
Cyperus flavescens
Cyperus cyperoides
Crassocephalum crepidioides
Chrysopogon aciculatus
Carex baccans
Canscora andrographioides
Blechnum orientale
Begonia sp.
Alpinia malaccensis
Ageratina riparia
Amorphophallus bulbifer
0
5
10
15
20

Cont…

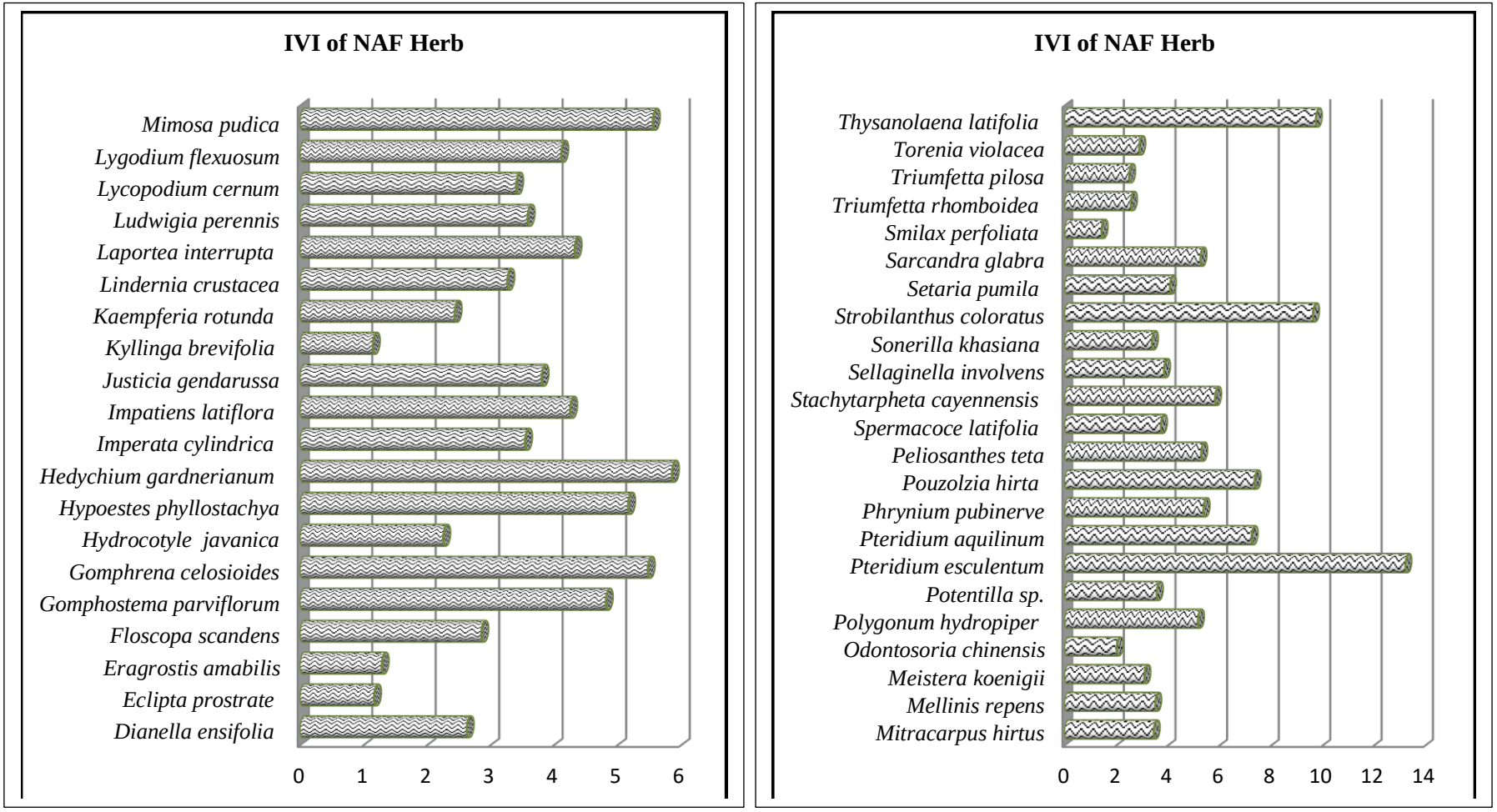


Fig. 3.5: Important value index (IVI) of herbs at CMAF and NAF

Table 3.8: Quantitative analysis of herbs at Coal mining affected forest (CMAF) of Changki

Scientific name	FQ	Abundance	Density/ha	BA (m^2/ha)	R.F	R.DOM	R.D	IVI	A/F ratio
Axonopus compressus	8.33	2.8	2333.33	0.125	3.267	0.814	1.199	5.28	0.34
Arundinella setosa	3.33	4	1333.33	0.125	1.307	0.814	0.685	2.81	1.2
Ageratum conyzoides	6.67	6.75	4500	0.196	2.614	1.272	2.313	6.20	1.01
Alternanthera philoxeroides	5	4	2000	0.196	1.960	1.272	1.028	4.26	0.8
Brachiaria sp.	3.33	3	1000	0.125	1.307	0.814	0.514	2.64	0.9
Bidens pilosa	3.33	11	3666.67	0.384	1.307	2.494	1.885	5.69	3.3
Blechnum orientale	5	4.67	2333.3	0.282	1.960	1.832	1.199	4.99	0.93
Canscora andrographioides	8.33	3.4	2833.33	0.196	3.267	1.272	1.456	5.99	0.41
Chrysopogon aciculatus	5	13.67	6833.33	0.196	1.960	1.272	3.513	6.75	2.73
Crassocephalum crepidioides	5	3	1500	0.502	1.960	3.258	0.771	5.99	0.6
Cyperus cyperoides	6.67	5	3333.33	0.125	2.614	0.814	1.713	5.14	0.75
Cyperus iria	3.33	5.5	1833.33	0.070	1.307	0.458	0.942	2.71	1.65
Cyclosorus dentatus	3.33	3.5	1166.6	0.125	1.307	0.814	0.599	2.72	1.05
Chromolaena odorata	16.67	18.5	30833.33	0.785	6.535	5.091	15.852	27.48	1.11
Commelina benghalensis	1.67	1	166.67	0.125	0.653	0.814	0.085	1.55	0.6
Christella dentata	3.33	4	1333.33	0.125	1.307	0.814	0.685	2.81	1.2
Dicranopteris linearis	13.33	17.25	23000	0.282	5.228	1.832	11.825	18.89	1.29
Drymaria cordata	3.33	2	666.67	0.070	1.307	0.458	0.342	2.11	0.6
Dianella ensifolia	6.67	3.5	2333.33	0.196	2.614	1.272	1.199	5.09	0.53
Digitaria setigera Roth	8.33	15.2	12666.67	0.196	3.267	1.272	6.512	11.05	1.82
Eupatorium adenophorum	6.67	5.25	3500	0.502	2.614	3.258	1.799	7.67	0.79
Erigeron linfolius	1.67	3	500	0.196	0.653	1.272	0.257	2.18	1.8
Euphorbia hirta	3.33	5	1666.67	0.196	1.307	1.272	0.856	3.44	1.5

Eleusine indica	3.33	18	6000	0.196	1.307	1.272	3.084	5.66	5.4
Fimbristyllis dichotoma	5	4	2000	0.125	1.960	0.814	1.028	3.80	0.8
Galinsoga parviflora	6.67	5.5	3666.67	0.196	2.614	1.272	1.885	5.77	0.825
Helichrysum luteoalbum	5	5.33	2666.67	0.502	1.960	3.258	1.371	6.59	1.07
Hydrocotyle javanica	3.33	4	1333.33	0.125	1.307	0.814	0.685	2.81	1.2
Hypoestes phyllostachya	6.67	6	4000	0.196	2.614	1.272	2.056	5.94	0.9
Imperata cylindrica	3.33	8.5	2833.33	0.125	1.307	0.814	1.456	3.59	2.55
Kyllinga brevifolia	3.33	3	1000	0.384	1.307	2.494	0.514	4.32	0.9
Lindernia crustacea	6.67	4.75	3166.67	0.196	2.614	1.272	1.628	5.52	0.71
Leucas aspera	1.67	5	833.33	0.282	0.653	1.832	0.428	2.92	3
Ludwigia perennis	3.33	3.5	1166.67	0.502	1.307	3.258	0.599	5.17	1.05
Lygodium flexuosum	5	3.33	1666.67	0.384	1.960	2.494	0.856	5.31	0.67
Mimosa pudica	11.67	12.43	14500	0.635	4.575	4.124	7.455	16.15	1.07
Mitracarpus hirtus	8.33	4	3333.33	0.384	3.267	2.494	1.713	7.48	0.48
Mellinis repens	3.33	1.5	500	0.196	1.307	1.272	0.257	2.84	0.45
Odontosoria chinensis	5	6.33	3166.67	0.070	1.960	0.458	1.628	4.05	1.27
Phyllanthus fraternus	6.67	3	2000	0.785	2.614	5.091	1.028	8.73	0.45
Polygonum hydropiper	8.33	4.2	3500	0.282	3.267	1.832	1.799	6.90	0.50
Potentilla sp.	6.67	3	2000	0.196	2.614	1.272	1.028	4.91	0.45
Pteridium esculentum	13.33	11.75	15666.67	2.543	5.228	16.496	8.054	29.78	0.88
Ponephrium nudatum	5	6.67	3333.33	0.196	1.960	1.272	1.713	4.94	1.33
Pteridium aquilinum	8.33	7.8	6500	1.326	3.267	8.604	3.341	15.21	0.94
Ranunculus diffusus	5	4	2000	0.502	1.960	3.258	1.028	6.25	0.8
Rumex crispus	5	2.67	1333.33	0.785	1.960	5.091	0.685	7.74	0.53
Setaria pumila	6.67	13.75	9166.67	0.125	2.614	0.814	4.712	8.14	2.06
Salomonia cantoniensis	6.67	5.75	3833.33	0.125	2.614	0.814	1.970	5.04	0.86
Spermacoce latifolia	3.33	6	2000	0.384	1.307	2.494	1.028	4.83	1.8

Stachytarpheta cayennensis	6.67	4.75	3166.67	0.635	2.614	4.124	1.628	8.37	0.71
Triumfetta rhomboidea	1.67	6	1000	0.635	0.653	4.124	0.514	5.29	3.6
Triumfetta pilosa	3.33	4.5	1500	0.635	1.307	4.124	0.771	6.20	1.35
Thysanolaena latifolia	13.33	12.63	16833.33	1.326	5.228	8.604	8.654	22.49	0.94

Table 3.9: Quantitative analysis of herbs at Non-affected forest (NAF) of Changki

Scientific name	**FQ**	**Abundance**	**Density/ha**	**BA (m^2/ha)**	**R.F**	**R.DOM**	**R.D**	**IVI**	**A/F ratio**
Amorphophallus bulbifer	3.33	4	1333.33	1.766	1.047	5.120	0.562	6.73	1.2
Ageratina riparia	6.67	13.75	9166.67	0.196	2.094	0.568	3.870	6.53	2.06
Alpinia malaccensis	3.33	3.5	1166.67	3.140	1.047	9.103	0.492	10.64	1.05
Begonia sp.	10	3.5	3500	0.785	3.141	2.275	1.477	6.09	0.35
Blechnum orientale	5	4	2000	0.282	1.570	0.819	0.844	3.23	0.8
Canscora andrographioides	8.33	4.4	3666.67	0.196	2.617	0.568	1.548	4.73	0.53
Carex baccans Nees	6.67	3.25	2166.67	0.635	2.094	1.843	0.914	4.85	0.49
Chrysopogon aciculatus	5	22.33	11166.67	0.196	1.570	0.568	4.714	6.85	4.47
Crassocephalum crepidioides	5	6.67	3333.33	0.502	1.570	1.456	1.407	4.43	1.33
Cyperus cyperoides	3.33	4.5	1500	0.125	1.047	0.364	0.633	2.04	1.35
Cyperus flavescens	5	4.33	2166.67	0.196	1.570	0.568	0.914	3.05	0.87
Chromolaena odorata	10	24	24000	0.785	3.141	2.275	10.133	15.55	2.4
Cheilanthes tenuifolia	5	3.67	1833.33	0.070	1.570	0.204	0.774	2.55	0.73
Cucurma augustifolia	1.67	2	333.33	2.833	0.523	8.215	0.140	8.88	1.2
Curculigo capitulata	3.33	4.5	1500	0.635	1.047	1.843	0.633	3.52	1.35
Curculigo orchioides	3.33	1.5	500	0.282	1.047	0.819	0.211	2.08	0.45
Dicranopteris linearis	8.33	16.2	13500	0.282	2.617	0.819	5.700	9.14	1.944
Desmodium triquetrum	11.67	6.86	8000	0.384	3.664	1.115	3.377	8.16	0.59

Dicliptera chinensis	5	8	4000	0.502	1.570	1.456	1.688	4.72	1.6
Dianella ensifolia	5	2.33	1166.67	0.196	1.570	0.568	0.492	2.63	0.47
Eclipta prostrate	1.67	4	666.67	0.125	0.523	0.364	0.281	1.17	2.4
Eragrostis amabilis	1.67	8	1333.33	0.070	0.523	0.204	0.562	1.29	4.8
Floscopa scandens	1.67	7	1166.67	0.635	0.523	1.843	0.492	2.86	4.2
Gomphostema parviflorum	3.33	3.5	1166.67	1.130	1.047	3.277	0.492	4.82	1.05
Gomphrena celosioides	6.67	10	6666.67	0.196	2.094	0.568	2.814	5.48	1.5
Hydrocotyle javanica	3.33	6	2000	0.125	1.047	0.364	0.844	2.26	1.8
Hypoestes phyllostachya	5	14.33	7166.67	0.196	1.570	0.568	3.026	5.17	2.87
Hedychium gardnerianum	3.33	2.5	833.33	1.538	1.047	4.460	0.351	5.86	0.75
Imperata cylindrica	5	7.67	3833.33	0.125	1.570	0.364	1.618	3.55	1.53
Impatiens latiflora	5	4	2000	0.635	1.570	1.843	0.844	4.26	0.8
Justicia gendarussa	5	5.33	2666.67	0.384	1.570	1.115	1.125	3.81	1.07
Kyllinga brevifolia	1.67	6	1000	0.070	0.523	0.204	0.422	1.15	3.6
Kaempferia rotunda	3.33	2	666.67	0.384	1.047	1.115	0.281	2.44	0.6
Lindernia crustacea	5	5.33	2666.67	0.196	1.570	0.568	1.125	3.27	1.07
Laportea interrupta	5	4.33	2166.67	0.635	1.570	1.843	0.914	4.33	0.87
Ludwigia perennis	5	2.67	1333.33	0.502	1.570	1.456	0.562	3.59	0.53
Lycopodium cernum	5	6	3000	0.196	1.570	0.568	1.266	3.41	1.2
Lygodium flexuosum	6.67	3.25	2166.67	0.384	2.094	1.115	0.914	4.12	0.49
Mimosa pudica	6.67	5.75	3833.33	0.635	2.094	1.843	1.618	5.56	0.86
Mitracarpus hirtus	5	3.67	1833.33	0.384	1.570	1.115	0.774	3.46	0.73
Mellinis repens	3.33	13.5	4500	0.196	1.047	0.568	1.900	3.52	4.05
Meistera koenigii	3.33	1.5	500	0.635	1.047	1.843	0.211	3.10	0.45
Odontosoria chinensis	3.33	5.5	1833.33	0.070	1.047	0.204	0.774	2.03	1.65
Polygonum hydropiper	6.67	8	5333.33	0.282	2.094	0.819	2.251	5.17	1.2
Potentilla sp.	6.67	3.25	2166.67	0.196	2.094	0.568	0.914	3.58	0.49

Pteridium esculentum	8.33	9.2	7666.67	2.543	2.617	7.373	3.237	13.23	1.10
Pteridium aquilinum	5	8.67	4333.33	1.326	1.570	3.846	1.829	7.25	1.73
Phrynium pubinerve	5	7.33	3666.67	0.785	1.570	2.275	1.548	5.39	1.47
Pouzolzia hirta	10	8.67	8666.67	0.196	3.141	0.568	3.659	7.37	0.87
Peliosanthes teta	8.33	6	5000	0.196	2.617	0.568	2.111	5.30	0.72
Spermacoce latifolia	5	5	2500	0.384	1.570	1.115	1.055	3.74	1
Stachytarpheta cayennensis	6.67	6.75	4500	0.635	2.094	1.843	1.900	5.84	1.01
Sellaginella involvens	6.67	4.25	2833.33	0.196	2.094	0.568	1.196	3.86	0.64
Sonerilla khasiana	5	3.33	1666.67	0.384	1.570	1.115	0.703	3.39	0.67
Strobilanthus coloratus	8.33	17.6	14666.67	0.282	2.617	0.819	6.192	9.63	2.11
Setaria pumila	3.33	19	6333.33	0.125	1.047	0.364	2.674	4.09	5.7
Sarcandra glabra	6.67	4.75	3166.67	0.635	2.094	1.843	1.337	5.27	0.71
Smilax perfoliata	1.67	5	833.33	0.196	0.523	0.568	0.351	1.44	3
Triumfetta rhomboidea	1.67	3	500	0.635	0.523	1.843	0.211	2.58	1.8
Triumfetta pilosa	1.67	2	333.33	0.635	0.523	1.843	0.140	2.51	1.2
Torenia violacea	5	5.33	2666.67	0.070	1.570	0.204	1.125	2.90	1.07
Thysanolaena latifolia	6.67	13.5	9000	1.326	2.094	3.846	3.800	9.74	2.03

Plate – VII: Some of the herb species found in the study area at Changki

Alternanthera philoxeroides (Mart.) Griseb.

Begonia palmate D. Don

Cyperus flavescens L.

Carex baccans Nees

Mimosa pudica L.

Cucurma augustifolia Roxb.

Dicranopteris linearis (Burm. fil.) Underw.

Eclipta prostrate (L.) L.

Blechnum orientale L.

Kyllinga brevifolia Rottb.

Lycopodium cernuum L.

Gomphostemma parviflorum Wall. ex Benth.

Odontosoria chinensis (L.) J. Sm.

Pteridium esculentum G. Forst Cockayne

Triumfetta pilosa Wall.

Canscora andrographioides Griff.

Kaempferia rotunda L.

Pouzolzia hirta Hassk.

Cheilanthes tenuifolia (Burm. f.)

Pteridium aquilinum (L.) Kuhn.

Justicia gendarussa Burm. fil.

Meistera koenigii (J. F. Gmel.) Skornick. & M. F. Newman

Alpinia malaccensis (Burm. f.) Roscoe

Hedychium gardnerianum Roscoe

Hydrocotyle javanica Thunb.

Impatiens latiflora Hook. F. & Th

Cyperus cyperoides (L.) Kuntze

Curculigo orchioides Gaertn.

Thysanolaena latifolia (Roxb. ex Hornem.) Honda

Curculigo capitulata (Lour.) Kuntze

Table 3.10: Diversity indices of Coal mining-affected forest (CMAF) and Non-affected forest (NAF) at Changki

Diversity indices	CMAF			NAF		
	Herb	**Shrub**	**Trees**	**Herb**	**Shrub**	**Trees**
Species richness (S)	54	13	36	62	22	44
Shannon-Wiener index (H′)	1.34	0.99	1.40	1.61	1.30	1.55
Simpson's diversity index (D)	0.92	0.88	0.95	0.97	0.95	0.97
Margalef richness index (R)	7.40	2.37	5.98	8.40	3.70	7.11
Pielou's evenness index (J)	0.34	0.37	0.39	0.39	0.43	0.41

Table 3.11: Similarity and dissimilarity of species composition between CMAF and NAF

Sorenson's Index	Similarity %	Dissimilarity %
Trees	40	60
Shrub	40	60
Herbs	48	52

3.3 DISCUSSION

3.3.1 Plant diversity and community attributes of CMAF in relation to NAF

The present study conducted at the CMAF and NAF of Changki, Nagaland elucidated a high floristic diversity of the area. Floristic composition of plant species in mine disturbed area provides insight into the environmental and ecological potential of these sites in the process of biological recultivation including the primary and secondary succession (Gajic and Pavlovic, 2018). In this study, the absolute species from one hectare area including herbs, shrubs and trees of NAF was comparatively higher than CMAF which represents a rich source of species diversity in the undisturbed area. Due to extensive coal mining, large forest areas of CMAF have been degraded and resulted in unfavorable habitat conditions for plants growth while the prevailing environmental quality has also limited the regeneration rate of many species, thereby reducing the number of species in the forest. IVI value of any species indicates their dominant nature in a mixed population and provides a comprehensive picture of the social arrangement of species in a group (Parthasarathy and Karthikeyan, 1997). The higher IVI value of *Chromolaena odorata, Melastoma malabathricum, Terminalia myriocarpa, Aporosa octandra, Phoebe lanceolata* and *Croton persimilis* species shows their pollution-tolerant nature at the coal mining polluted site. Sarma *et al.* (2010) has reported the dominance of *Pinus kesiya*, *Paspalum orbiculare* and *Schima wallichii* in the coal mine disturbed forest of Jaintia Hills district, Meghalaya, North East India. Although different dominant plants were recorded in the present study sites due to varying geographical layouts and species distribution compared to Meghalaya, similar inductive results can be reasoned. Such as the dominant nature of plants in mining areas suggest their resilient ability to grow in

the disturbed forest as they multiply rapidly and subjugate other species irrespective of the environmental conditions (Mondal *et al*., 2020) including low nutrient, acidic soil, high bulk density, low moisture and reduced organic carbon (Semy *et al*., 2021). Similar tolerant species like *Eleusine indica, Pteridium aquilinum* (Chu, 2008), *Euphorbia* sp. (Jimenez *et al*., 2011) and *Rumex crispus* (Randjelovic *et al*., 2014) has also been reported to survive in adverse mine affected areas due to their high ecological potential. Moreover, these species act as pioneers as they begin the process of revegetation by providing erosion control, improving the physico-chemical composition of mine spoil, retaining moisture and vitalizing nutritional substances that will be later used by spontaneous colonizers (Gajic *et al*., 2016). The prominent population of *Chromolaena odorata*, *Pteridium esculentum*, *Mussaenda roxburghii* and *Terminalia myriocarpa* in CMAF as depicted by IVI shows that man-made intrusion pressures have created an environment for these species to flourish over the other populations. However, considering this phenomenon such selective integration or elimination of some species would affect forest species composition, stand structure and also create a more subtle impact on that region (Brandl *et al*., 2002).

The dominance of tree families Euphorbiaceae, Moraceae, Lauraceae, Anarcardiaceae, Malvaceae, Fagaceae and Fabaceae indicates the type of Northern tropical semi deciduous forest in Nagaland (Leishangthem and Singh, 2018). The present study reciprocates to the floristic findings in neighbouring states of Assam and Manipur such as the dominance of Asteraceae and Poaceae among the herb population recorded by Devi *et al*. (2014) in their floristic diversity of Sangla valley in Indian Himalaya. The dominance of Rubiaceae, Fabaceae, Anacardiaceae, Malvaceae and Apocynaceae were also reported from Barail Wildlife Sanctuary, Assam (Bora and Bhattacharyya, 2017). From Western Ghats, the dominance of Poaceae, Euphoriaceae, Acanthaceae and Fabaceae was reported by Palanisamy and Arumugam (2014) at Madukkarai hills. Donggan *et al*. (2011) presented the presiding nature of Asteraceae, Cyperaceae and Caprifoliaceae in the coal mine area which were also dominant in CMAF. The pre-potent nature of Lythraceae, Verbenaceae, Primulaceae, Theaceae, Vitaceae, Solanaceae, Meliaceae, Thelypteridaceae and Cryophyllaceae in the disturbed coal mine area could represent its presiding nature and of a habitat that is conducive to more typical tolerant families, which suggest that biased habitat loss is exerting a selective influence on the population and that the increased number of a particular family could be a response to that selection. Higher basal area was recorded at NAF in all three basis of plant forms which was in conformity with Sarma and Barik (2011).

This result however contradicts the findings of Sarma *et al*. (2010) where the basal area was comparatively greater in the mined areas than the unmined area at Jaintia hills district of Meghalaya, India. *Terminalia myriocarpa* the East Indian almond or Hollock which is native to India and Southeast Asia contributed the highest overall basal area cover in both the forest. The difference in density and basal area cover of the two forests apart from mining activities may be attributed to altitudinal variation, species composition, age structure, successional stage of the forest and degree of disturbances (Sundarapandian and Swamy, 2000). Tree density at NAF (1684 trees/ha) was higher than CMAF (1392 trees/ha) and consonant with reports of Pandey *et al*. (2014) in mining areas. The tree density measured in this study can be compared to tree density values reported in tropical forest by Adekunle *et al*. (2013) and Akash *et al*. (2018). The A/F ratio generates the distribution pattern analysis which shows species dispersion across a span of time at any given site. This pattern may depend on the environmental variables exhibiting in the area as well as reflect on the biological peculiarities of the organisms themselves. In all three basis of plant life forms, the analysis of distribution patterns along the two forests indicates that contiguous distribution was the most common, which according to Odum (1971) is a result of small but significant variations in the ambient environmental conditions. A similar observation was made by Sarma (2005) and Sarma *et al*. (2010) in the mined areas where majority of the species showed contiguous pattern of distribution. In India, several workers (Majumdar and Datta, 2015; Shameem *et al*., 2017; Saravanan *et al*., 2019) have reported similar distribution patterns in the forest vegetation.

Biodiversity indices are generated to bring the diversity and abundance of species in different habitats to a similar scale for comparison and assess ecosystem health and ecological processes (Naidu and Kumar, 2016). The high value of Shannon-Wiener index at the NAF represents a diverse community which was in conformity with Pandey *et al*. (2014) at an undisturbed site compared to Raniganj and Jharia coalfield both for the herbaceous and woody vegetation. The diversity value in NAF and CMAF were similar with an observation value of 1.43-1.84 by Bachan (2003). However, the diversity index of tree species in the two forests is comparatively lesser than the tropical forest of Eastern Ghats, Andhra Pradesh ranging between 3.76 - 3.96 (Naidu and Kumar, 2016). Sundarapandian and Swamy (2000) and Sahu *et al*. (2012) stated that the diversity value for Indian forests is in the range of 0.8 to 4.1. In the present study, the diversity values of herb, shrub and trees obtained in both the forests falls under the reported range of Indian tropical forests. Simpson diversity index value of the three plant forms represents higher diversity at NAF than CMAF. Sarma (2002) has

also reported low species diversity in the mined areas as compared to unmined areas from Nokrek biosphere reserve, Meghalaya. NAF harbors greater biodiversity value than CMAF due to balanced vegetation composition as it provides sustenance on habitat suitability, ecosystem productivity and successional pathways while lower species diversity in CMAF imparts information on the forest susceptibility to anthropogenic disturbances and altered trophic structures. The Pielou's evenness index of all three plant forms did not significantly vary between the sites suggesting that the equability of the NAF and CMAF forest located in one region is influenced by similar weather patterns which could have its impact on their evenness. Evenness in the study area was quite low compared to Shameem *et al*. (2017) in Kashmir Himalaya, India where they reported a high evenness index of 0.90. Species composition and richness vary widely according to the frequency of disturbances. NAF harbors diverse vegetation and presented a higher Margalef richness value in all three plant forms compared to CMAF. The community stability is coherently related to the species diversity, greater the diversity index, higher will be the stability of community structure and function. Evidently, the species richness had a greater influence over species diversity than evenness as observed in this study. Sorensen's index which was used to compare the associations between the two forests shows the percentage of similarity is lower than the dissimilarity index. Since CMAF and NAF are located in one geographical region, coal mining activities had reflected a more pronounced effect on species composition apart from the influence of microclimate, soil properties, species compositions, productivity and competition which might also have contributed to the variation in species similarity between the study sites (Criddle *et al*., 2003). Lower tree girth classes were annotated with higher total number of individual species and density while middle girth classes have higher basal area in both the forest which was in conformity with Basyal *et al.* (2011). Sarma and Barik (2011) reported that in the un-mined areas, the young and middle-size trees were higher than the old trees, indicating a stable tree population structure that was relevant to the NAF stands. The existing tree population structure in the two sites is represented by a normal case and suggests that the forest is growing and would continue to exist and stabilize under the environmental gradients until or unless the region is affected by severe anthropogenic disturbances. However, in the disturbed areas of CMAF, extensive coal mining could cause rampant changes in the forest landscape over a period of time which may affect the tree population structure if measures are not taken.

Since the NAF and CMAF areas were located at similar climatic, edaphic and physiographic features, the changes and the differences in species composition could be attributed to the land-use patterns. NAF depicts a community structure that is heterogeneous because of the low pollution load at the forest which favors the growth, survival and regeneration of natural vegetation. However, in case of CMAF over a period of time the habitats in close proximity with mining areas may subsequently lose their sensitive plant species and create a niche that will favor the dominance of more tolerant species. The dominant nature of some species at CMAF showed resistance to the impact of mining pollutants and other man-made disturbances and suggests that species gets acclimatized to stress conditions. Moreover, the changes in species diversity observed at CMAF indicated an increase in the proportion of resistant herbs and grasses of the family Poaceae, Asteraceae and Cyperaceae presenting a positive tendency towards a definite selection strategy of an ecosystem in response to the prevailing environmental conditions. As variations in environmental factors impose the adaptive abilities of organisms, only those species which resilient to new conditions or those which can become accustomed to the changing forest structure, participate in the community formation (Agrawal and Agarwal, 2000). The regional patterns of species richness and its succession to stabilization as a community are a collaborative effect of different interacting factors, species dynamics as well as species pool. Such processing effect was observed in the study as the total numbers of individual species and families participating in the community structure as dominants or co-dominants were higher at NAF compared to CMAF. The biodiversity indices obtained from the study has indicated that anthropogenic stress associated with intermittent small scale folds were pervasive in the forest due to the open cast mining, rat-hole mining, logging of trees, collection of fodders, grazing of cattle, stone quarries, passage of national highway and Jhum cultivations. So, if the trends of dumping overburden mine spoils and other anthropogenic activities continue, detrimental environmental changes will affect the survivability, reproductive potential and hamper the growth of the existing species composition.

3.4 SUMMARY AND CONCLUSION

The critical assessment on the plant community structure in the Coal mining-affected forest (CMAF) and Non-affected forest (NAF) at Changki has provided insight interpretation of plant diversity in the Northern tropical semi-deciduous forest of Nagaland, India. At NAF, a total of 421 tree individuals representing 44 genera constituting 29 families were identified

whereas at CMAF, a total of 348 individual trees belonging to 36 genera and 12 families were recorded. Based on the IVI obtained in NAF and CMAF, *Terminalia myriocarpa* the East Indian almond, contributed the highest IVI. A total of 291 shrubs comprising 21 genera and 12 families were recorded in NAF whereas, in CMAF, a total of 239 shrubs belonging to 12 genera and 9 families were identified. *Mussaenda roxburghii* contributed the highest at NAF, while in CMAF, *Melastoma malabathricum* had the highest IVI. NAF had a total of 1440 individual herbs representing 58 genera and 37 families whereas CMAF had a total of 1290 individual herbs belonging to 51 genera and 30 families. Both in NAF and CMAF, *Chromolaena odorata* contributed the highest IVI. Shannon-Wiener index and Simpson's diversity index showed that NAF has higher diversity than CMAF which was also observed in the. Similarly, Margalef richness index and species evenness was recorded higher in NAF. In all the plant forms, Sorenson's index shows a lower similarity and a higher dissimilarity between the two forests. The most common plant distribution pattern of the two sites was the contiguous pattern, which is a result of small but significant variations in the ambient environmental conditions. Some prominent families such as Zingiberaceae, Bigoniaceae, Gnetaceae and Balsaminaceae were absent in CMAF but present in NAF. Moreover, the population growth curve of NAF and CMAF shows that the region is dominated by young trees and the forest is growing and would continue to exist and stabilize over the years if extreme anthropogenic activities is reduced.

The biodiversity indices points out the variation in species diversity and richness of the two forests induced by mining activities. The decade long dumping of coal spoils into the forest has thwarted the normal plant populations' upto an extent where the influence is observed in the CMAF. While the community protected NAF accounts for very few anthropogenic activities; it has a rich species diversity providing a balanced ecosystem for a sustaining habitat. The changes in the dominance of the plant species at CMAF indicate their acclimatization state being susceptible due to the mining effects. However, few species are resilient to the coal mining stress and adapt by enhancing their colonization rate in the disturbed forest. Through the study, it can be stated that consistent quantitative and qualitative information of floristic data and their records are required to understand the regional forest biodiversity affected by anthropogenic activities. Overall, the database collected in this research can be an important source for the local authorities as well as researchers and environmentalists working on the Indo-Burma biodiversity hotspot to

promote the use of the botanical records as part of conserving biological diversity and promoting sustainable development.

CHAPTER-4

SOIL PHYSICOCHEMICAL PROPERTIES AND QUALITY STATUS OF COAL MINING AFFECTED AND NON-AFFECTED FOREST

4.1 INTRODUCTION

Soils are made up of inorganic particles and organic materials and have a wide range of chemical and physical qualities. Soil serves as a structural support to plants and is also their source of nutrients and water. Processes such as leaching, weathering and microbial activities combines to create a diverse spectrum of soil types. Over the years of anthropogenic activities such as indiscriminate timber and fuel wood extraction, clear-felling for shifting cultivation and mining excavation (Adewoye, 2005) have altered the forest landscape across the country. Northeast India, a mega biodiversity hotspot region, has been facing a tremendous challenge on forest soil quality due to illegal coal mining practices particularly in the tribal dominant state of Meghalaya and Nagaland. The removal of forest cover has greatly affected the soil characteristics, including soil fertility, chemistry, and texture (David and Mark, 2005) of the region. Coal mining also leads to the extensive loss of natural carbon sink and further emission of CO_2 in atmosphere (Ahirwal *et al*., 2017;

Ahirwal and Maiti, 2017). Underground and open-pit coal mining includes a phase of development that involves the removal of native soils and surrounding rocks, which are low in coal content (<30%), high in iron sulfide minerals and toxic metals. Variety of rock types with different compositions are exposed to atmospheric conditions and undergo accelerated weathering and these materials are often deposited nearby as mine waste dumps (Bhuiyana *et al*., 2010). These mine dumps leads to declination of the soil quality due to stock piling of overburden dumps (Mukhopadhyay and Maiti, 2011), as these dumps are low in soil organic carbon, poor in nutrients, contain loosely adhered particles of shale, stones, boulders, cobbles and so forth devoid of real soil characters (Boruah, 2006). The excavation and dumping of the overburden dumps from coal mines when deposited in forest ultimately change the landscape of the area and create various environmental issues (Maiti, 2007). Coal mining industry being the largest contributor (~ 70 %) of total power generation in India, it leads to severe land degradation of forest areas (Maiti, 2013). Therefore, forest soil ecology is greatly influenced by such external pressures which can modify the standing forest structure and deteriorate environmental quality. Ahirwal and Maiti (2018) have demonstrated that reclamation and revegetation can be adopted in mining affected forest areas. Thus, it is important to check the current forest soil status and establish appropriate soil quality indicators from the physical, chemical and biological soil variables that are sensitive enough to describe the effect of different impacts on the soil (Moffat, 2003). To avoid difficulty in interpreting the complex nature of soil characteristics, a numerical dimensionless Soil Quality Index (SQI), focused on the integration of considered soil properties is calculated to evaluate soil quality (Mukhopadhyay *et al*., 2015). With the increase of land-use pressures, assessment on soil quality is in rising demand, thus a standard set of protocols and procedures to assign a SQI would be beneficial (Armenise *et al*., 2013) especially in India where overpopulation has resulted in excessive land-use practices even in the forested regions. Over the years integrating soil quality by means of indices has been successfully adopted both at a regional scale and on-farm level (Glover *et al*., 2000; Masto *et al*., 2008) through the use of weighted SQI and additive SQI.

Although SQI has been extensively used as a tool to evaluate crop productivity (Liu *et al*., 2014), agro soil fertility (Rayo *et al*., 2017) and agroecosystem (Triantafyllidis *et al*., 2018) there is a perceptible lack of studies using SQI to monitor seasonal soil quality on

forest soils affected by coal mining activities, though it is often regarded as the most environmentally degrading activity in developing countries. This lack of knowledge is especially evident for India, where most soil quality studies have concentrated on agricultural and horticultural sectors (Bhardwaj *et al*., 2011). Thus, the need arises to undertake research in the aforementioned subject. Since soil is an integral component of the environmental quality and a base of providence to forest health, considering its importance to the ecosystem and socio-cultural life of indigenous people, the study was conducted by selecting a forest disturbed by coal mining activities and an undisturbed community forest, to examine the variations in the soil physicochemical parameters and to comparatively determine the seasonal SQI. This study will highlight the effects of coal mining on the soil quality in tropical forest.

4. 2 RESULTS

Analysis of variance (ANOVA) between seasonal soil parameters are presented in **Table 4.1**. Monthly values for all the soil physicochemical parameters obtained from CMAF and NAF are presented in **Appendix I**.

Table 4.1: Analysis of variance (ANOVA) between seasonal groups of NAF and CMAF with *F* and *P* value

Soil parameters	**NAF**		**CMAF**	
	F - value	*P* - value	*F* - value	*P* - value
BD	23.72	<.001	5.73	.022
SP	27.43	<.001	3.75	.060
Clay	1.80	.225	3.63	.064
Sand	10.81	.003	2.67	.119
Silt	2.33	.151	2.87	.104
pH	32.08	<.001	65.48	<.001
Moisture	19.40	<.001	67.51	<.001
Temperature	562.13	<.001	623.21	<.001
EC	8.98	.006	85.17	<.001
CEC	8.59	.007	54.77	<.001
OC	33.02	<.001	1.835	.219
P	45.48	<.001	21.6	<.001
K	15.45	<.001	6.37	.016
AN	27.16	<.001	10.87	.003
TN	3.67	.063	4.72	.035

The mean difference is significant at the 0.05 level

4. 2.1 Seasonal soil physical variables

Clay (%)

The average clay percentage in CMAF was recorded highest at 0-10 cm depth of soil in autumn (20.86±1.02%) and lowest at 20-30 cm in summer (15.23±0.25%) as shown in **Fig. 4.1**, however, there was no significant difference among the seasons (F = 3.63; P = .064). In NAF, the observed clay content was maximum in autumn at 0-10 cm (27.63±3.23%) and minimum during winter in 20-30 cm soil depth (17.43±0.75%) but showed no significant difference at the $p < 0.05$ level.

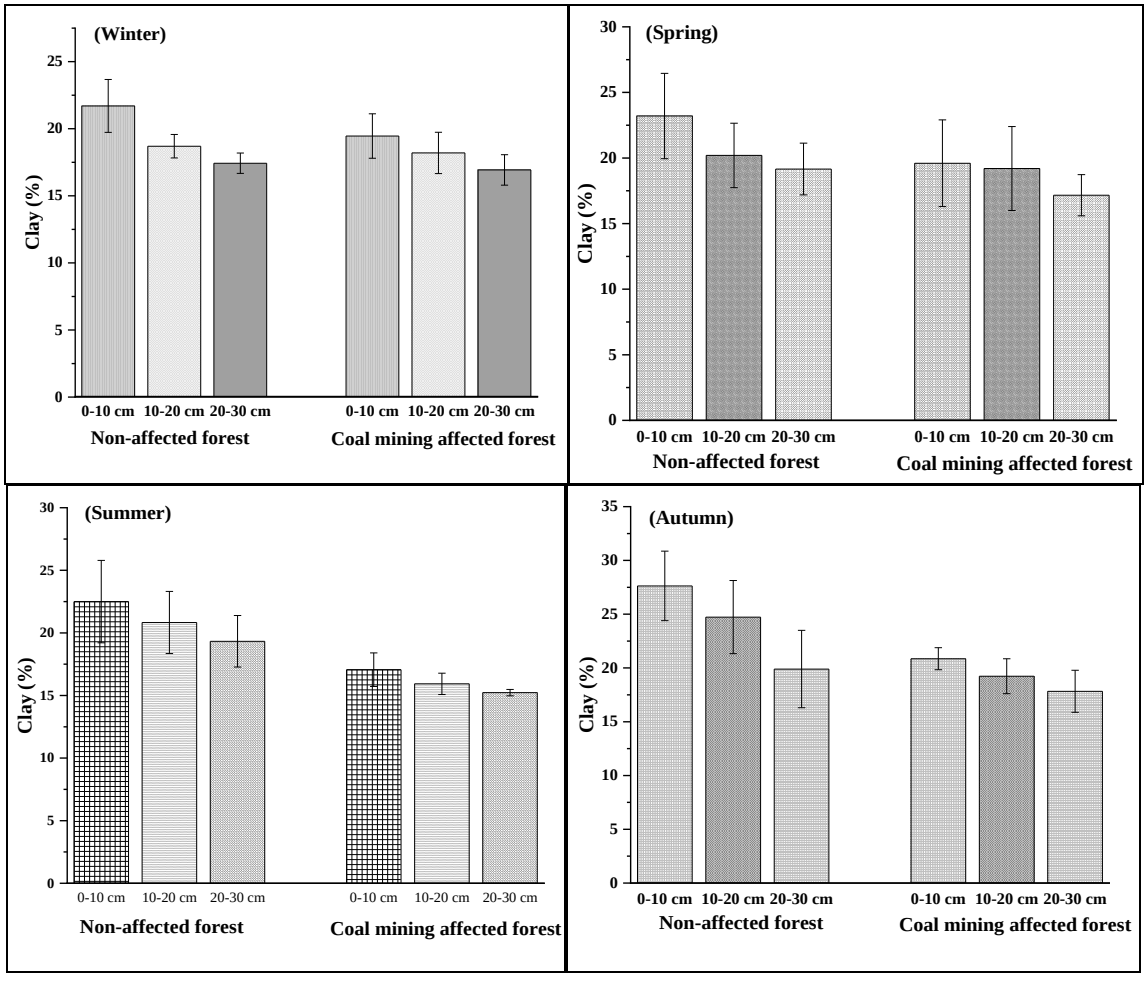


Fig. 4.1: Seasonal variation of Clay (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Silt (%)

In CMAF, the soil depth 0-10 cm presented the maximum value of 21.96±0.60% during summer and a minimum value of 19.96±0.89% in autumn **(Fig. 4.2)**. While in NAF, autumn (23.33±2.66%) at 20-30 cm has the highest recorded value of silt and spring (18.60±2.70%) the lowest. Analysis of variance shows no observable significant difference at the $p < 0.05$ level between the seasons for both the sites.

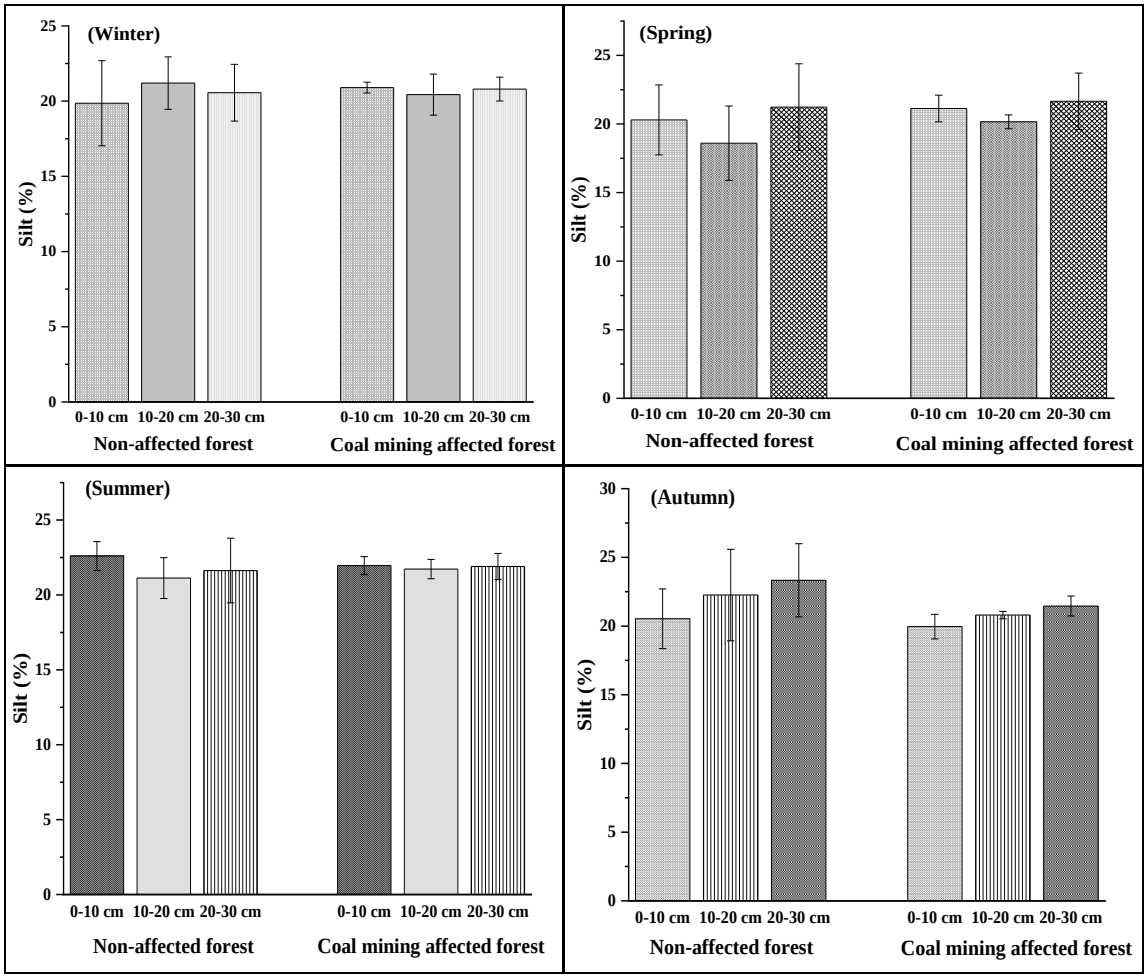


Fig. 4.2: Seasonal variation of Silt (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Sand (%)

Seasonally, in CMAF, the highest sand content was detected during summer (62.96±0.85%) and lowest was recorded in autumn (59.16±1.61%) both at 0–10 cm soil depth **(Fig. 4.3)**. While in NAF, the maximum was estimated from winter season (62±1.15%)

at 20-30 cm and minimum was observed during autumn (51.83±4.64%) at 0-10 cm. In NAF, a statistical significant difference (F = 10.81; P = .003) was analyzed between the seasons while in CMAF such difference was not valid.

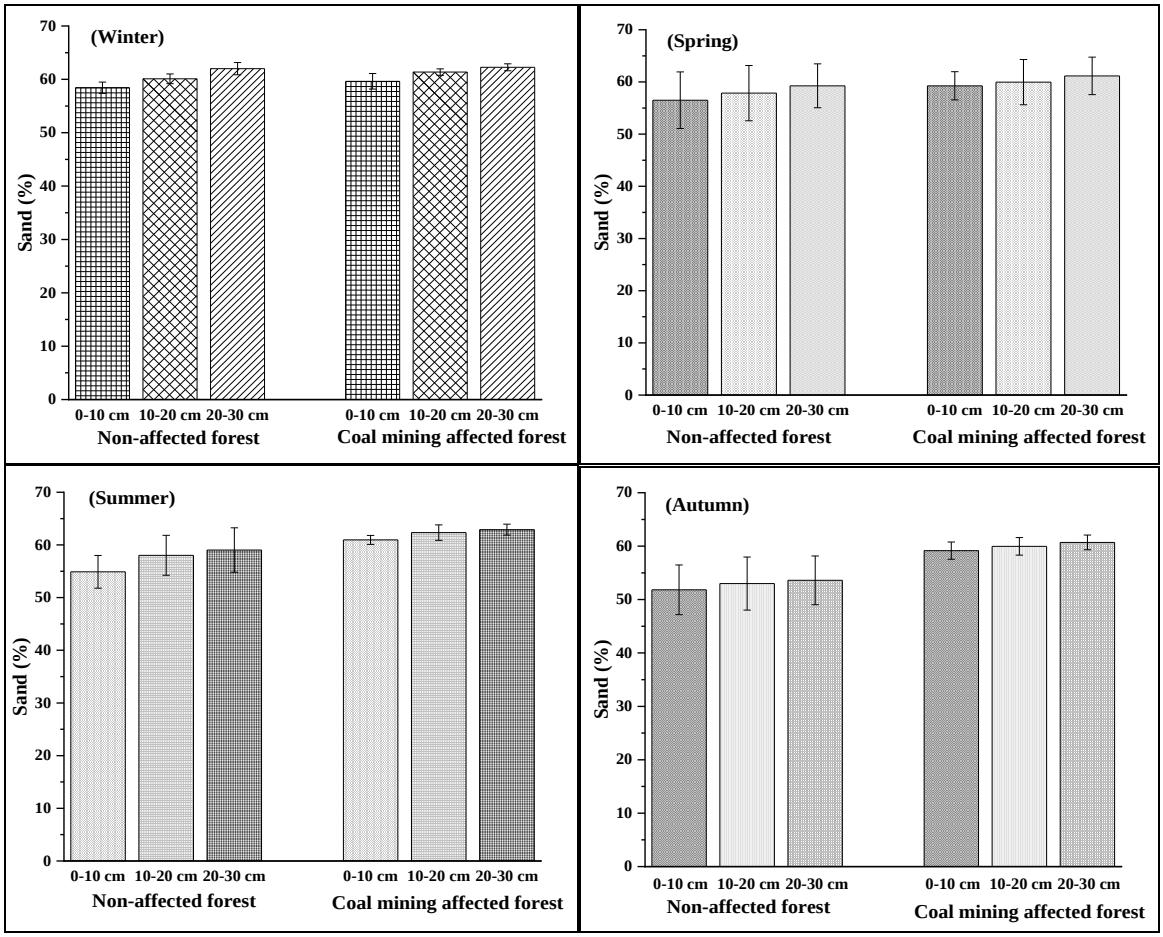


Fig. 4.3: Seasonal variation of Sand (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Bulk Density (g/cm^3)

Depth wise, 20-30 cm during winter (1.57±0.04 g/cm^3) at CMAF holds maximum BD while 0-10 cm in autumn (1.32±0.02 g/cm^3) has the minimum **(Fig. 4.4)**. In NAF, a maximum and minimum value of 1.43±0.07 g/cm^3 (20-30 cm) and 1.09±0.06 g/cm^3 (0-10 cm) was estimated during winter and autumn season respectively. The BD in CMAF (F = 5.73; P = .002) and NAF (F = 23.72; P < .001) reveals a statistical difference between seasons.

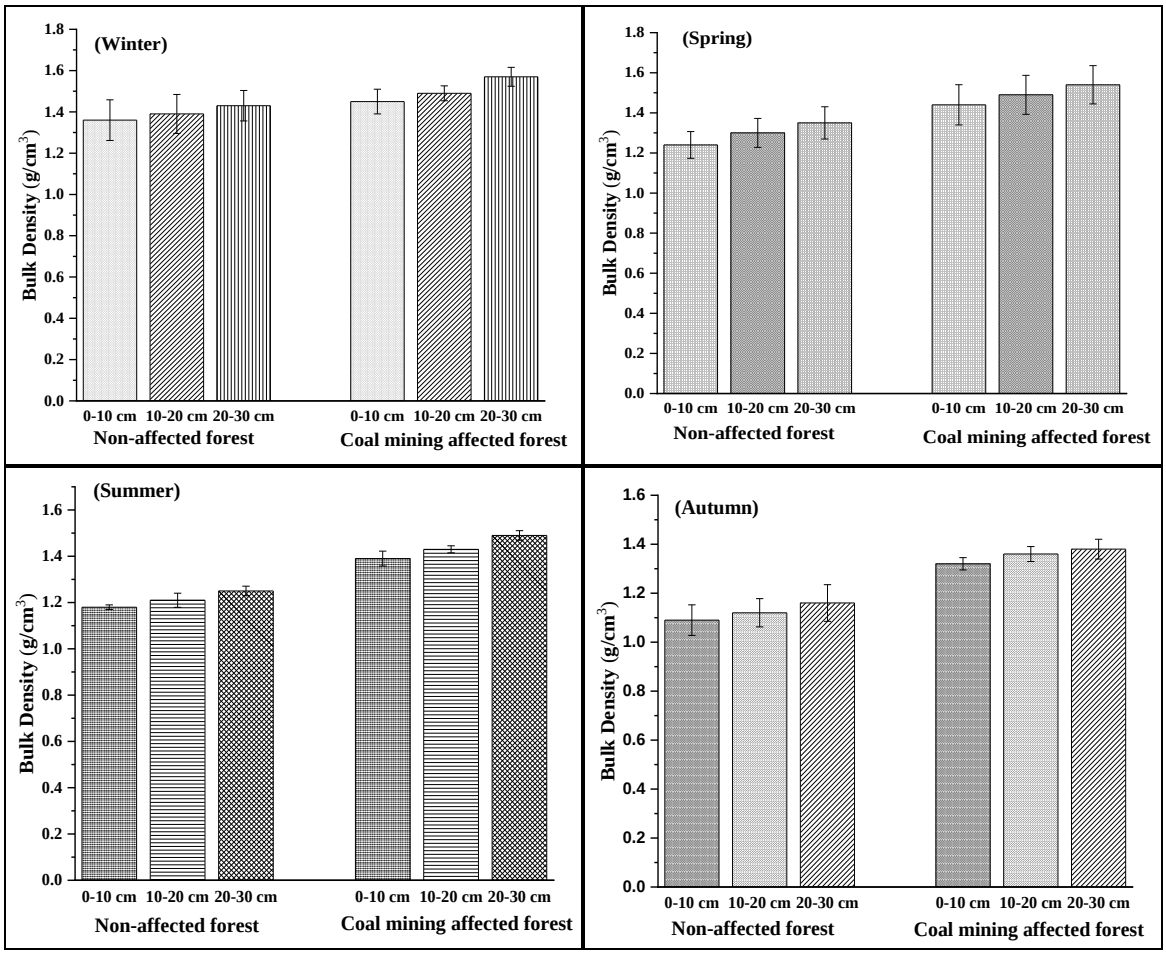


Fig. 4.4: Seasonal variation of Bulk Density (g/cm^3) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Soil Porosity (%)

In both the sites, autumn season (CMAF - 0.46±0.01%; NAF - 0.55±0.02%) and the soil depth 0-10 cm has the maximum soil porosity while winter (CMAF – 0.38±0.02%; NAF – 0.44±0.03%) at 20-30 cm has the minimum value **(Fig. 4.5)**. The analysis of variance shows no mean significant difference between the seasonal groups in CMAF (F = 3.75, p = .060) whereas a highly significant difference was observed for NAF (F = 27.43, p < .001).

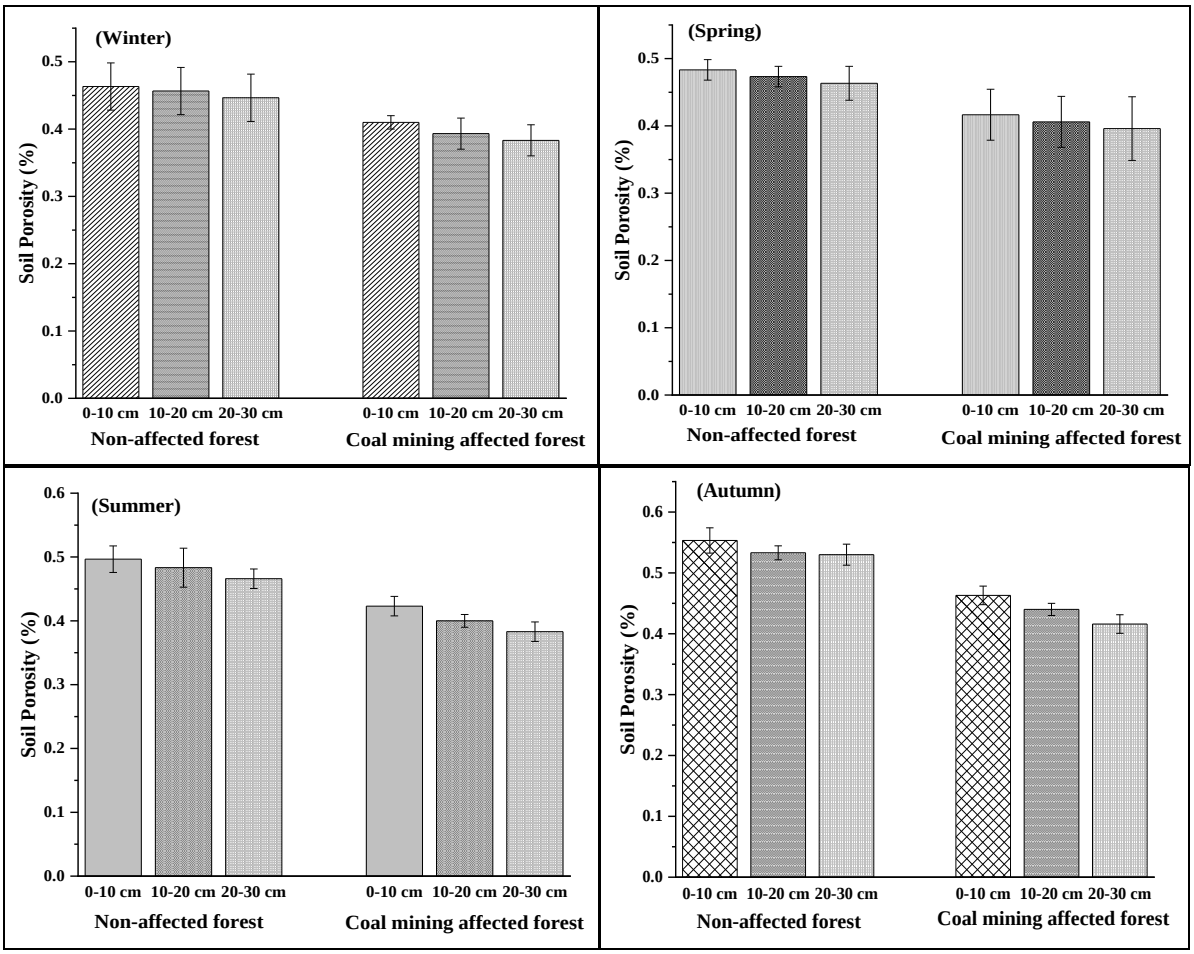


Fig. 4 .5: Seasonal variation of Soil Porosity (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Soil Moisture (%)

Seasonally, soil moisture showed variation among the sites and layers of soil. Soil layer 0-10 cm recorded the maximum moisture for CMAF (35.96±2.35%) and NAF (43.90±4.05%) during summer **(Fig. 4.6)**. A minimum mean value was detected from 20-30 cm soil layer during the winter season (CMAF – 17.60±4.02%; NAF – 26.03±3.63%). In both the forest a significant difference ($P < .001$) was recorded between the seasons.

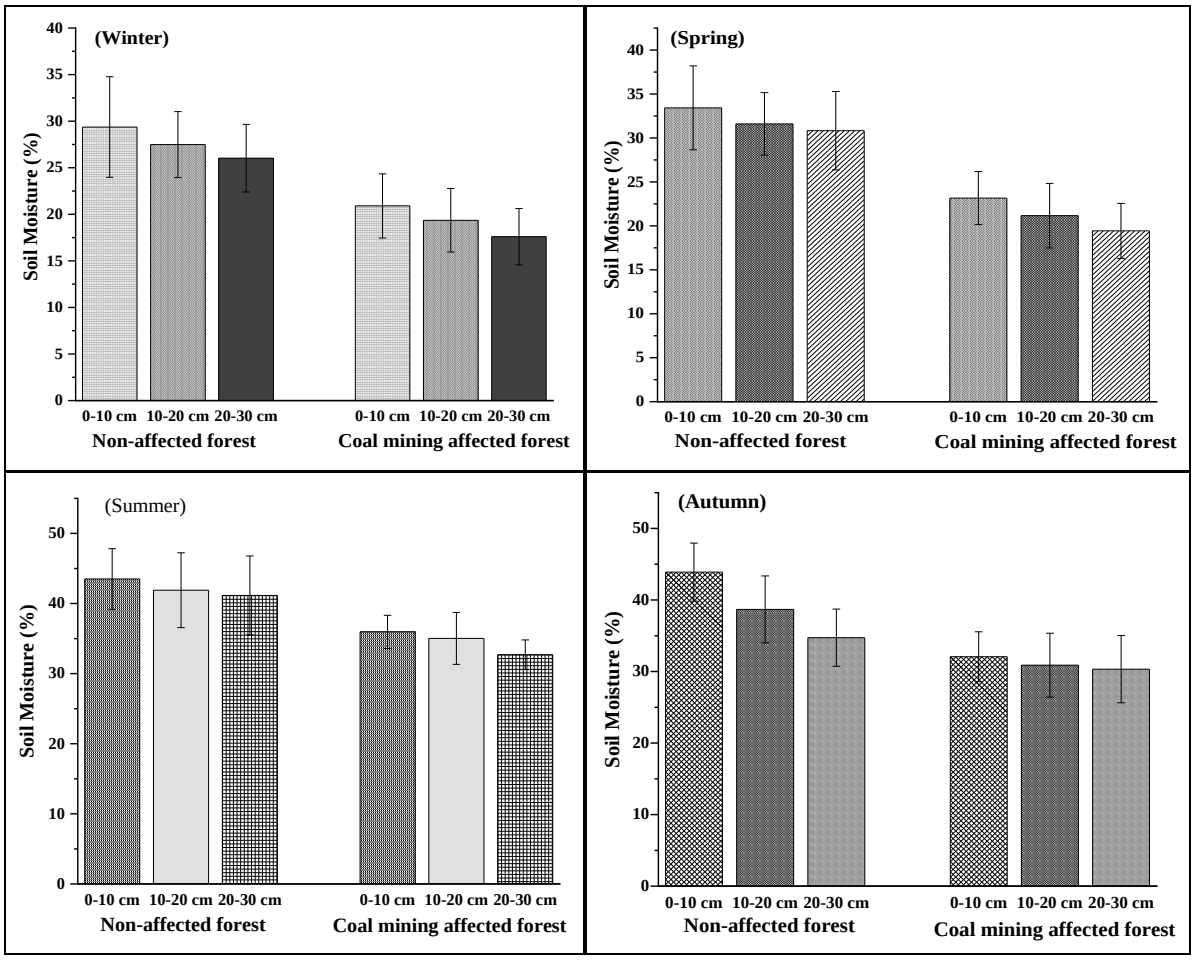


Fig. 4.6: Seasonal variation of Soil Moisture (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Soil Temperature (°C)

Considerable seasonal variation in soil temperature was recorded from the study sites. Summer season influenced higher soil temperature for CMAF (35.03±2.05°C) and NAF (32.40±3.43°C) at the top layer of soil **(Fig. 4.7)**. During the winter months, a minimum value of mean soil temperature was detected in CMAF (24.10±3.25°C) at 0-10 cm soil depth and NAF (22.03±2.62°C) at 10-20 cm. The analysis of variance shows a significant difference ($P < .001$) between the seasons for both the forest.

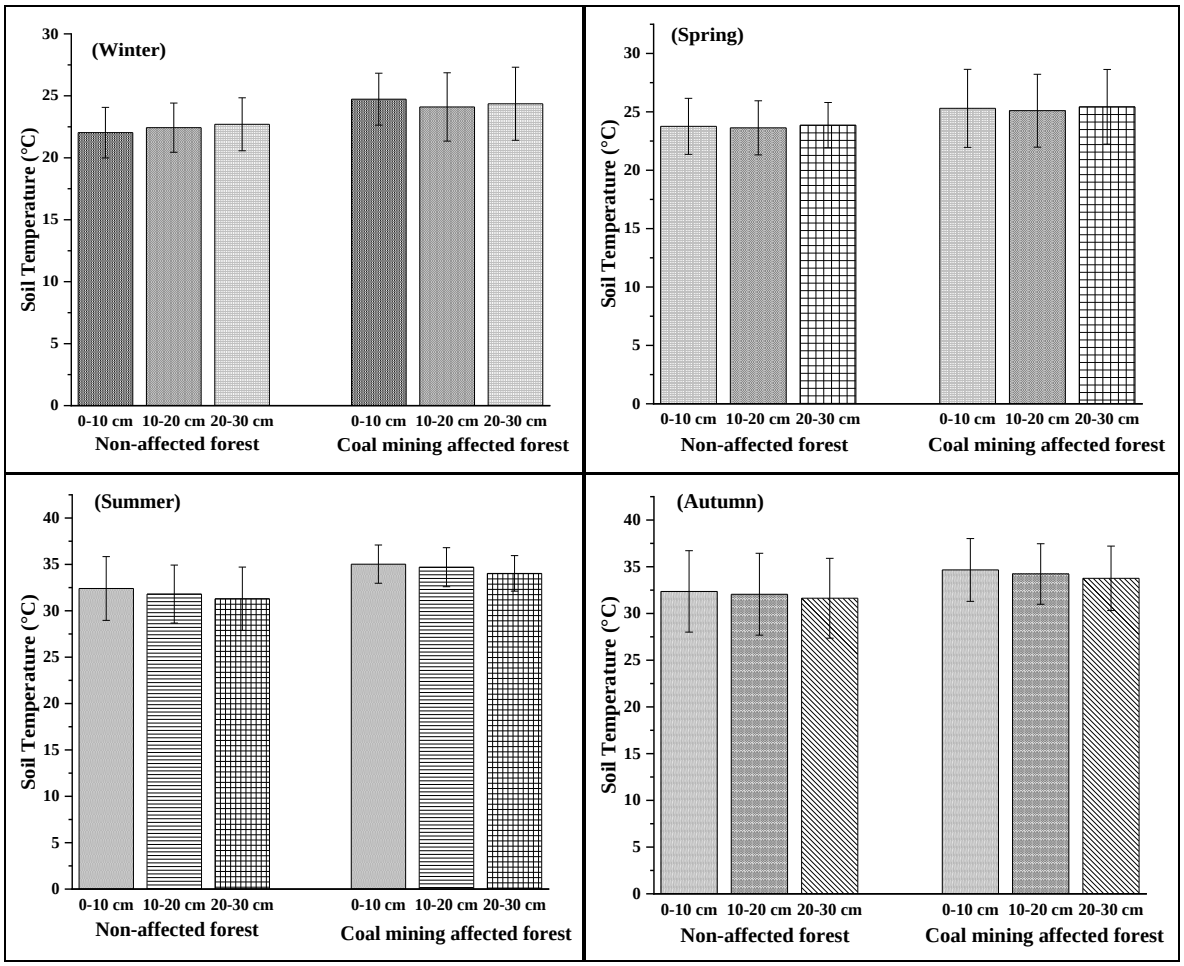


Fig. 4.7: Seasonal variation of Soil Temperature (°C) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

4. 2.2 Seasonal soil chemical variables

Organic Carbon (%)

Seasonally, in both the sites, soil organic carbon was detected highest during autumn (CMAF – 1.46±0.39%; NAF – 2.89±0.24%) at 0-10 cm soil depth and lowest during winter (CMAF - 1.03±0.19%; NAF – 1.66±0.16%) at 20-30 cm soil layer **(Fig. 4.8)**. CMAF OC was insignificant at the $p < 0.05$ level while NAF OC differ significantly ($p < .001$) between seasons.

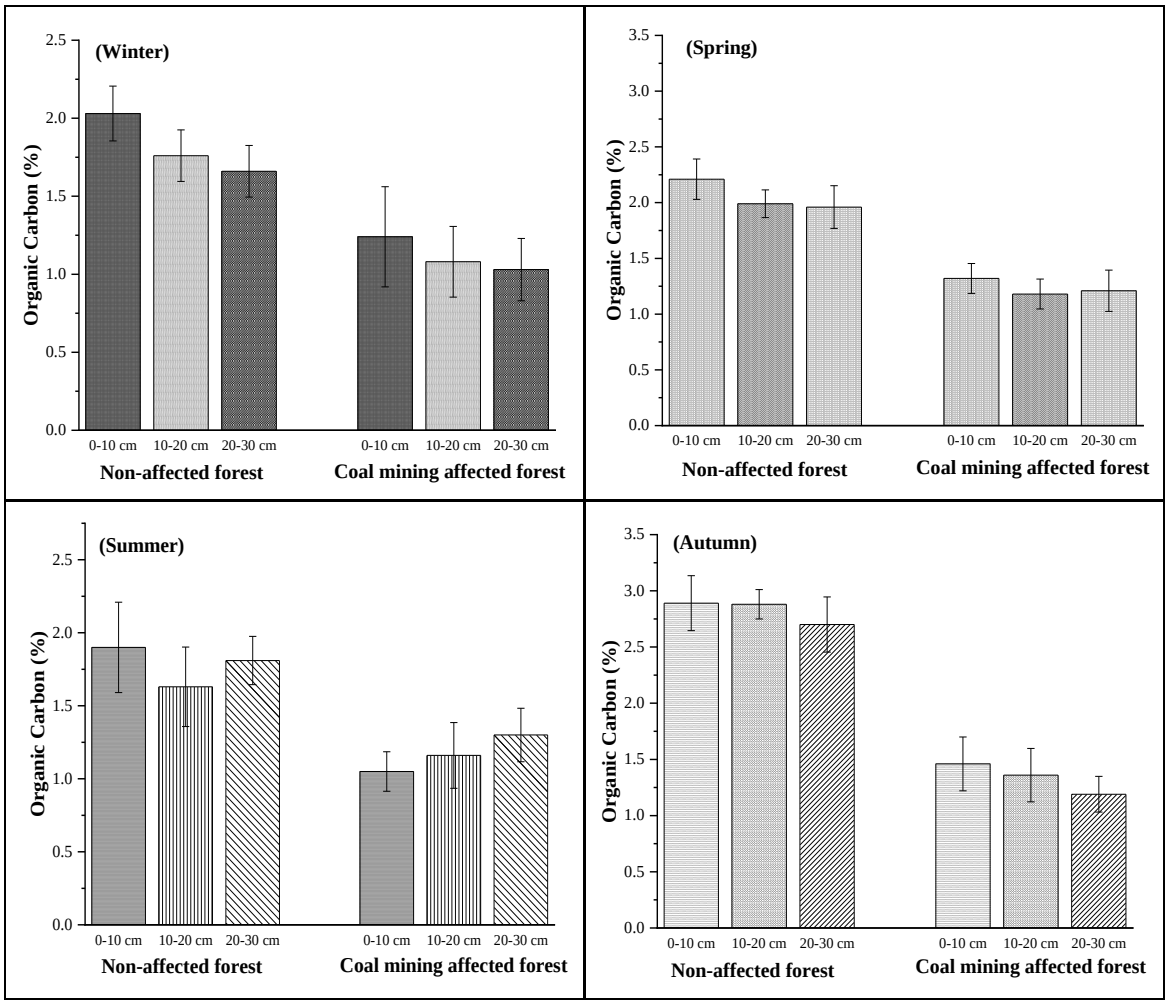


Fig. 4.8: Seasonal variation of Organic Carbon (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Cation Exchange Capacity (meq/100g)

As depicted in **Fig. 4.9**, the seasonal soil depth wise, 0-10 cm during autumn at CMAF (32.38±2.70 meq/100g) and NAF (37.68±6.63 meq/100g) holds maximum CEC, while 20-30 cm soil depth recorded minimum CEC for CMAF in winter (16.89±2.15 meq/100g) and NAF during summer (29.30±1.55 meq/100g). Analysis of variance shows that CEC was significant in NAF (F = 8.59, p = .007) and CMAF (F = 54.7, p < .001) at the $p < 0.05$ level.

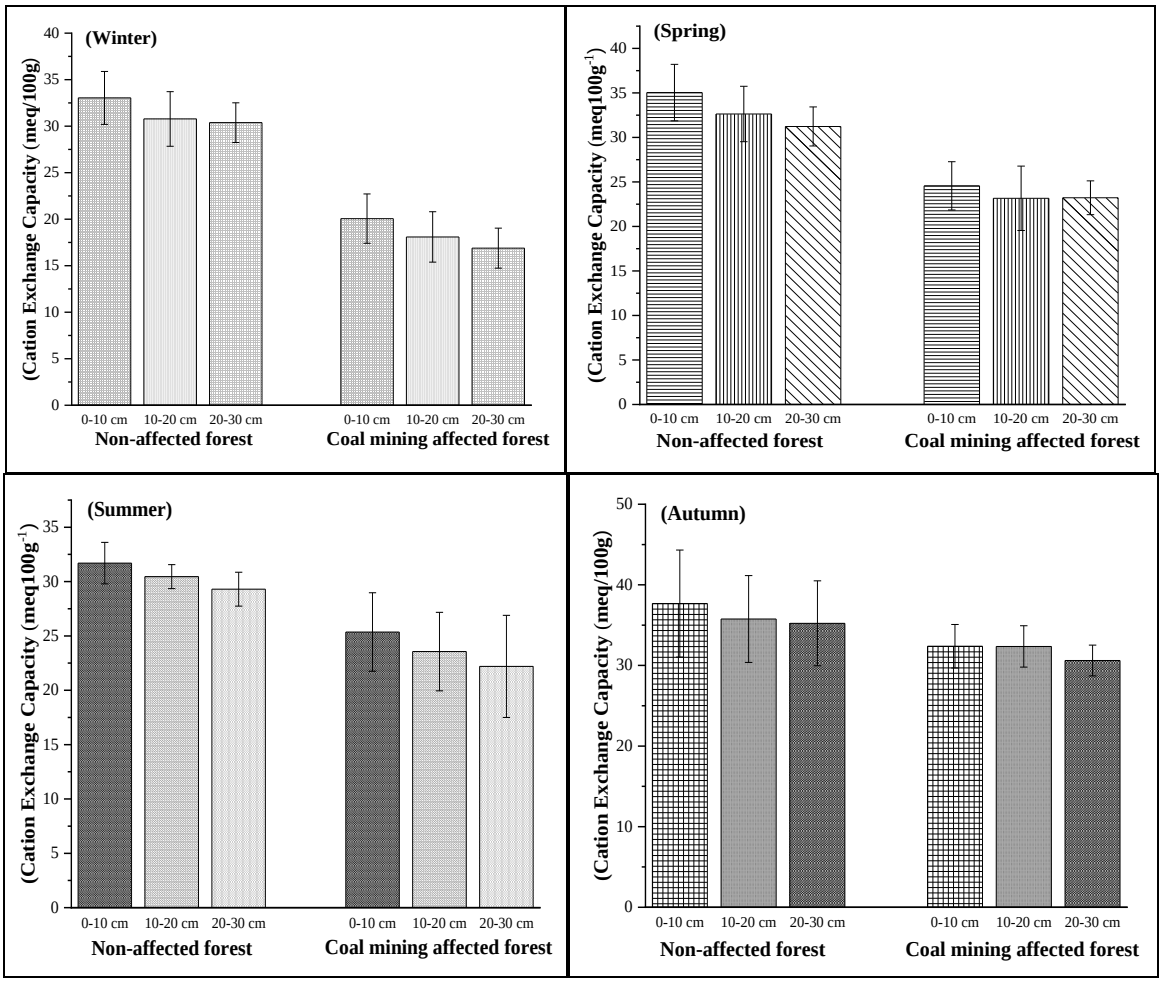


Fig. 4.9: Seasonal variation of Cation Exchange Capacity (meq/100g) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Electrical Conductivity (µS/cm)

Mean values of EC in CMAF was recorded highest in summer (334.7±6.70 µS/cm) at 0-10 cm and minimum in winter (265.36±3.32 µS/cm) at 20-30 cm as presented in **Fig. 4.10**, with a significant difference ($F = 85.17$; $p < .001$) between the seasons. Whereas in NAF, the highest EC was detected in spring (245±5.11 µS/cm) at 0-10 cm and the lowest was observed from 20-30cm soil depth during winter (214.56±3.02 µS/cm); there was no mean significant difference at the $p < 0.05$ level.

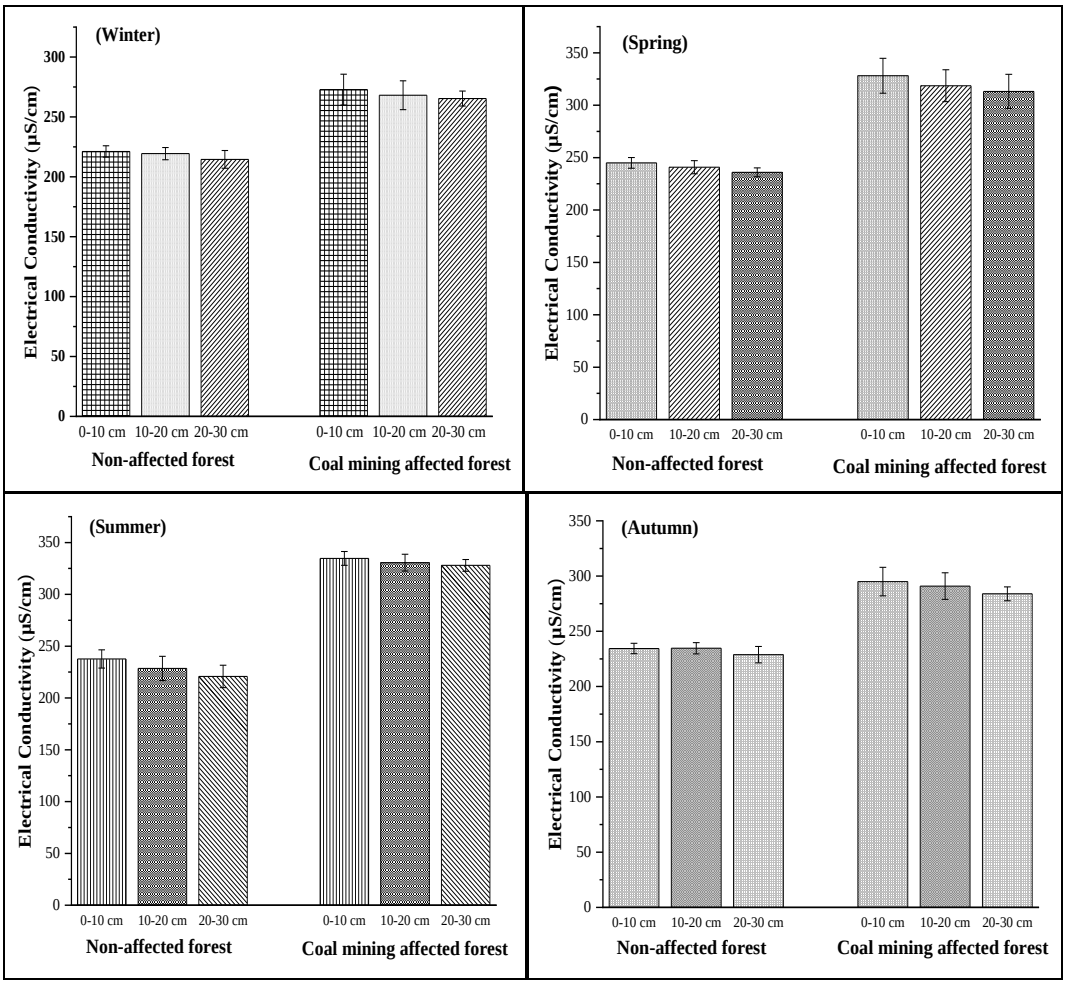


Fig. 4.10: Seasonal variation of Electrical Conductivity (µS/cm) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

pH

The maximum pH in CMAF, was recorded during autumn (4.13±0.20) at the soil layer of 20-30 cm and minimum in winter (2.96±0.20) at 0-10 cm **(Fig. 4.11)**. Whereas in NAF, the soil depth 10-20 cm has the highest and lowest value in varying seasons of summer (5.46±0.11) and autumn (4.43±0.10) respectively. The soil pH in NAF and CMAF shows a mean statistical difference at $p < 0.05$ between the seasons.

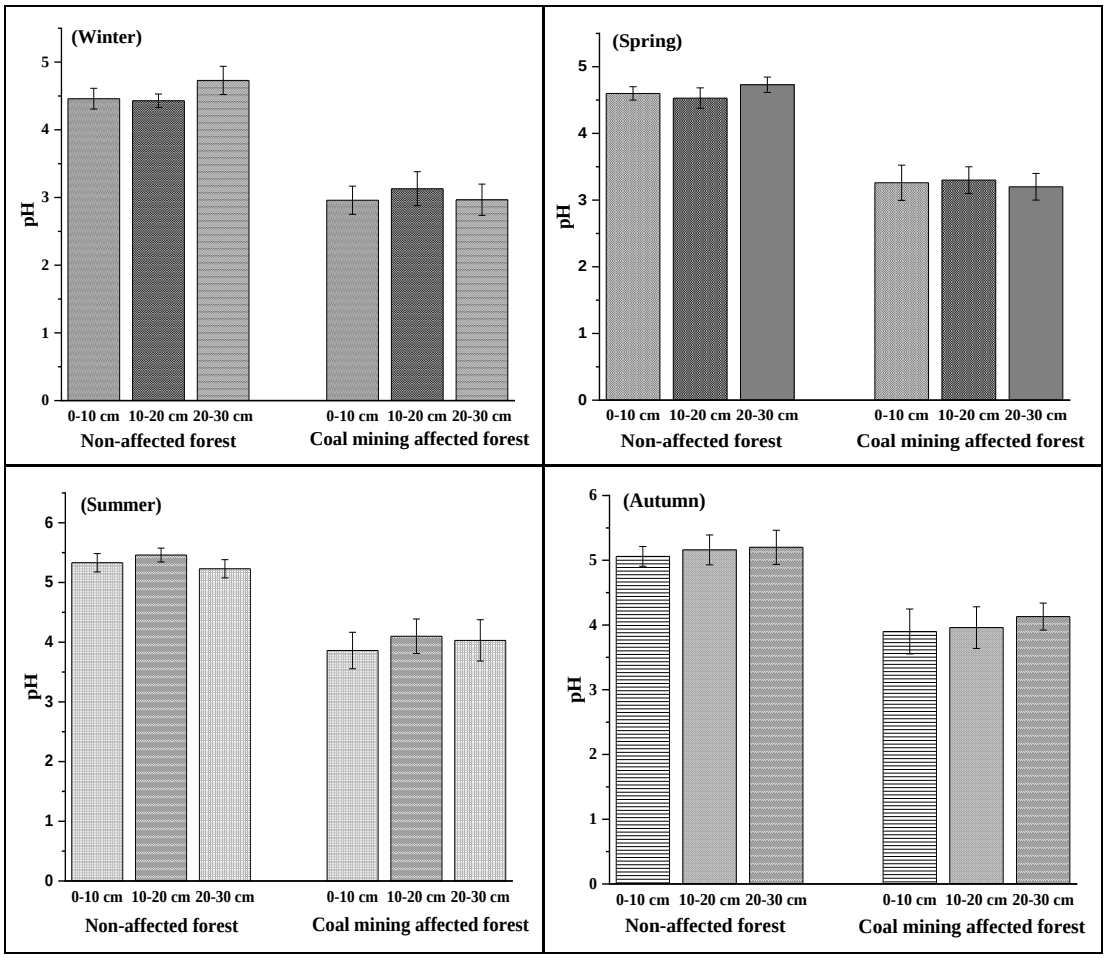


Fig. 4.11: Seasonal variation of pH across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Total Nitrogen (%)

In CMAF, mean soil TN was recorded maximum at 0-10 cm and minimum at 20-30 cm soil depth during autumn (0.96±0.03%) and spring (0.75±0.05%) respectively **(Fig. 4.12)**. Whereas in NAF, the soil depth 0-10 cm content the highest total nitrogen during autumn (1.92±0.03%) while the lowest concentration was detected from 20-30 cm during winter (1.59±0.08%). A seasonal significant difference was estimated from CMAF (F = 4.72; p = .035) while there was no significant difference at the $p < 0.05$ level for NAF.

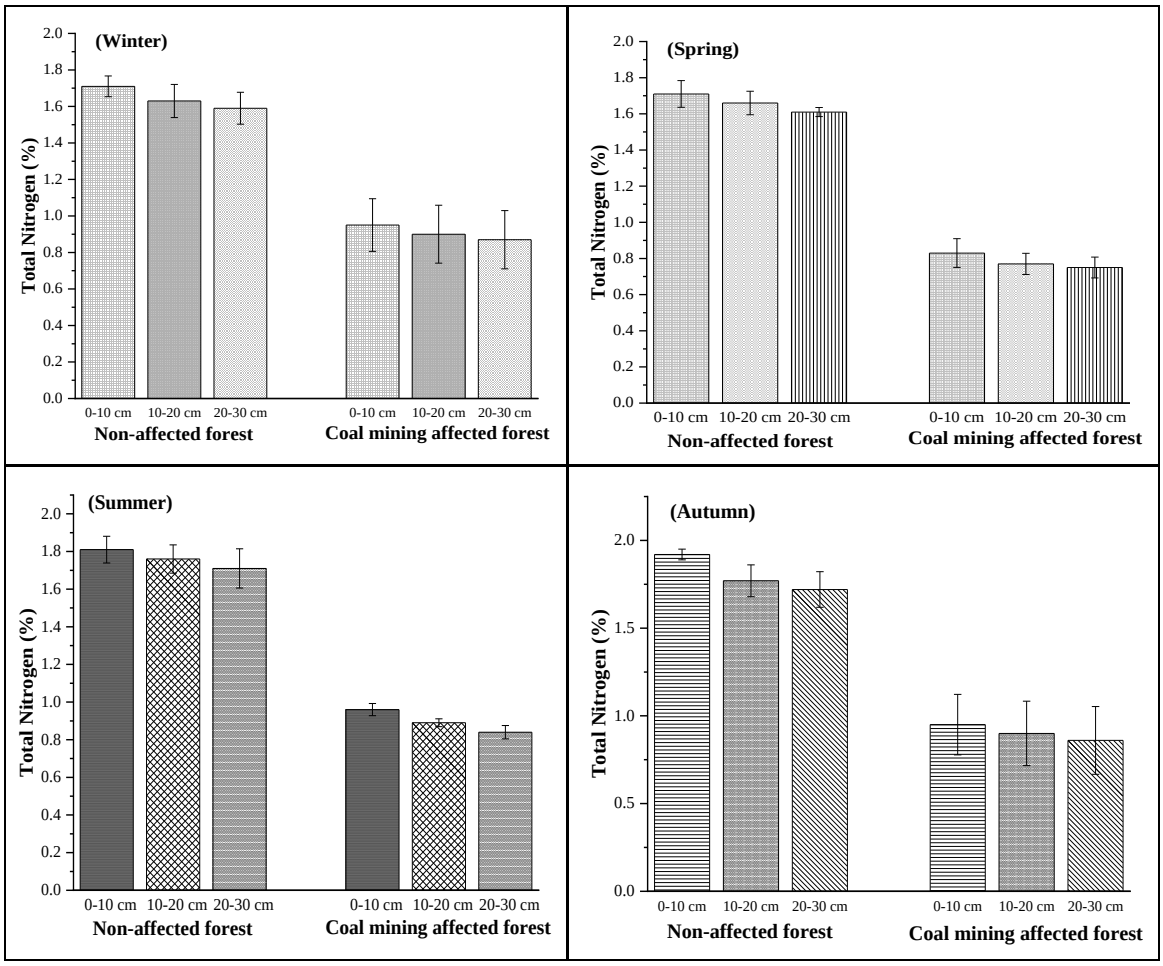


Fig. 4.12: Seasonal variation of Total Nitrogen (%) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Available Nitrogen (Kg/ha)

Maximum available nitrogen was detected during summer (105.96±12.99 Kg/ha) at 0-10 cm soil layer and minimum was recorded during winter (59.1±8.40 Kg/ha) at 20-30 cm from CMAF **(Fig. 4.13)**. Analysis of variance for available nitrogen in CMAF at $p < 0.05$ difference level was tenable between seasons. In NAF maximum mean available nitrogen was recorded in soil depth 0-10 cm during autumn (202.6±9.59 Kg/ha) and minimum in spring (29.30±1.55 Kg/ha) at 20-30 cm while a seasonal significant difference ($F = 27.16$, $p < .001$) was recorded at the $p < 0.05$ level.

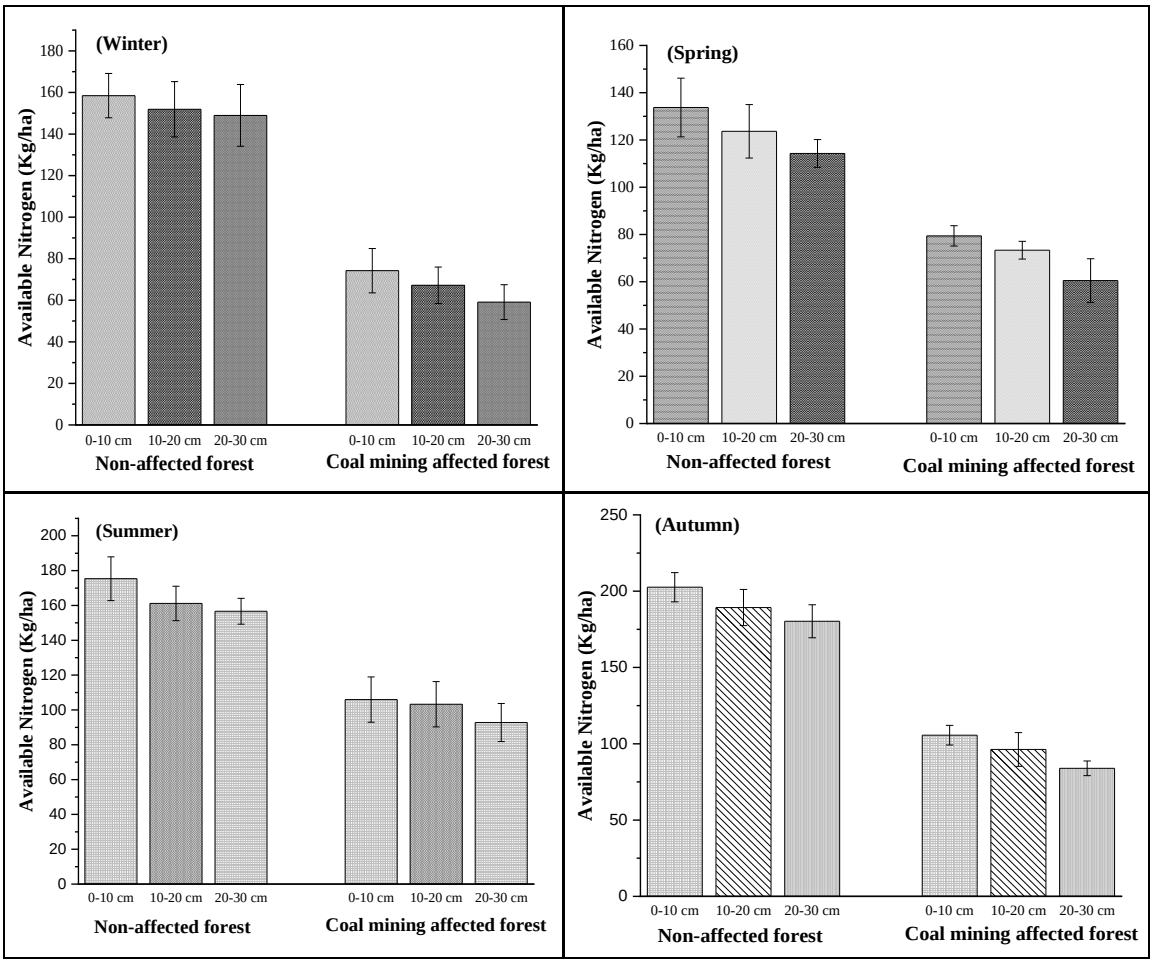


Fig. 4.13: Seasonal variation of Available Nitrogen (Kg/ha) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Potassium (Kg/ha)

Graphical **Fig. 4.14** shows that in the disturbed forest CMAF, the potassium content was significantly different ($F = 6.37$, $p < 0.001$) between seasons with the maximum value was recorded at 0-10 cm soil depth during autumn (178.43±8.25 Kg/ha) and minimum at 20-30 cm during winter (143.4±6.36 Kg/ha). Mean potassium in NAF was highest in autumn (272.46±9.20 Kg/ha) at 0-10 cm soil depth and lowest in winter (237.33±11.71 Kg/ha) at 20-30 cm with a statistically significant difference ($F = 15.45$, $p < .001$) between the seasons.

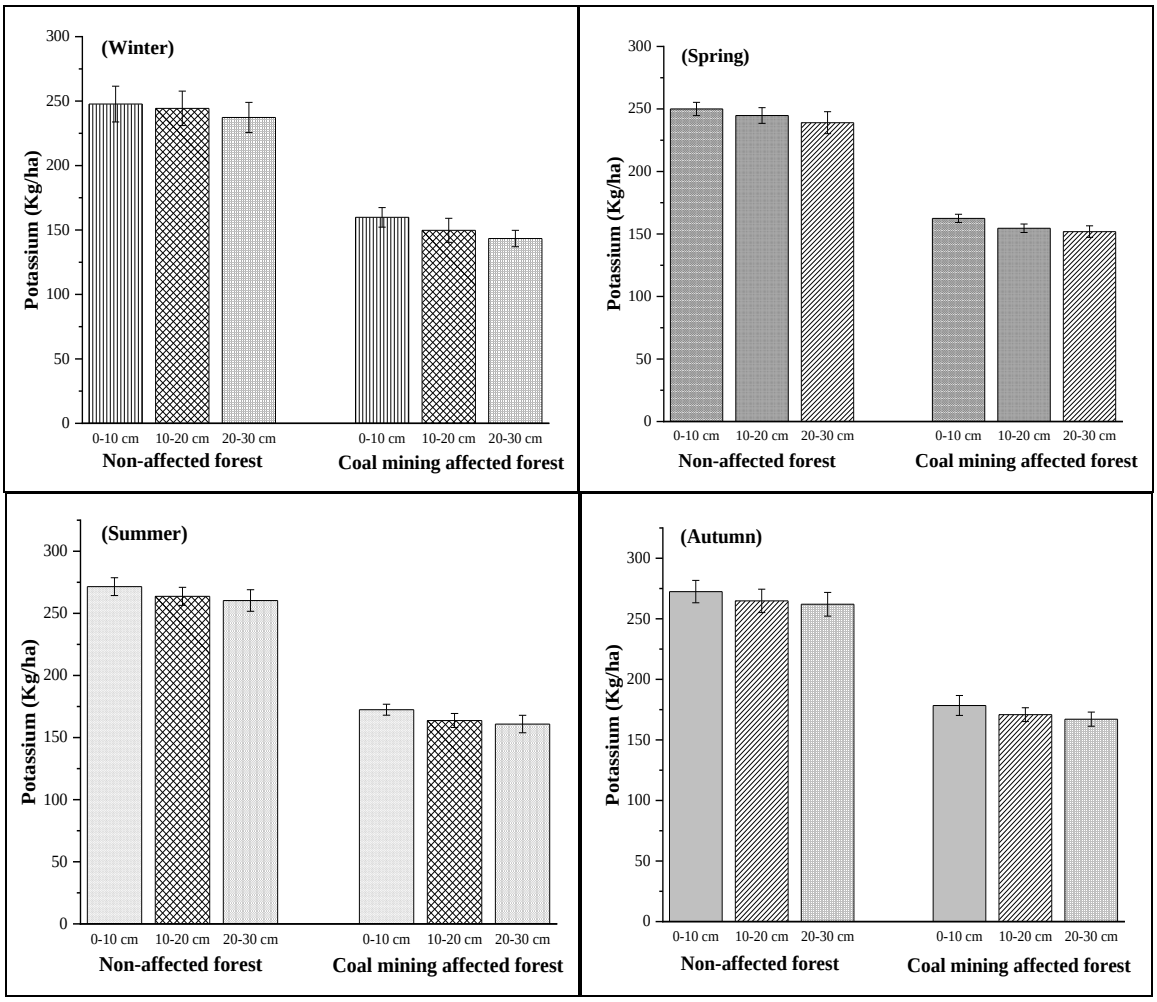


Fig. 4.14: Seasonal variation of Potassium (kg/ha) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

Phosphorus (Kg/ha)

In CMAF, mean phosphorus was recorded maximum at 0-10 cm and minimum at 20-30 cm soil depth during summer (8.3±1.27 Kg/ha) and winter (5.53±0.30 Kg/ha) respectively. Whereas in NAF, the soil depth 10-20 cm exhibits the highest phosphorus value during summer (10.53±0.61 Kg/ha) while the lowest concentration was detected from 20-30 cm soil layer during winter (6.93±0.23 Kg/ha) as presented in **Fig. 4.15**. Soil nutrient parameter phosphorus was significant in CMAF ($F = 21.6$, $p < .001$) and NAF ($F = 45.48$, $p < .001$) at the $p < 0.05$ level.

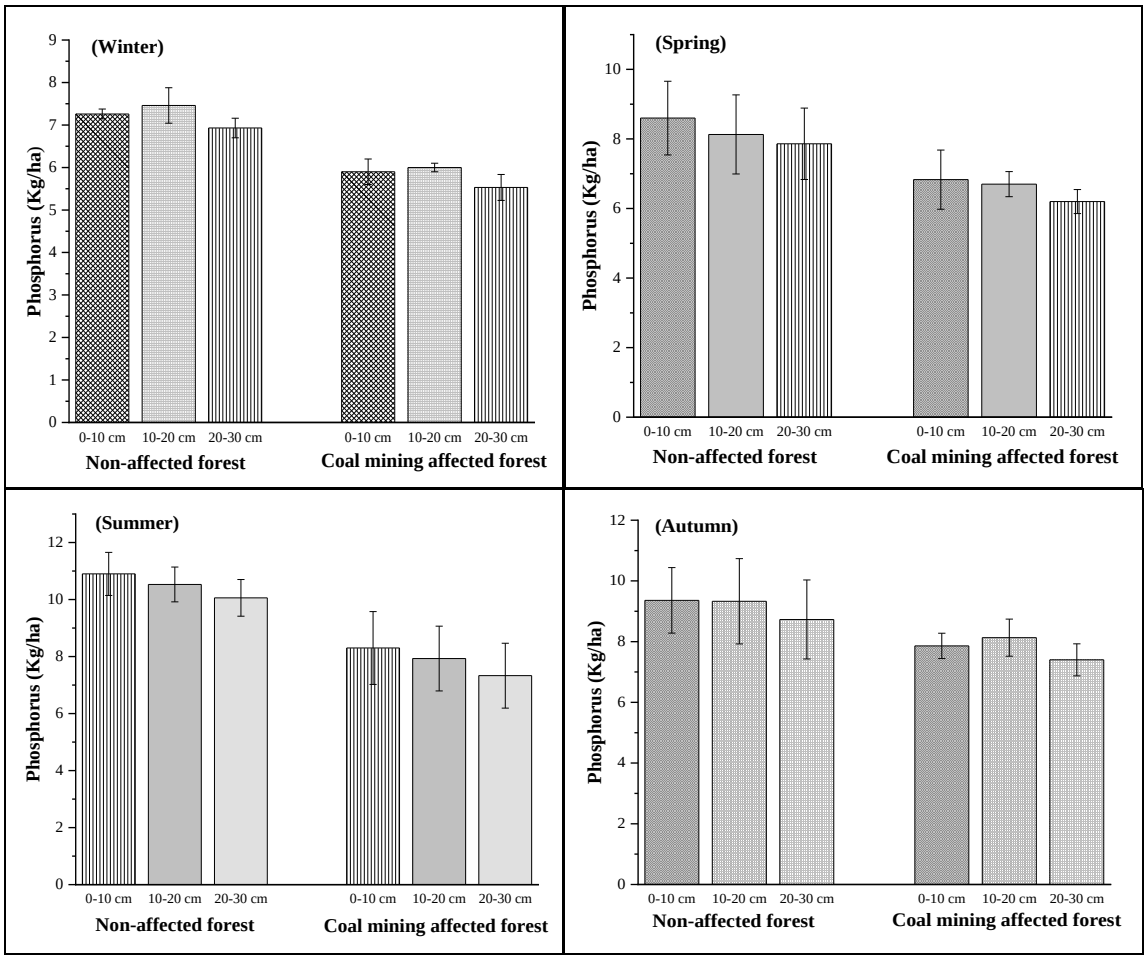


Fig. 4.15: Seasonal variation of phosphorus (kg/ha) across the vertical depth (0-10, 10-20 and 20-30 cm) in the CMAF and NAF soil

4.2.3 Correlations among the soil physicochemical parameters

The Pearson's correlation coefficient values of CMAF and NAF soil properties are presented in **Table 4.2** and **Table 4.3** respectively. In CMAF, clay was significant with silt (r = -0.776), sand (r = -0.950) and soil porosity (r = +0.732) at the $p < 0.01$ level. Sand was negatively correlated with soil porosity (r = -0.757) while the physical soil parameter, bulk density was highly negatively significant with soil porosity (r = -0.889), pH (r = -0.676), soil temperature (r = -0.724), soil moisture (r = -0.720), CEC (r = -0.862), total nitrogen (r = -0.587), available nitrogen (r = -0.815), potassium (r = -0.955) and phosphorus (r = -0.798). Electrical conductivity was insignificant with other variables at the two tailed level of correlation. On the otherhand, soil porosity was positively correlated with CEC (r = 0.841)

Table 4.2: Correlation status among the soil physicochemical parameters in CMAF

Parameters	Clay	Silt	Sand	BD	EC	SP	pH	SOC	Temp	SM	CEC	TN	AN	K	P
Clay	1	-.776**	-.950**	-.472	-.315	.732**	-.252	.515	-.216	-.231	.411	.212	.004	.332	-.027
Silt		1	.561	.119	.528	-.393	.372	-.331	.368	.425	-.075	-.094	.210	.065	.275
Sand			1	.538	.105	-.757**	.165	-.495	.134	.117	-.498	-.159	-.090	-.447	-.097
BD				1	-.124	-.889**	-.676*	-.456	-.724**	-.720**	-.862**	-.587*	-.815**	-.955**	-.798**
EC					1	.017	.434	.045	.392	.526	.190	-.279	.493	.341	.562
SP						1	.388	.548	.475	.441	.841**	.471	.606*	.842**	.605*
pH							1	.259	.963**	.935**	.711**	.224	.841**	.742**	.902**
OC								1	.225	.167	.586*	-.049	.278	.471	.249
Temp									1	.972**	.703*	.410	.908**	.810**	.923**
SM										1	.625*	.438	.956**	.823**	.944**
CEC											1	.177	.652*	.856**	.772**
TN												1	.550	.523	.338
AN													1	.894**	.941**
K														1	.875**
P															1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

and nutrient parameters such as available nitrogen (r = 0.606), potassium (r = 0.842) and phosphorus (r = 0.605). At the $p < 0.01$ level, pH was profoundly correlated positively with various soil variables including soil temperature (r = 0.963), soil moisture (r = 0.935), CEC (r = 0.711), available nitrogen (r = 0.841), potassium (r = 0.742) and phosphorus (r = 0.902). Soil OC was significantly correlated with CEC (r = 0.586) at the $p < 0.05$. A positive correlation was observed for soil temperature with soil moisture (r = 0.972), CEC (r = 0.703), available nitrogen (r = 0.908), potassium (r = 0.810) and phosphorus (r = 0.923). The parameter CEC (r = 0.625), available nitrogen (r = 0.956), potassium (r = 0.823) and phosphorus (r = 0.944) showed a highly positive correlation with soil moisture. CEC was positively significant with nutrient parameters like available nitrogen (r = 0.652), potassium (r = 0.856) and phosphorus (r = 0.772). At $p < 0.01$ level, available nitrogen presented a significant correlation with potassium (r = 0.894), phosphorus (r = 0.941) while potassium was significant with phosphorus (r = 0.875).

At NAF, the soil texture variable clay was negatively significant with sand (r = -0.837), bulk density (r = -0.777), soil porosity (r = -0.796) and positively correlated with OC (r = 0.734), soil moisture (r = 0.623), cation exchange capacity (r = 0.811), total nitrogen (r = 0.882), available nitrogen (r = 0.624) including potassium (r = -0.687). As observed in $p < 0.05$ level, silt was positively significant with pH (r = 0.668) and soil temperature (r = 0.646). The correlation status shows that sand was significant with bulk density (r = 0.934), soil porosity (r = -0.971), OC (r = -0.876), soil temperature (r = -0.706), soil moisture (r = -0.666), CEC (r = -0.843), total nitrogen (r = -0.838), available nitrogen (r = -0.720) and potassium (r = -0.807). Among the soil parameters, bulk density recorded the highest negative correlation with maximum variables including soil porosity (r = -0.925), pH (r = -0.712), OC (r = -0.734), soil temperature (r = -0.877), soil moisture (r = -0.855), CEC (r = -0.662), total nitrogen (r = -0.872), available nitrogen (r = -0.718), potassium (r = -0.914) and phosphorus (r = -0.752). Electrical conductivity was insignificant with other soil variables at the two tailed level of correlation. Soil porosity was highly correlated with soil temperature (r = 0.738), soil moisture (r = 0.646), CEC (r = 0.839), total nitrogen (r = 0.817), available nitrogen (r = 0.780) and potassium (r = 0.790). Among the parameters, pH recorded the highest positive correlation with soil temperature (r = 0.940), soil moisture (r = 0.842), total

Table 4.3: Correlation status among the soil physicochemical parameters in NAF

Parameters	Clay	Silt	Sand	BD	EC	SP	pH	SOC	Temp	SM	CEC	TN	AN	K	P
Clay	1	.007	-.837**	-.777**	.536	.796**	.258	.734**	.486	.623*	.811**	.882**	.624*	.687*	.418
Silt		1	-.388	-.447	-.099	.411	.668*	.278	.646*	.391	.047	.226	.514	.517	.466
Sand			1	.934**	-.556	-.971**	-.479	-.878**	-.706*	-.666*	-.843**	-.838**	-.720**	-.807**	-.519
BD				1	-.516	-.925**	-.712**	-.734**	-.877**	-.855**	-.662*	-.872**	-.718**	-.914**	-.752**
EC					1	.431	.078	.394	.186	.355	.508	.357	-.124	.269	.353
SP						1	.524	.900**	.738**	.646*	.839**	.817**	.780**	.790**	.473
pH							1	.194	.940**	.842**	.024	.580*	.587*	.806**	.872**
OC								1	.449	.331	.930**	.592*	.620*	.506	.121
Temp									1	.914**	.277	.759**	.742**	.931**	.874**
SM										1	.250	.854**	.611*	.931**	.947**
CEC											1	.613*	.527	.428	.036
TN												1	.792**	.917**	.689*
AN													1	.822**	.462
K														1	.858**
P															1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

nitrogen (r = 0.580), available nitrogen (r = 0.587), potassium (r = 0.806) and phosphorus (r = 0.872). At the $p < 0.05$, soil temperature was positively significant with soil moisture (r = 0.914), total nitrogen (r = 0.759), available nitrogen (r = 0.742), potassium (r = 0.931), phosphorus (r = 0.874). OC was positively correlated with parameters like CEC (r = 0.930), total nitrogen (r = 0.592) and available nitrogen (r = 0.620). A positive correlation was observed between soil moisture and nutrient parameters such as total nitrogen (r = 0.854), available nitrogen (r = 0.611), potassium (r = 0.931) and potassium (r = 0.947). CEC was positively correlated with total nitrogen (r = 0.613) while inherent good soil parameter total nitrogen was highly significant with available nitrogen (r = 0.792), potassium (r = 0.917) and phosphorus (r = 0.689). In $p < 0.01$ level of correlation, available nitrogen was positively significant with potassium (r = 0.822) while potassium was significant with phosphorus (r = 0.858).

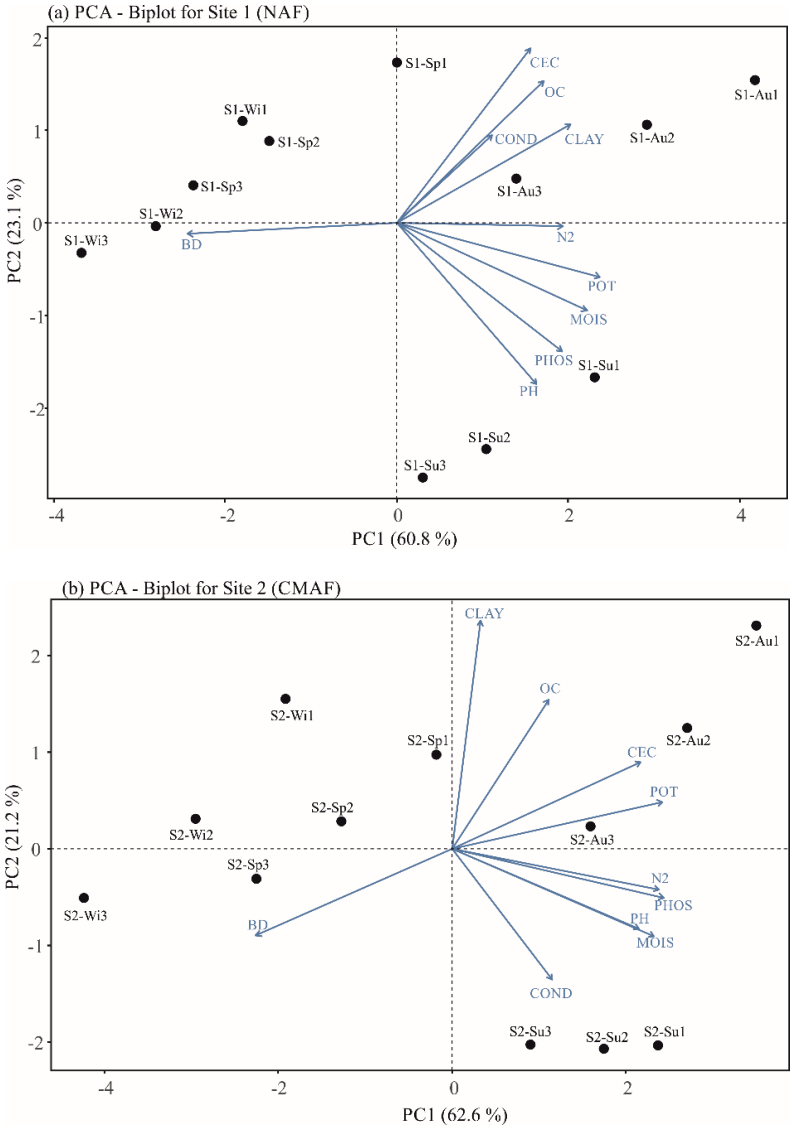
4.2.4 Soil Quality Index

PCA of statistically significant variables are presented in **Table 4.4**.

Table 4.4: Principle component analysis result of significant soil quality indicators considered for minimum data set (MDS)

Forest	NAF			CMAF	
Principal component	PC-1	PC-2	PC-3	PC-1	PC-2
Eigen value	6.08	2.31	1.16	6.25	2.11
% Variance	44	38	13	55	29
% Cumulative variance	44	82	95	55	84
Factor loadings					
CEC	-0.03	***0.97***	0.22	0.62	0.69
AN	0.55	0.67	-0.46	*0.92*	0.26
OC	0.1	*0.94*	0.07	0.13	0.74
pH	*0.95*	-0.05	-0.16	*0.91*	0.07
SM	*0.94*	0.26	0.16	***0.98***	0.07
Clay	0.34	0.81	0.28	-0.28	***0.9***
EC	0.15	0.32	***0.93***	0.64	-0.29
BD	-0.71	-0.65	-0.21	-0.65	-0.7
K	0.87	0.48	-0.01	0.78	0.59
P	***0.97***	0.02	0.22	*0.96*	0.24

PC- principal components; italicized factor loadings are considered highly weighted; Bold italicized factors are identified indicators, retained in the MDS.



*S1- Non-affected forest, S2- Coal mining affected forest, Wi1- winter (0-10 cm), Wi2- winter (10-20 cm), Wi3- winter (20-30 cm), Sp1- spring (0-10 cm), Sp2- spring (10-20 cm), Sp3- spring (20-30 cm), Su1- summer (0-10 cm), Su2- summer (10-20 cm), Su3- summer (20-30 cm), Au1- autumn (0-10 cm), Au2- autumn (10-20 cm), Au3- autumn (20-30 cm).

*BD- bulk density, OC- soil organic carbon, CEC- cation exchange capacity, POT- potassium, N2- available nitrogen, PHOS- phosphorus, MOIS- moisture, COND- electrical conductivity

Fig. 4.16: Biplots of Principal component analysis (PCA) based on soil physicochemical parameters used for Soil Quality Index (SQI) in determining forest soil status of a) NAF and b) CMAF

The normalized varimax rotation of PCA corresponding to NAF and CMAF explained 95% and 84% of the total data variance. PCA results were visualized using biplots representing dominant principal components, individual samples and variables **(Fig. 4.16)**. In NAF, Phosphorus of PC1, CEC of PC2 and EC of PC3 were selected for the MDS while in CMAF, soil moisture of PC1 and clay of PC2 were retained in the MDS. Highest factor loading for NAF PC1 is 0.97 (phosphorus), PC2 is 0.97 (CEC) and PC3 is 0.93 (EC); whereas for CMAF, the maximum factor loading for PC1 is 0.98 (soil moisture) and PC2 is 0.90 (clay). After scoring and weights assigned to the indicators, the seasonal SQI was calculated using the integrated quality index equations. The value of NAF and CMAF seasonal SQI are ranked as autumn>summer>spring>winter for additive and weighted SQI except CMAF weighted SQI which was categorized as summer>autumn>spring>winter **(Fig. 4.17)**.

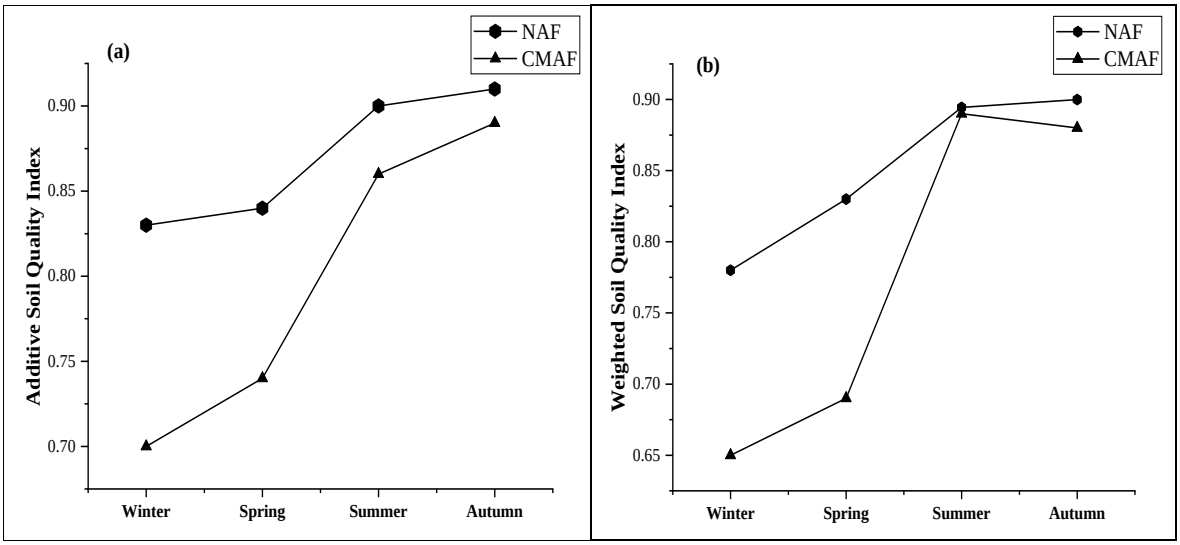


Fig. 4.17: Seasonal qualitative soil status of CMAF and NAF (a) Additive SQI b) Weighted SQI

The additive soil quality index recorded a value of 0.83, 0.84, 0.9**,** 0.91 in NAF and 0.70, 0.74, 0.86, 0.89 in CMAF for winter, spring, summer and autumn. Seasonally, the soil quality rating values for weighted SQI are 0.78, 0.83, 0.89, 0.90 in NAF and 0.65, 0.69, 0.89, 0.88 in CMAF for winter, spring, summer and autumn respectively **(Table 4.5)**.

Table 4.5: Seasonal soil quality index mean value (± SD) from the three layers soil depth

Seasons	Additive SQI		Weighted SQI	
	NAF	CMAF	NAF	CMAF
Winter	0.83±0.01	0.70±0.05	0.78±0.02	0.65±0.03
Spring	0.84±0.02	0.74±0.05	0.83±0.03	0.69±0.04
Summer	0.9±0.01	0.86±0.04	0.89±0.02	0.89±0.03
Autumn	0.91±0.01	0.89±0.04	0.90±0.02	0.88±0.02

4.3 DISCUSSION

4.3.1 Seasonal changes in soil parameters

The analysis of soil physicochemical variance showed that in both the forest all the soil parameters differed seasonally except for silt, clay, TN, EC in NAF and soil porosity, sand in CMAF. This could be due to the environmental factors like rainfall, atmospheric humidity, atmospheric temperature, wind, erosion, thermal regulation, nutrient cycles and biotic factors such as organic matter from litter fall, etc. (Mirza and Patil, 2020) prevailing in the region as these factors plays a crucial role in the cumulative function of the soil at varying seasons. According to the investigation from NAF and CMAF, the summer and autumn months have a slight increase in CEC, OC, EC, soil moisture including the nutrient parameters of soil compared to the dry winter and spring months. The difference in soil properties is generally due to the accessible rainfall as well as the enhanced mineralization rate (Grogan *et al.*, 2003; Ahmad *et al.*, 2011). In addition, such results can be reasoned with the frequent availability of soil moisture, warmer temperature accompanied by higher organic matter and microbial activities in the soil during the rainy summer months and post monsoon autumn seasons of the year in the study area; similar trends were reported by Leishangthem and Singh (2021) in Nagaland tropical forest soil. However, with no such occurrences during winter months the bulk density and soil porosity increases in all soil depth due to soil compaction and lack of organic matter, soil acidity also increases because of the limited rainfall, along with the gradual disappearance of OC and soil nutrients (Omer *et al.*, 2018). Thereby, seasonal environmental factors exquisitely exhibit the conducive outcome in the variability of soil characteristics at the northern tropical forest of Changki.

4.3.1 Soil physical characteristics

Soil texture

Soil texture is known to influence successful vegetation, as well as water holding capacity, bulk density, soil moisture availability and nutrient content, thereby, establishing the preliminary soil quality status of the forests (Semy *et al*., 2022). It also represents the relative content of different-sized particles like sand, silt and clay. As observed, the texture classifications of the two forest soils are categorized as sandy clay loamy soil which was in conformity with Mishra *et al*. (2019) in Nagaland tropical forest soil. The textural analysis of soil samples exhibit that the CMAF soils contains considerably an extended amount of sand particles and reflects that the greater percentage of sand content in CMAF increases aeration of soil which has restricted the presence of soil moisture. In both the sites, soil physical parameter clay decreases with an increase in soil depth. Clay was considerably greater in NAF throughout the seasons, and it serves as a medium for organic matter and water retention capacity, impacting nutrient composition through sequestration and stabilization in the undisturbed forest, resulting in increased soil fertility. However, there were no prominent differences between the seasonal silt content for NAF and CMAF. The reason for higher percentage of coarse textured soil in CMAF, as found in our study, appears to be caused by the weathering of rocks, pebbles and stones from coal mine waste dumps, erosion and surface runoffs that reached the disturbed forest.

Bulk Density

Bulk density is another important property for gaseous exchange, such as high bulk density would pose restriction to the growth of deeper rooted plants and may be one of the reasons of cessation of plant growth (Ghose, 2004). According to Brzezinska *et al*. (2011), the seasonal recorded range of BD in NAF (1.09 - 1.43 gcm^{-3}) and CMAF (1.32 - 1.57 gcm^{-3}) are unlikely to have adverse effects on plants. However, higher BD was detected in CMAF due to compaction of forest soil caused by the landuse pattern and machinery activities including low organic matter and soil moisture.

Soil Porosity

The abundance of organic substances corresponds to the overall improvement in porosity in native soil (Gairola and Soni, 2010); apparently, the biomass from vegetation at NAF is higher than CMAF impacting the soil porosity as well. Significantly, in both the

sites, the decrease of soil macropore volume in winter can be a result of soil compaction due to the decline of soil organic residues in the forest (Yimer, 2008) while the increase in soil porosity during autumn and summer seasons can be attributed to organic matter from forest litters (Gairola and Soni, 2010). On average, soil porosity was higher at NAF in the upper layer at all seasons and decreases with an increase in soil depth. The CMAF and NAF forest subsurface soil layers have reduced organic matter, aggregation and root penetration compared to surface layers and therefore contains less pore space which was in conformity with Muhammad *et al*. (2011).

Soil Moisture

In both the forests, soil moisture was higher during the rainy summer months and reduced with coming of the dry winter seasons. Hence, this data interpretation showed a direct relation of soil moisture with precipitation and its variability with seasons. Such result was evident with Mohapatra and Goswami (2012) where they stated that moisture content in forest soil is more in the rainy season as the soil capillaries (porosity) retain a lot of water from the runoffs. Moreover, the alteration and reduction of the soil volume macropores in disturbed forest often have negative impact on soil infiltration capacity and its moisture content which is reflected in CMAF soils. In addition, low soil moisture in CMAF is due to higher accumulation of sand, stone and lack of organic substances while higher organic plant matters and finer soil texture in NAF retains the soil moisture. CMAF site has more sunlight exposed area with intermittent patches of land that could have decreased soil moisture compared to NAF which was in conformity with Zaimes *et al*. (2010). Similarly, Dejun *et al*. (2016) proved that the average concentration of forest soil moisture content was reduced by mining effects, offering a quantitative evidence of coal mining impact on soil moisture.

Soil Temperature

The temperature of the soil is measured as a function of thermal flux in the soil as well as heat exchanges between the soil and its environments (Elias *et al.*, 2004). It varies seasonally, monthly, daily possibly due to variations in solar radiation and energy fluctuation passing through the soil surface, as well as the rate of organic matter decomposition and mineralization of various organic components (Onwuka, 2016). There was a significant seasonal changes in soil temperature. In both the forest, summer season recorded the maximum soil temperature due to the influence of higher atmospheric temperature on the

forest, whereas, with the coming of the cold winter months the soil temperature gradually drops. However, higher seasonal mean soil temperature in CMAF is due to less forest canopy cover, less moisture and direct exposure of sunlight on the soil surface while the rich vegetation and moisture content in NAF counters the intensification of soil temperature upto some extent. Depth wise, in both the sites soil temperature decreases with an increase in soil depth as the subsurface layers are less prone to sun exposure which corresponds to Leishangthem and Singh (2021) on their tropical forest soil research.

4.3.2 Soil chemical characteristics

Electrical Conductivity

Although EC does not directly detect individual ions or salt molecules, it has been linked to nitrates, potassium, sodium, chloride, sulphate, and ammonium concentrations. According to Lal (1994), electrical conductivity below 200 indicates low salt level, 200-500 shows acceptable salt level for plants, and > 500 indicates high salt level, which may have negative effects on vegetation. Observed range of mean EC in CMAF (265.37 – 334.70 µS cm^{-1}) and NAF (214.57 – 237.67 µS cm^{-1}) were under optimum level. However, in comparison to NAF, EC was detected higher in CMAF throughout the four seasons. In anthropogenic disturbed forest like CMAF, during the monsoon periods, soluble salts from coal waste and rocks are flushed or precipitated on the soil surface which includes salts of various chemicals, dissolved solids, trace metals, colloidal substances, ions and thus enhances soil electrical conductivity (Vishwakarma *et al.*, 2020).

pH

pH was acidic in the northern tropical NAF as well as in CMAF soil which corresponds to former Nagaland tropical forest soil studies by Semy *et al*. (2021) and Konthoujam *et al.* (2021). The leaching rate of forest wastes, soil nature, chemical composition, decomposition of organic matter producing organic acids, etc. could be accountable for the forest soil acidity (Goswami and Sarma, 2007). Nonetheless, CMAF soil was comparatively more acidic than NAF due to the coal spoils that are rich in pyrites, sulphates and toxic metals which on oxidation can acidify soil pH of the disturbed forest (Upadhyay *et al*., 2016). The acidic nature of the soil in coal mining affected forest is also reported by Rai *et al*. (2011).

Soil Organic Carbon

Soil organic carbon is an inherent good quality of soil as it is known to accelerate the rejuvenating properties of soil. In natural forest, plant litter, decaying stems and decomposing roots are the main sources of soil organic carbon and such formation is more prevalent in NAF than in CMAF because of the favorable environmental conditions for microbial activity in the process of organic matter breakdown (Yadav *et al*., 2015). Thus, the unmined site NAF supports greater OC content and vegetation growth. Such trend of results was also reported by Vishwakarma *et al.* (2020) in the south eastern Indian coal fields. Soil OC as categorized by Lal (1994) and Feiza *et al*. (2011): 2-3% - moderate limitation, SOC > 3.0% - slight to no limitation. In CMAF soil, all the seasons have low mean value of OC while NAF has varied distribution of low to moderate OC. As observed in the study, organic matter decreases with soil depth which correlates to OC (Barzani *et al*., 2011).

Cation Exchange Capacity

The CEC of a soil determines the number of positively charged ions that the soil can hold and can have a significant effect on the fertility management of the soil. Since a soil's CEC is attributed from the clay and organic matter present (Mengel, 1993), CMAF soil with more or less sandy type and lesser clay content, holds fewer CEC than NAF soils which accounts for higher organic matter, nutrient parameters and clay percentage throughout the seasons in all three soil depth.

Soil Nutrient Parameters

The mean nutrient concentrations of TN, AN, P and K in CMAF and NAF followed a decreasing trend in the subsequent layers. Since higher coarse-textured soils (sand) content show a slow process of nutrient accumulation (Prescott *et al*., 2000) and are not very good accumulator of nutrients as compared to fine-textured soils (silt + clay). Hence, a higher percentage of fine textured soil also leads to a higher accumulation of total nitrogen, available nitrogen, phosphorus and potassium in NAF. Although there are positive nutrient impacts on soil characteristic in CMAF, it would not show an enhanced soil quality like the undisturbed NAF (Guo *et al*., 2018). The soil nutrient such as available nitrogen, phosphorus and potassium are conducive to the accumulation of the increase in soil organic matter (Six *et al*., 2002). Such trend was propitious in the NAF compared to CMAF as the substantial nutrient composition and organic carbon were significantly higher in the undisturbed forest.

In addition, the observable amount of organic plant matter, soil moisture and CEC were relatively low in the coal mine disturbed forest which might have induced low nutrient composition in CMAF. Rai *et al*. (2010) stated that lower values of nutrient elements in mining affected forest site was due to lower rates of mineralization in the waste dump entering the forest and also due to loss of organic carbon which affects nitrogen and nitrogen fixing microorganisms. Depth wise, the surface soil (0-10 cm depth) has maximum nutrient concentration and decreases with depth in all the seasons at both the forest. A similar trend was reported by Lkr *et al*., (2020b).

4.3.3 Correlation status among the soil variables

The recorded correlation analysis of NAF and CMAF soil shows similar trend of results. Soil temperature have significant positive correlation with the soil nutrient properties; this can be reasoned with Gahoonia and Nielsen (2003) where they stated that, soils temperatures have high influence over nutrient parameters because the release of nutrients from organic material is reduced by low temperature. As observed in both the sites, a gradual increase in soil temperature facilitates the decomposition of plant organic matter and accelerate the accumulation of soil available nutrients (Conant *et al*., 2011). The physical parameter sand tends to have a negative correlation with all the nutrient parameters which was in conformity with Leishangthem and Singh (2021). On the otherhand, clay had a positive significant correlation with organic carbon, total nitrogen, available nitrogen and potassium. The bulk density of soils increased with decreasing content of moisture in soil which corresponds to the work of Urik and Nemcek (2012). Sandy soils have a limited capacity to stabilize organic compounds on mineral surfaces compared with clay, which affects the capacity, magnitude and rate of soil organic carbon storage (Feng *et al.*, 2013). CMAF has coarse textured soils (sand), which adsorb lesser quantities of cations and this implication hinders nutrient availability and its correlations. Whereas, NAF has higher percentage of finer soil texture (silt + clay) and hence, induced more positive affinity for the parameters such as soil moisture, CEC, TN, AN, P and K which are inherently good soil quality indicators. The correlation of organic carbon, available nitrogen, phosphorus and potassium with other soil parameters was similar to the findings of Adhikari and Bhattacharyya (2015) where they obtained correlations existing among SOC and plant

nutrients. Considerably, the relation status among the nutrient parameters depicts a close proximity over one another due to their positive associations influenced by the abiotic and biotic conditions prevailing in the area.

4.3.4 Soil quality status

Determining the soil quality status around the mining areas and the impacts of anthropogenic activities on the soil chemistry is a comparatively complicated work due to a very high heterogeneity of contaminant concentrations in mine soils and also the interruption of the physical properties of soil horizons (Hudson *et al*., 1997). This however is minimized by selecting distinctive soil variables most suitable for evaluating soil quality and presenting it in terms of SQI value (Mishra *et al*., 2019). In both the sites, the additive SQI presented higher soil quality than the weighted SQI, such trend of result was reported by Vasu *et al*. (2016) on their study of SQI in a semi-arid Deccan plateau. Comparative seasonal soil quality status, on the other hand, reveals that NAF has a superior SQI grade than CMAF. Liu *et al*. (2014) determined that SQI values on paddy soils were maximum in high productivity paddy soil (0.82) and minimum in low productivity paddy soil (0.50). Their research demonstrated that, higher the SQI, better the soil quality. Autumn can thus be tagged with the "highest soil productivity rate" and as the "most productive" season in the NAF and CMAF, followed by summer, spring, and winter. Moreover, according to Mukhopadhyay *et al*. (2015), vegetation governs the SQI of an area as such, NAF with greater vegetation diversity administered better soil quality. Comparative soil composition also shows that NAF has greater amounts of CEC, AN, P, SOC, soil moisture, clay, and K all of which are indicators of superior soil quality. The finding reveals NAF soil is supported by thick natural vegetation cover that provides essential organic matter in supporting the rejuvenating process of the soil and its nutrient sources. Seasonally, the climatic variation in both the forest may have played a role in influencing the changes in soil properties through its aggregate effects. Nonetheless, deforestation, logging, soil erosion, stone quarries and coal mining operations, all have an impact on the soil quality at CMAF site. According to the overall soil profile, the deteriorating soil quality in CMAF is defined by significantly low pH, reduced nutrients content and limited soil organic carbon, which was consistent with earlier reports on coal mining-affected forest soil (Sarma, 2002; Rai *et al*., 2011). Furthermore, the finding

reflects the cumulative effects of coal mining activities on the soil properties and it is evident that the dumping of overburden spoils into forest areas has collaterally damaged the environmental variables.

4.4. SUMMARY AND CONCLUSION

Changki coal mine is an asset for Nagaland it has been playing a vital role for fulfilling the increasing demand of energy. But the lack of poor infrastructure for coal mining regulation and inadequate treatment of mine drainages, the activity is altering the surrounding soil to a large extent. Healthy soils are essential for terrestrial ecosystems to remain intact or recover from disturbances, and soil degradation is a source of concern for human, animal and plant health. From the soil analysis it has been identified that several important physicochemical parameters that is necessary for plant growth are reduced in the CMAF. Parameters such as soil organic carbon, cation exchange capacity, soil moisture, clay and silt content, total nitrogen, available nitrogen, phosphorus and potassium which are the inherent good soil quality indicators are prominently greater in the NAF compared to CMAF. While the presence of higher coarse sand content and bulk density in the disturbed forest represents a deteriorating tropical forest soil structure. The impact of mining on the soil properties was felt even upto 30 cm in depth, suggesting that mining activities can disrupt the natural vegetation.

The additive and weighted SQI illustrated the deteriorated CMAF soil, primarily because of the anthropogenic stresses caused by uncontrolled landfills and dumping of coal mine spoil into the forest area. The parameters P, CEC, EC in the community protected NAF and soil moisture, clay in the disturbed CMAF were selected as minimum data set and represented the sensitive soil indicators. These soil variables played the central role in determining the SQI after normalization and elimination of datas through the principal component analysis. The outcome of the assessed correlation analysis at NAF and CMAF soil reveals a similar tendency among their individual site variables. In both the forest, temperature of the soil has a significantly positive correlation with the nutrient qualities of the soil. The textural soil parameter, sand has a negative association with all of the nutrient properties, whereas clay has a substantial positive correlation with organic carbon, total nitrogen, available nitrogen, and potassium. Moreover, the analysis of variance confirms the

seasonal environmental factors had influenced the spatial soil characteristics such as the nutrient parameters (NPK) including OC, soil temperature and soil moisture in both the forest as majority of the soil variables were significant at the mean difference of $p < 0.05$ level.

The present investigation provides clear evidence that CMAF soil is degraded because of the lack of proper coal waste pile management, unscientific precept, random mining operations and improper disposal of mine water into the forest area. In regards to CMAF impaired soil quality, mitigation management strategies and coal mine-dumping regulations should be formulated and enforced by policymakers. Moreover, the research ascertains that when determining soil quality status in an anthropogenically disturbed forest, the seasonal soil physicochemical parameters should be explicitly included. Because SQI accommodates a variety of soil metrics to indicate soil quality, thus combining them to forecast the influence of variation in soil attributes will improve soil conservation knowledge and preservation accuracy. The current approach used for quantifying forest soil could be considered as a preliminary screening test for administering tropical forest soil in Nagaland which will aid in coal mining pollution control programs including biodiversity reclamation projects for the state.

CHAPTER-5

SPATIO-TEMPORAL VARIATION ON PHYSICOCHEMICAL WATER PARAMETERS AND QUALITY STATUS OF TSURANG RIVER

5.1 INTRODUCTION

Water plays a crucial role in sustaining livelihood and maintaining various sectors of the economy both in the urban and rural areas and the sources of freshwater include lakes, rivers, streams, ponds and rivulets. The water quality of a region has a considerable importance for the reason that these water resources are generally used for multiple purposes such as residential water supplies, agriculture (irrigation), hydroelectric power plants, infrastructure, tourism, recreation, and other suitable means of using water (Venkatramanan *et al*., 2014). However, pollution of water sources caused by various anthropogenic activities has expanded dramatically over time, resulting in a global shortage of potable water in many developing countries. Tiwary (2001), Singh *et al*. (2012), Tambekar *et al.* (2012), Nigam *et al.* (2015) and Sahoo *et al.* (2016) have all reported on the deterioration of water as a result of coal mining activities. Coal mining is regarded as progressive in terms of economic advantages in the current development situation, but it has been proven to be environmentally harmful. Coal produces dust and radiation from excavation to loading and unloading, which has a direct negative influence on the environment, biodiversity and health of the surrounding communities (Chaulya *et al.*, 2011) due to its land-use pattern. As such altering landscape deteriorates water

quality as they influence the flows of energy and material between the terrestrial and aquatic interface (Fausch *et al*., 2010). Water pollution from wastewater disposal is one of the environmental hazards linked to coal mining (Tiwary, 2001), and it impairs the water's rejuvenating ability. Active mining activities cause rampant pollution to both surface and groundwater at an extreme rate. The emission of obnoxious substances compounds such as ash, oil, phosphate, ammonia, urea and acids degrades the surface water quality in mining regions during the early phase (Reza and Singh, 2010). While long term contamination of water through acid mines drainage is the reason behind the low pH which creates hazardous conditions for aquatic life (Swer and Singh, 2004) which eventually escalate various types of pollution and then ultimately render poor water quality. Furthermore, anthropogenic activities such as the dumping of domestic sewage, runoff from agricultural land and unregularized public policy on river maintenance can all contribute to water quality degradation (Yisa and Jimoh, 2010; Shah and Joshi, 2017). The physical, chemical and biological properties of water from any specific place or source can be examined to determine its quality, and it can be classified as fit or unfit for human consumption and other agricultural operations if well-defined criteria are fulfilled (BIS, 2012; ICMR, 1975). Accordingly, the Water Quality Index (WQI) is presented in terms of its suitability. Considering the significance of water in the current scenario, water quality assessment is highlighted as a critical issue, especially as freshwater would become a rare resource in the future (Varol *et al*., 2012).

WQI calculates the overall water quality at a given time and location using a set of characteristics that can be reduced to a single number. It simplifies and logically explains the data by converting the majority of information from many water quality criteria into a value (Semiromi *et al*., 2011). WQI allows comparisons between different sampling points and events, as well as imparts knowledge about the water quality status of specific sampling stations at a predetermined hour (Yogendra and Puttaiah, 2008). Duly, the category of water for its use is appropriately addressed in terms of the water quality index (WQI), which serves as an acceptable and effective means of describing water quality status. Initially, WQI was developed by Horton (1965); however, Brown *et al.* (1970) established a new WQI that is quite similar to Horton's index which has undergone much improved modification. In India, Ramakrishnaiah *et al*. (2009), Chauhan and Singh (2010), Rao *et al.* (2010), Kumar *et al*. (2011), Sharma and Kansal (2011), Balan *et al*. (2012), Singh and Kamal (2014) and Shah and Joshi (2017) have worked on WQI of rivers in different states. WQI studies from Northeastern India, mainly confined

to Assam (Singh *et al*., 2016), Manipur (Bora and Goswami, 2017) and Nagaland (Lkr *et al*., 2020a) have been reported. However, research employing WQI to assess seasonal water quality on rivers affected by coal mine and agricultural operations in this region are still scarce. This lack of understanding is particularly evident in Nagaland, where massive coal mining and cultivations are carried out along the forested mountains and river banks, resulting in forest reduction, landscape alteration, wildlife loss and contamination of drinkable river water.

The Tsurang river, which flows through Assam-Naga foothills, has a significant impact on the delineation of ancestral land between the two states. The Tsurang literally means "Water and many things" in Ao-Chungli dialect is an iconic river that receives considerable attention in regards to its relation with folklore, traditions, irrigations and fulfilling the demands of water shortage to the local community. However, in the last few decades' coal mining activities at Changki and the adjoining villages have drastically changed the forest landscape affecting the river and other water bodies. Large lowland river like the Tsurang river receives effluents from the coal mines and are vulnerable to different forms of anthropogenic landuse pattern. Although, these devastating activities have triggered public concern about the water quality and prompted environmental concerns, so far, no research work has been initiated to check the water quality status. Therefore, the current study aims to evaluate the water physicochemical parameters and generate the overall water quality index (WQI) in order to assess the suitability of water from the Tsurang river.

5.2 RESULTS

The monthly values of the water physicochemical parameters from the three sampling stations of Tsurang river are presented in **Appendix II**. Similarly, analysis of variance (ANOVA) Tukey post-hoc test for each sampling site is shown in **Appendix III**.

5.2.1 Physicochemical parameters and the analysis of variance

Analytical results with permissible limit (BIS/ICMR/WHO) and the descriptive statistics concerning the seventeen physicochemical water parameters from the three sampling stations are presented in **Table 5.1. Table 5.2, 5.3** and **5.4** represent the seasonal physicochemical characteristics of water samples from the three sampling stations of Tsurang river.

Table 5.1: Descriptive statistics of the observed water quality variables with respect to the three sampling stations

Parameter	Winter		Spring		Summer		Autumn		ICMR/BIS /WHO
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	
pH	5.10-6.6	6.19 ±0.11	5.20-6.90	5.95 ±0.10	3.30-4.90	4.04 ±0.05	3.40-4.90	4.34 ±0.19	6.5-8.5
Turbidity	2.63-2.93	2.79 ±0.15	3.43-3.8	3.6 ±0.19	9.06-9.7	9.34 ±0.32	7.47-8.0	7.74 ±0.26	5
WT	17-23	20.33 ±0.33	20-24	21.77 ±0.68	22-24	22.33 ±0.58	20-24	21.33 ±0.33	32
EC	171-194	183.64 ±2.86	170-196.1	185.67 ±8.24	197-249	218.58 ±11.86	171-227	196.48 ±8.79	300
TDS	105-156	125.33 ±12.91	107-163	135.33 ±10.10	138-177	159.55 ±12.21	143-183	161.99 ±15.18	500
TH	108-144	132.22 ±3.78	98-132	115.55 ±5.59	80-124	98.88 ±5.39	76-100	85.10 ±4.07	300
Free CO_2	6.60-15.40	10.02 ±1.52	11-22	14.90 ±1.84	15.40-28.6	21.75 ±4.03	15.40-26.4	20.53 ±1.47	22
TA	175-230	197.22 ±10.18	175-215	194.44 ±8.39	130-180	158.88 ±9.177	120-155	136.66 ±10.92	120
Ca^{2+}	48-70.04	62.67 ±5.01	35.9-70.04	50.18 ±3.92	28.02-58	46.89 ±4.42	32-58	44.15 ±4.55	75
Mg^{2+}	12.10-18.50	16.19 ±1.05	14.6-17.1	15.64 ±0.105	10.7-16.1	12.62 ±1.14	8.7-11.2	10.22 ±0.601	30
DO	6.20-9.20	7.95 ±0.402	6.0-8.0	6.71 ±0.27	4.0-5.40	4.66 ±0.17	5.60-6.80	6.24 ±0.23	5
BOD	3.00-3.80	3.53 ±0.33	2.40-4	3.31 ±0.29	2-3.6	2.58 ±0.35	3-4.44	3.68 ±0.38	5
Cl^-	28.40-52.00	38.39 ±4.70	31.20-41.10	36.86 ±2.63	49.70-69.50	59.75 ±4.11	62-79.5	70.44 4.10	250
SO_4^{2-}	158-225	185.88 ±12.40	164-220	192.33 ±8.35	253-308	279.88 ±14.81	231-286	253.77 ±16.34	150
NO_3^-	2.10-3.80	2.85 ±0.29	2.30-3.90	3.12 ±0.31	3.70-4.90	4.42 ±0.30	3.20-4.80	3.98 ±0.22	45
PO_4^{3-}	0.20-0.32	0.25 ±0.02	0.21-0.39	0.26 ±0.02	0.34-0.48	0.42 ±0.04	0.28-0.46	0.38 ±0.05	0.5
K	2.20-4.90	3.54 ±0.40	4.00-7.50	5.54 ±0.54	7.10±9.70	8.60 ±0.50	5.70±8.80	7.19 ±0.51	12

All the parameters are expressed in mg/l except for pH, turbidity (NTU), WT (°C) and EC (µS/cm)

Table 5.2: Seasonal water quality parameters at sampling station 1 (S1)

Parameters	Winter	Spring	Summer	Autumn	ICMR/BIS/WHO standard limits
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
pH	5.83±0.66	5.83±0.78	4.00±0.75	4.13±0.66	6.5-8.5
Turbidity	2.40±0.68	3.43±0.72	9.07±0.40	7.47±0.62	5
WT	20.00±2.00	21.00±1.73	22.67±0.57	21.67±1.52	32

EC	181.67±9.86	194.70±5.98	230.43±18.02	206.00±19.00	300
TDS	113.33±9.71	123.67±17.00	148.00±10.00	147.33±4.51	500
TH	135.33±8.08	112.00±10.12	92.67±8.00	80.67±6.42	300
Free CO_2	8.80±2.20	16.87±2.58	25.67±2.54	22.00±3.40	22
TA	188.33±18.92	186.67±16.07	150.00±18.02	125.00±5.00	120
Ca^{2+}	58.01±2.01	47.27±9.05	44.02±8.99	40.8±8.64	75
Mg^{2+}	15.35±2.34	15.77±0.28	11.8±0.98	10.5±0.81	30
DO	8.33±0.75	6.93±0.94	4.53±0.76	6.27±0.61	5
BOD	3.53±0.30	3.67±0.42	2.27±0.11	3.47±0.46	5
Cl^-	34.00±7.56	34.50±3.57	56.30±6.36	66.57±4.50	250
SO_4^{2-}	199.00±25.05	201.00±17.35	293.33±16.80	271.33±16.80	150
NO_3^-	2.53±0.67	2.80±0.50	4.10±0.36	3.73±0.55	45
PO_4^{3-}	0.23±0.03	0.24±0.04	0.37±0.03	0.32±0.03	0.5
K	3.23±0.10	5.30±0.30	8.10±0.89	6.77±0.66	12

Table 5.3: Seasonal water quality parameters at sampling station 2 (S2)

Parameters	Winter	Spring	Summer	Autumn	ICMR/BIS/WHO
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	standard limits
pH	5.90±0.62	6.00±0.81	4.03±0.80	4.40±0.50	6.5-8.5
Turbidity	2.80±0.62	3.57±0.58	9.27±0.42	7.77±0.70	5
WT	20.67±2.51	22.00±1.73	23.67±0.58	22.67±1.52	32
EC	186.93±3.40	183.80±13.97	218.63±15.31	194.8±20.46	300
TDS	123.67±13.20	141.00±18.33	158.33±10.01	161.00±5.57	500
TH	128.00±10.32	112.67±10.04	102.44±9.03	86.00±8.71	300
Free CO_2	9.53±1.36	14.67±2.58	22.00±2.20	19.07±3.36	22
TA	195.00±18.02	193.33±7.64	158.33±16.07	138.33±5.77	120
Ca^{2+}	62.67±5.03	48.66±7.68	44.68±9.03	42.32±6.85	75
Mg^{2+}	15.87±3.34	15.57±1.27	13.93±2.02	10.63±0.81	30
DO	8.02±0.90	6.80±0.53	4.61±0.36	6.00±0.20	5
BOD	3.20±0.34	3.13±0.64	2.53±0.50	3.47±0.42	5
Cl^-	37.83±6.41	36.4±2.95	58.67±6.71	70.03±5.71	250
SO_4^{2-}	184.33±26.27	191.67±16.50	282.33±16.80	251.00±8.18	150
NO_3^-	3.10±0.60	3.13±0.60	4.70±0.36	4.07±0.66	45
PO_4^{3-}	0.28±0.03	0.27±0.07	0.45±0.04	0.42±0.05	0.5
K	3.40±0.65	5.17±0.92	8.63±0.66	7.07±1.35	12

Table 5.4: Seasonal water quality parameters at sampling station 3 (S3)

Parameters	Winter	Spring	Summer	Autumn	ICMR/BIS/WHO
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	standard limits
pH	6.10±0.62	6.03±0.70	4.10±0.75	4.50±0.52	6.5-8.5
Turbidity	2.93±0.68	3.80±0.53	9.70±0.36	8.00±0.76	5

WT	20.33±3.05	22.33±1.52	23.00±1.00	23.00±1.00	32
EC	182.33±11.50	178.53±9.39	206.70±13.96	188.67±16.25	300
TDS	139.00±16.52	141.33±19.08	172.33±4.51	177.67±6.11	500
TH	133.33±10.26	122.00±10.02	102.00±8.00	88.67±9.86	300
Free CO_2	11.73±1.36	13.20±1.20	17.60±2.20	20.53±1.27	22
TA	208±18.92	203.33±12.58	168.33±12.58	146.67±7.63	120
Ca^{2+}	61.98±9.15	54.64±8.25	51.99±5.24	49.34±7.56	75
Mg^{2+}	17.38±1.12	15.6±1.32	12.13±2.22	9.53±0.76	30
DO	7.53±1.15	6.47±0.50	4.87±0.11	6.47±0.41	5
BOD	3.60±0.20	3.17±0.25	2.97±0.65	4.13±0.23	5
Cl^-	43.37±8.27	39.70±1.40	64.30±7.82	74.73±5.92	250
SO_4^{2-}	174.33±23.29	184.33±22.19	264.00±11.00	239.00±7.00	150
NO_3^-	2.93±0.65	3.43±0.56	4.46±0.51	4.17±0.25	45
PO_4^{3-}	0.26±0.03	0.30±0.04	0.44±0.02	0.39±0.04	0.5
K	4.00±0.9	6.17±0.17	9.10±0.65	7.76±0.10	12

pH

The mean concentration of pH in the water sample was found to vary from 4.04±0.05 (summer) to 6.19±0.11 (winter). The water pH was recorded minimum during the summer season in all the three stations with the lowest value (4.00±0.75) at S1 while

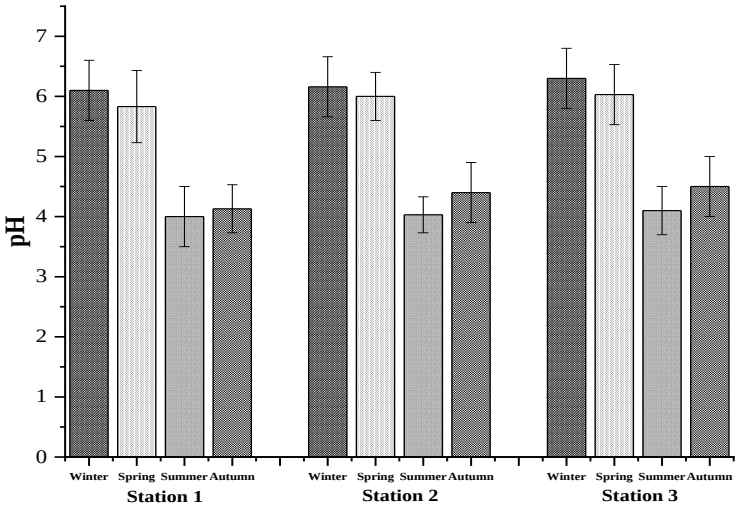


Fig. 5.1: Seasonal variations of pH at the three sampling stations of Tsurang river

the maximum pH was observed in winter with the highest value (6.10±0.62) at S3. In all the three sampling stations, pH was significantly different at the $p < 0.05$ level for winter–summer and spring–summer.

Water temperature

In all the stations, higher surface water temperature was observed during summer with the maximum value (23.67±0.58°C) at S2. During the cold winter season, the water temperature also drops down in all the sampling sites with the lowest mean value (20.00±2.00°C) at S1. However, analysis of variance detected no significant difference of water temperature at the $p < 0.05$ level between seasons in all the three sampling stations.

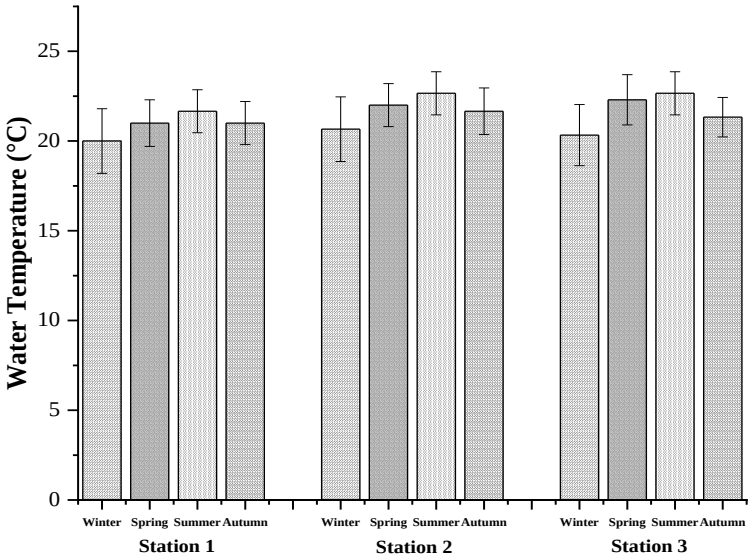


Fig. 5.2: Seasonal variations of Water Temperature (°C) at the three sampling stations of Tsurang river

Free CO_2

Both the highest and lowest value of free CO_2 were recorded in S1 during summer (25.67±2.54 mg/l) and winter (8.80±2.20 mg/l) respectively. In S1 and S2, seasonal Free CO_2 was highly significant between winter-summer and winter-autumn while in S3, a significant difference of $p < 0.05$ level was obtained between winter-autumn and spring-autumn.

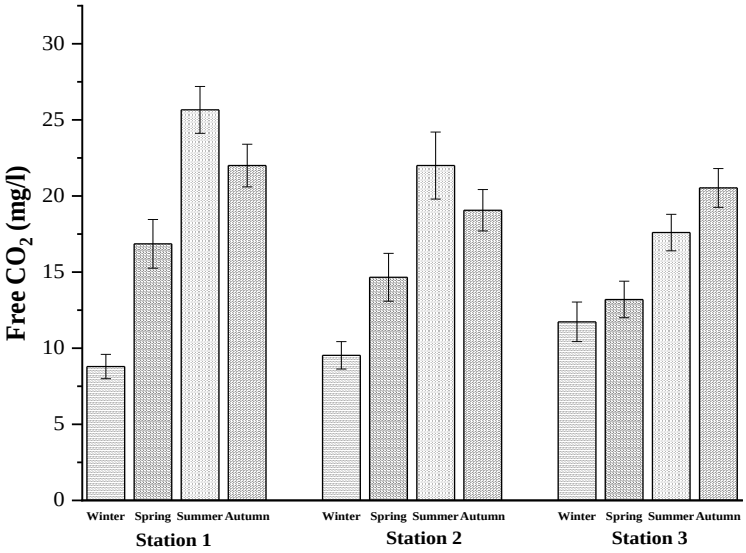


Fig. 5.3: Seasonal variations of Free CO_2 at the three sampling stations of Tsurang river

Turbidity

The lowest concentration of turbidity was seen at S1 (2.40±0.68 NTU) during winter and the highest was observed at S3 (9.70±0.36 NTU) during summer. A high significant difference of $p < 0.05$ level was observed for winter-summer, winter-autumn, spring-summer and spring-autumn at the three stations.

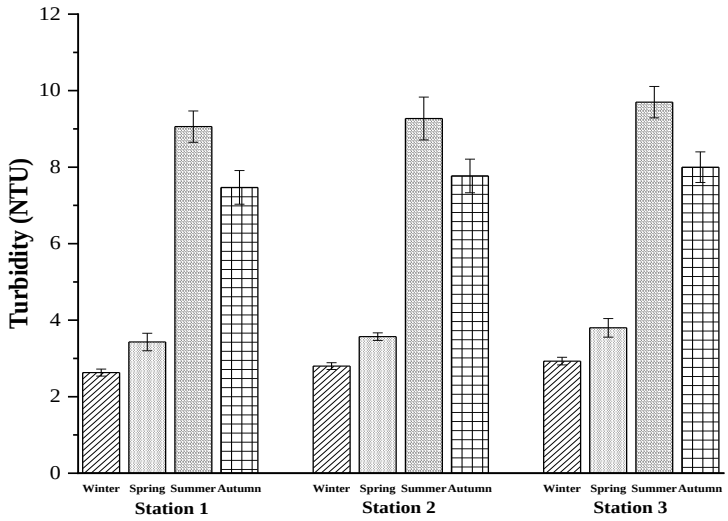


Fig. 5.4: Seasonal variations of Turbidity (NTU) at the three sampling stations of Tsurang river

Electrical conductivity

EC varies seasonally with the highest mean value estimated in summer at S1 (230.43±18.02 µS/cm) and lowest in spring at S3 (178.53±9.39 µS/cm). EC showed a significant difference between winter–summer (p=.013) in S1 while in S2 and S3 such differences were not valid between seasons.

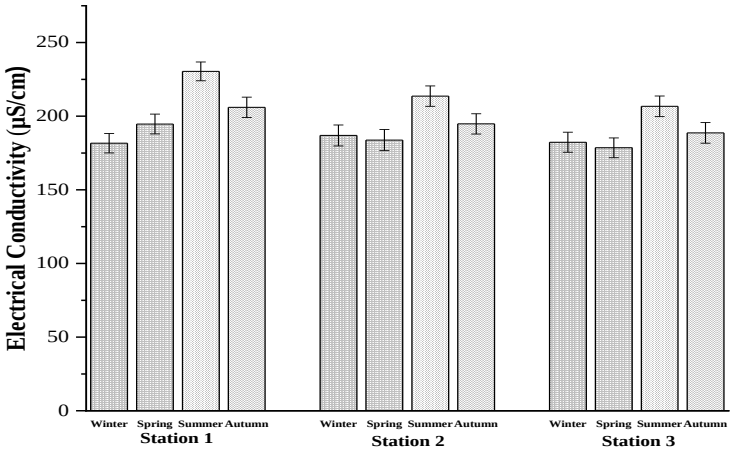


Fig. 5.5: Seasonal variations of Electrical Conductivity (µS/cm) at the three sampling stations of Tsurang river

Total Dissolved Solids

The mean value of TDS varied seasonally with the lowest concentration in winter (125.33±12.91 mg/l) followed by spring (135.33±10.10 mg/l), summer (159.55±12.21 mg/l) and autumn (161.99±15.18 mg/l). The highest TDS was recorded in S3 (177.67±6.11 mg/l) during autumn and lowest was observed at S1 (113.33±9.71 mg/l) during winter. A seasonal significant difference of $p < 0.05$ level in TDS was observed between winter-summer and winter-autumn in S1 and S2 whereas, in S1 significant difference was recorded between winter-autumn (p=.029) and spring-autumn (p=.039).

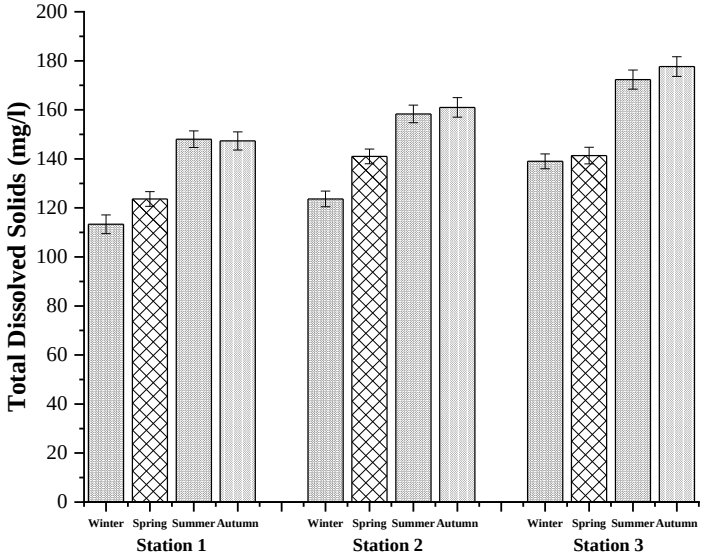


Fig. 5.6: Seasonal variations of Total Dissolved Solids (mg/l) at the three sampling stations of Tsurang river

Sulphate

The recorded mean value of SO_4^{2-} was maximum during summer (279.88±14.81 mg/l) followed by autumn (253.77±16.34 mg/l) spring (192.33±8.35 mg/l) and winter (185.88±12.40 mg/l). Maximum value was recorded from S1 (293.33±16.80 mg/l) in summer and minimum at S3 (174.33±23.29 mg/l) during winter. Seasonal significant difference at $p < 0.05$ level for SO_4^{2-} was recorded between winter-summer, winter-autumn, spring-summer and spring-autumn in all the three sampling points.

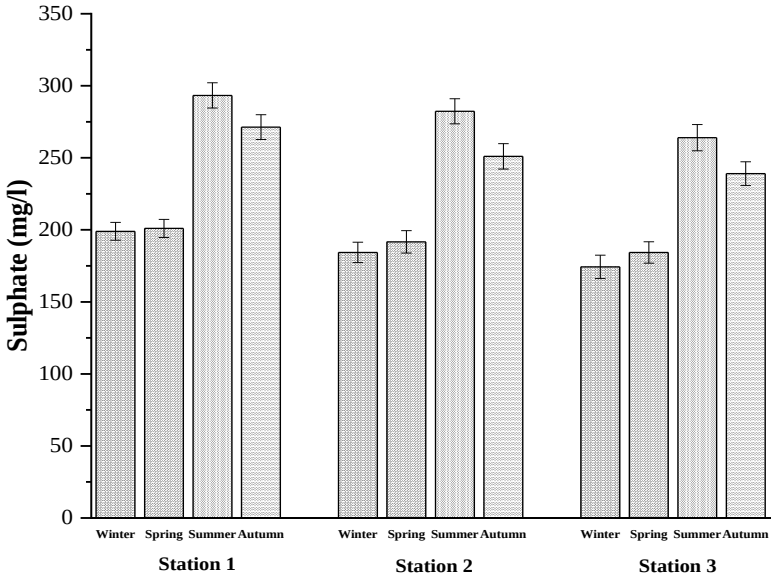


Fig. 5.7: Seasonal variations of Sulphate (mg/l) at the three sampling stations of Tsurang river

Total Alkalinity

During the dry winter season, total alkalinity was seen to have the highest mean value of 197.22±10.18 mg/l ranging from 175-230 mg/l and the value decreases in the rainy seasons of summer (158.88±9.177 mg/l) and autumn (136.66±10.92 mg/l). TA showed a seasonal significant difference between winter-summer (p=.005) and spring-autumn (p=.006) at S1. At S2, it was significantly different between winter-summer (p=.035), winter-autumn (p=.003), spring-summer (p=.044) and spring-autumn (p=.004) while in S3, seasonal recorded TA presented a mean difference between winter-summer (p=.028), winter-autumn (p=.002) and spring-autumn (p=.004).

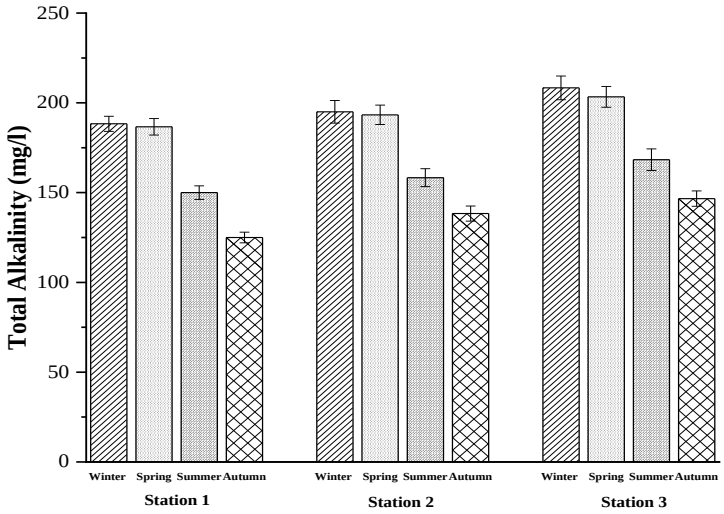


Fig. 5.8: Seasonal variations of Total Alkalinity (mg/l) at the three sampling stations of Tsurang river

Total Hardness

Both the maximum and minimum value of total hardness was observed in S1 during winter (135.33±8.08 mg/l) and autumn (80.67±6.42 mg/l) respectively. In S1, winter showed a significant difference with spring (p=.184), summer (p=.014) and autumn (p=.003). Seasonal mean value of TH in S3 differed significantly for winter-autumn (p=.011) and spring-autumn (p=.048). On the otherhand, no such seasonal difference was detected in S2.

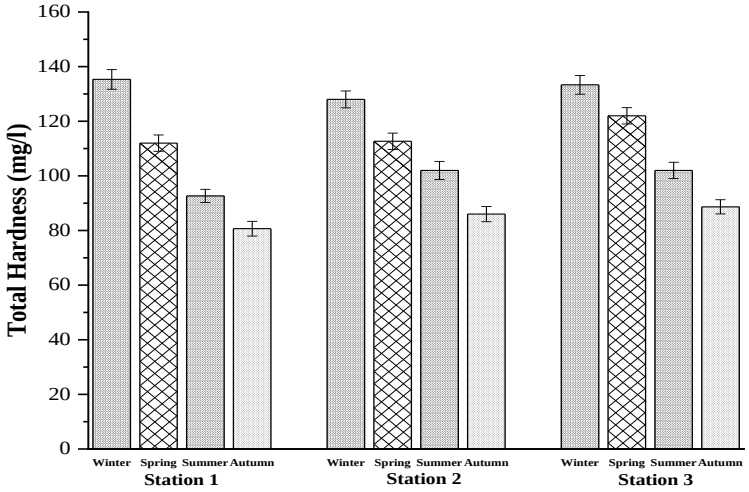


Fig. 5.9: Seasonal variations of Total Hardness (mg/l) at the three sampling stations of Tsurang river

Calcium Hardness

The concentration of Ca^{2+} was found to be considerably high during winter season at S2 (62.67±5.03 mg/l) and lowers down with the onset of autumn and summer months. Seasonally in S1, a significant difference was observed for winter-summer (p=.047), winter-autumn (p=.007), spring-summer (p=.028) and spring-autumn (p=.006). Whereas, in S2 and S3 no observable seasonal mean difference at the $p < 0.05$ level was recorded.

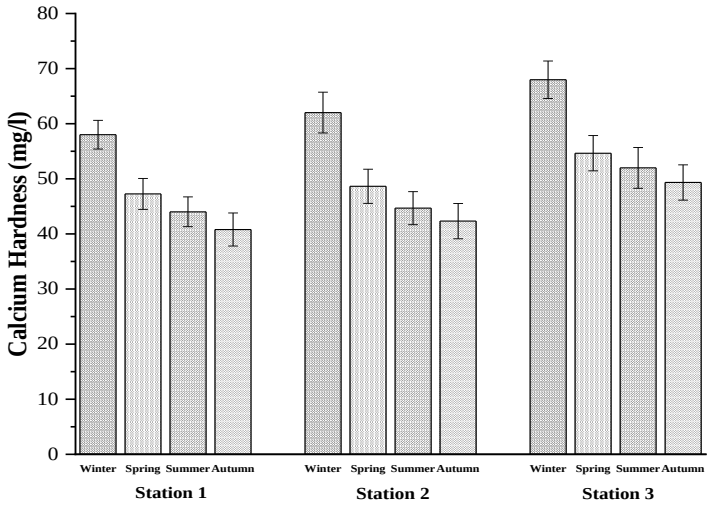


Fig. 5.10: Seasonal variations of Calcium Hardness (mg/l) at the three sampling stations of Tsurang river

Magnesium Hardness

Similar observation was seen for Mg^{2+} during winter season with the highest value in S3 (17.38±1.12 mg/l) while the lowest value was observed during autumn in S3 (9.53±0.76 mg/l). In S1, a significant difference between winter-summer (p=.047), winter-autumn (p=.007), spring-summer (p=.028) and spring-autumn (p=.006) was observed. No significant difference was tenable between seasons in S2 while in S3, analysis of variance presented the season winter-summer (p=.036), winter-autumn (p=.004) and summer-autumn (p=.017) to be significantly different.

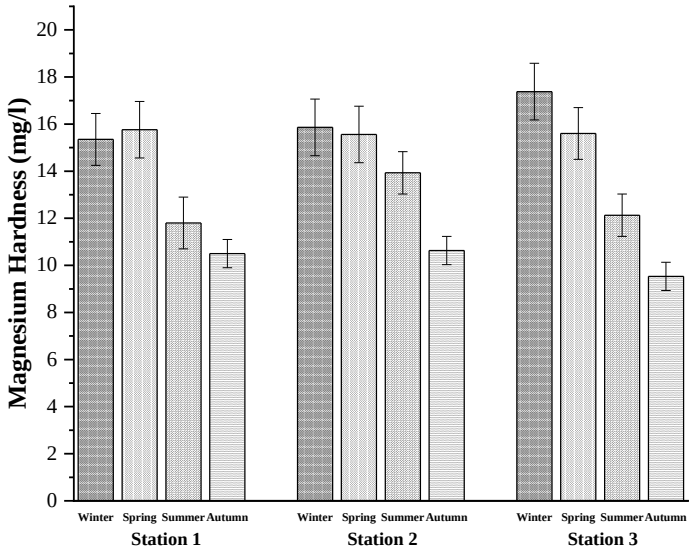


Fig. 5.11: Seasonal variations of Magnesium Hardness (mg/l) at the three sampling stations of Tsurang river

Chloride

An average Cl^- value of 36.86±2.63 mg/l, 38.39±4.705 mg/l, 59.75±4.11 mg/l and 70.44±4.10 mg/l were recorded in spring, winter, summer and autumn respectively. The highest concentration was estimated during autumn at S3 (74.73±5.92 mg/l) and the lowest was recorded in winter at S1 (34.00±7.56 mg/l). Winter showed a significant difference with summer (p=.006) and autumn (p=.001) while spring was significantly different with summer (p=.007) and autumn (p=.001) at S1. The post hoc test shows a

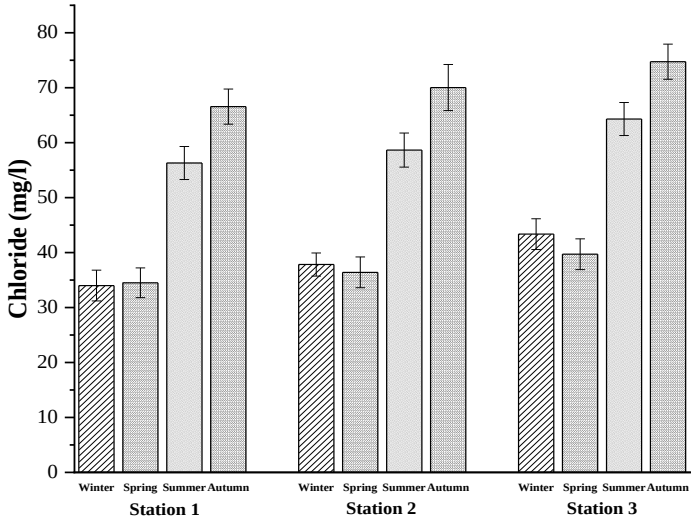


Fig. 5.12: Seasonal variations of Chloride (mg/l) at the three sampling stations of Tsurang river

significant difference between winter-summer (p=.008), winter-autumn (p=.001), spring-summer (p=.006), spring-autumn ($p < .001$) and summer-autumn (p=.008) at S2. Whereas in S3, a significant difference was detected between winter-summer (p=.017), winter-autumn (p=.002), spring-summer (p=.007) and spring-autumn (p=.001).

Nitrate

Seasonally, the value of nitrate in winter (2.85±0.29 mg/l), spring (3.12±0.31 mg/l), summer (4.42±0.301 mg/l) and autumn (3.98±0.22 mg/l) were recorded. Highest concentration was estimated from S2 (4.70±0.36 mg/l) during summer while S1 (2.53±0.67 mg/l) has the lowest amount of nitrate in winter. At S1 and S3, analysis of variance shows that nitrate was significantly different between winter-summer at the $p < 0.05$ level while in S2, the season winter-summer (p=.036) and spring-summer (p=.040) were statistically different.

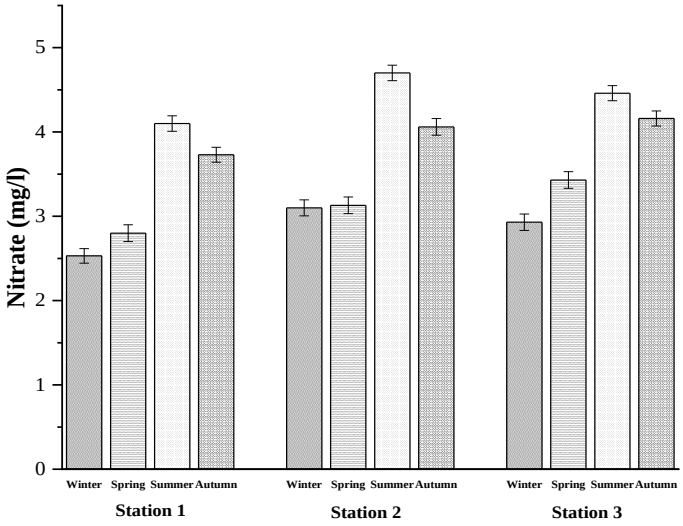


Fig. 5.13: Seasonal variations of Nitrate (mg/l) at the three sampling stations of Tsurang river

Potassium

Similarly, potassium was recorded maximum in summer at S3 (9.10±0.65 mg/l) and minimum during winter season at S1 (3.23±0.10 mg/l). Potassium showed a significant seasonal difference between winter-summer, winter-autumn and spring-summer in all the three stations at the $p < 0.05$ level.

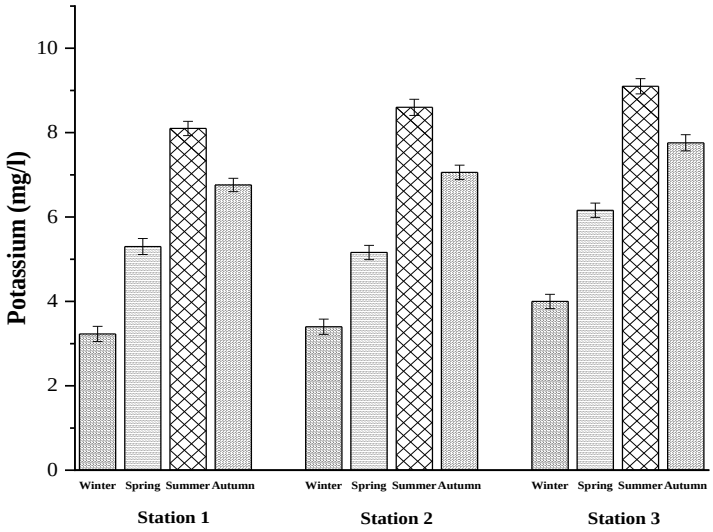


Fig. 5.14: Seasonal variations of Potassium (mg/l) at the three sampling stations of Tsurang river

Inorganic Phosphorus

The lowest concentration was observed from S1 (0.23±0.03 mg/l) during winter and highest at S2 (0.45±0.04 mg/l) during summer. A significant difference of PO_4^{3-} was tenable between winter-summer (p=.004) and spring-summer (p=.005) in S1. While in S2, winter-summer (p=.019), winter-autumn (p=.045), spring-summer (p=.014) and spring-autumn (p=.033) showed a significant difference. On the otherhand, S3 presented a significant difference between winter-summer (p=.010), winter-autumn (p=.043) and spring-summer (p=.043).

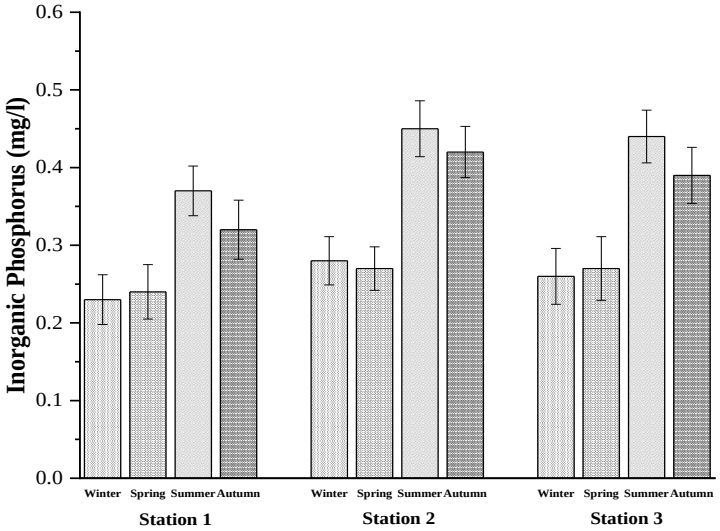


Fig. 5.15: Seasonal variations of Inorganic Phosphorus (mg/l) at the three sampling stations of Tsurang river

Dissolved Oxygen

The mean concentration of DO availability in the water sample was found to vary from 4.66±0.17 mg/l (summer) to 7.95±0.40 mg/l (winter). Highest estimated value was seen in winter from S1 (8.33±0.75 mg/l) and lowest was observed during summer season from S1 (4.53±0.76 mg/l). The mean value of DO in winter at S1 was significant with summer (p=.001) and autumn (p=.046) while spring was significant with summer (p=.022). Whereas in S3, a mean significant difference at the p<0.05 level was detected between winter-summer (p=.005) while S2 DO exhibited no valid difference between seasons.

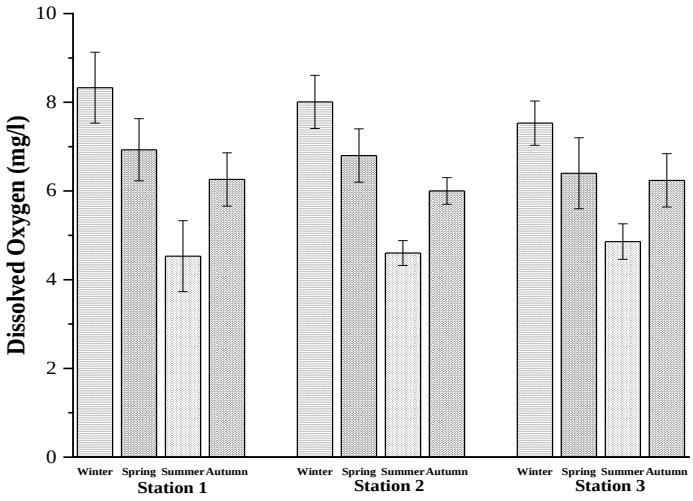


Fig. 5.16: Seasonal variations of Dissolved Oxygen (mg/l) at the three sampling stations of Tsurang river

Biological Oxygen Demand

Mean value of BOD was observed maximum during autumn (3.68±0.38 mg/l) followed by winter (3.53±0.33 mg/l), spring (3.31±0.29 mg/l) and summer (2.58±0.35 mg/l). Summer recorded the lowest BOD content in S1 (2.27±0.11 mg/l) while autumn has the highest BOD in S3 (4.13±0.23 mg/l). At the mean significant difference of p<0.05 level, BOD was seasonally significant between winter-summer (p=.010), spring-summer (p=.005) and summer-autumn (p=.013) in S1 but in S2 such results were not recorded. In S3, a significant difference of p=.023 was tenable between summer-autumn.

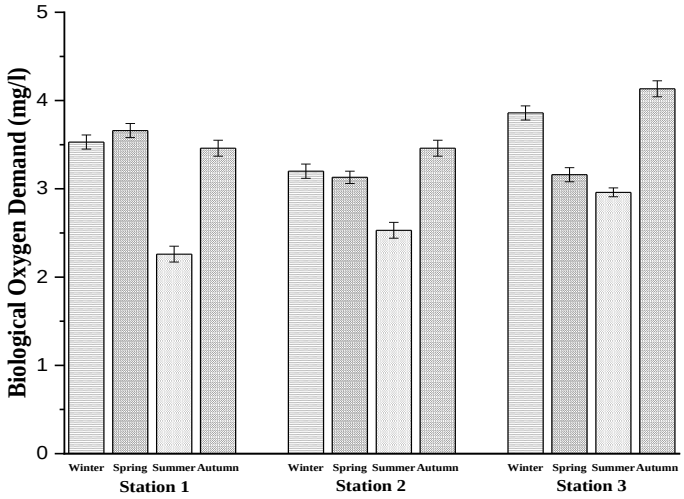


Fig. 5.17: Seasonal variations of Biological Oxygen Demand (mg/l) at the three sampling stations of Tsurang river

5.2.2 Water Quality Status

Table 5.5 shows the drinking water quality standards (BIS/ICMR) for each parameter, as well as the unit weights used in the WQI computation. The characteristics unit weight value of each element has a major impact on the WQI result and the parameters turbidity, DO and BOD were assigned the highest weightage of 0.24.

Table 5.5: Unit weights (W_n) of the parameters and their standards to determine WQI

Parameters	BIS/ICMR Standards (V_s)	Unit weight ($W_n=k/V_s$)
pH	6.5-8.5	0.14449359
Turbidity	5	0.245639103
EC	300	0.004093985
TDS	500	0.002456391
TH	300	0.004093985
TA	120	0.010234963
Ca^{2+}	75	0.01637594
Mg^{2+}	30	0.040939851
Cl^{-}	250	0.004912782
NO_3^{-}	45	0.027293234
SO_4^{2-}	150	0.00818797
DO	5	0.245639103
BOD	5	0.245639103
$\sum W_n = 1.00$		

The values observed for each selected seasonal physicochemical parameter from the three sampling locations, as well as their related WQI, are presented in **Tables 5.6, 5.7,** and **5.8**. WQI was highest during the monsoon summer seasons, with the maximum value in S3 (63.77) followed by S2 (61.66) and S1 (58.81). While autumn experienced a moderate WQI with the lowest value in S1 (53.08) followed by S2 (57.90) and S3 (59.03). The WQI of winter at the three stations is recorded as: S1 (44.40), S2 (45.19) and S3 (45.68). On the otherhand, spring recorded a WQI of 49.78 in S1, 49.86 in S2 and 50.99 in S3. The study area's seasonal rainfall is highest during the summer and autumn seasons, which span the monsoon and post-monsoon period of the year, and gradually declines as the dry winter months approach. As such, the mean flow rate of the coal mine drainages was also recorded maximum in summer (4.89 ± 0.35 m^3/s) followed by autumn (3.84 ± 0.41 m^3/s), spring (2.87 ± 0.36 m^3/s) and winter (2.24 ± 0.45 m^3/s) (**Table 5.9**). The PCA biplot of **Fig. 5.18** represents a strong inter-relation between the flow rates of drainages (D) with the WQI of summer and autumn. The overall WQI has a significantly positive correlation with the flow rate of D1 (r = 0.97), D2 (r = 0.98), D3 (r = 0.99), D4 (r = 0.98) and D5 (r = 0.98). The seasonal flow rate can be categorized as summer > autumn > spring > winter which correlates to the WQI value of Tsurang river.

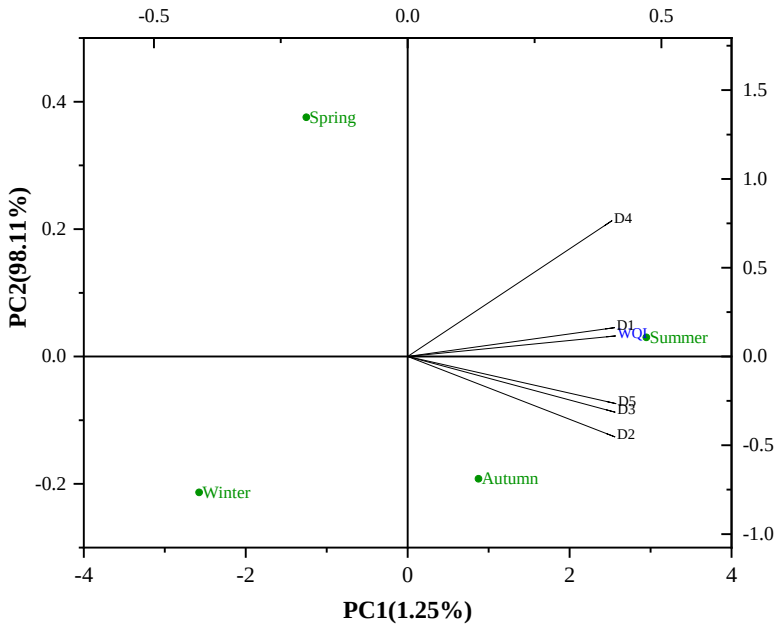


Fig. 5.18: PCA - biplot for the flow rate of coal mine drainages and water quality index (WQI) at varying seasons

Table 5.6: Calculation of WQI at station 1 (S1)

Parameters	Winter			Spring			Summer			Autumn		
	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n
pH	6.1	-60	-8.66961	5.83	-78	-11.2705	4	-200	-28.8987	4.13	-191.3333	-27.6464
Turbidity	2.63	52.6	12.92061	3.43	68.6	16.85084	9.06	181.2	44.50980	7.47	149.4	36.69848
EC	181.66	60.5533	0.247904	194.7	64.9	0.265699	230.43	76.81	0.314458	206	68.6667	0.281120
TDS	113.33	22.666	0.055676	123.66	24.732	0.060751	148	29.6	0.072709	147.33	29.466	0.072380
TH	135.33	45.11	0.184679	112	37.3333	0.152842	92.66	30.8867	0.126449	80.66	26.8867	0.110073
TA	188.33	156.9416	1.606292	186.66	155.55	1.592048	150	125	1.279370	125	104.1667	1.066141
Ca^{2+}	58.01	77.3466	1.266624	47.26	63.0133	1.031902	44.01	58.68	0.960940	40.8	54.4	0.890851
Mg^{2+}	15.35	51.1666	2.094755	15.76	52.5333	2.150706	11.8	39.3333	1.610300	10.5	35	1.432894
Cl^-	34	13.6	0.066813	34.5	13.8	0.067796	56.3	22.52	0.110635	66.56	26.624	0.130797
NO_3^-	2.53	5.6222	0.153448	2.8	6.22222	0.169824	4.1	9.1111	0.248671	3.73	8.2889	0.226230
SO_4^{2-}	199	132.6667	1.086270	201	134	1.097187	293.33	195.5533	1.601184	271.33	180.8867	1.481094
DO	8.33	65.3125	16.04330	6.93	79.8958	19.62554	4.53	104.8958	25.76651	6.26	86.875	21.33989
BOD	3.53	70.6	17.34212	3.66	73.2	17.98078	2.26	45.2	11.10288	3.46	69.2	16.99822
	$\sum W_nQ_n$=44.3988			$\sum W_nQ_n$=49.775			$\sum W_nQ_n$=58.805			$\sum W_nQ_n$=53.081		
	WQI=44.4			WQI=49.78			WQI=58.81			WQI=53.08		

Table 5.7: Calculation of WQI at station 2 (S2)

Parameters	Winter			Spring			Summer			Autumn		
	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n
pH	6.16	-56	-8.09164	6	-66.6667	-9.63290	4.033	-197.8	-28.5808	4.4	-173.333	-25.045
Turbidity	2.8	56	13.75578	3.57	71.4	17.53863	9.27	185.4	45.54148	7.77	155.4	38.1723
EC	186.93	62.31	0.255096	183.8	61.26667	0.250824	218.63	72.8767	0.298355	194.8	64.93333	0.26583
TDS	123.66	24.732	0.060751	141	28.2	0.069270	158.33	31.666	0.077784	161	32.2	0.07909
TH	128	42.6667	0.174676	112.66	37.5533	0.153742	102	34	0.139195	86	28.66667	0.11736
TA	195	162.5	1.663181	193.33	161.1083	1.648937	158.33	131.9417	1.350418	138.33	115.275	1.17983
Ca^{2+}	62.02	82.6933	1.354181	48.65	64.86667	1.062252	44.68	59.57333	0.975569	42.32	56.42667	0.92403
Mg^{2+}	15.86	52.8667	2.164353	15.56	51.86667	2.123413	13.93	46.43333	1.900973	10.63	35.43333	1.45063
Cl^-	37.83	15.132	0.074340	36.4	14.56	0.071530	58.66	23.464	0.115273	70.03	28.012	0.13761
NO_3^-	3.1	6.88889	0.188020	3.13	6.955556	0.189839	4.7	10.44444	0.285062	4.06	9.022222	0.24624
SO_4^{2-}	184.33	122.887	1.006192	191.66	127.7733	1.046204	282.33	188.22	1.541139	251	167.3333	1.37012
DO	8.01	68.6458	16.86210	6.8	81.25	19.95817	4.6	104.1667	25.58740	6	89.58333	22.0051
BOD	3.2	64	15.72090	3.13	62.6	15.37700	2.53	50.6	12.42933	3.46	69.2	16.9982
	$\sum W_nQ_n$=45.187			$\sum W_nQ_n$=49.856			$\sum W_nQ_n$=61.661			$\sum W_nQ_n$=57.90		
	WQI=45.19			WQI=49.86			WQI=61.66			WQI=57.90		

Table 5.8 Calculation of WQI at station 3 (S3)

Parameters	Winter			Spring			Summer			Autumn		
	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n	V_n	Q_n	W_n*Q_n
pH	6.16	-56	-8.09164	6	-66.6667	-9.63290	4.033	-197.8	-28.5808	4.4	-173.3333333	-25.0455
Turbidity	2.9	58	14.24706	3.8	76	18.66857	9.7	194	47.65398	8	160	39.30225
EC	186.93	62.31	0.255096	183.8	61.26667	0.250824	218.63	72.87667	0.298355	194.8	64.93333333	0.265836
TDS	123.66	24.732	0.060751	141	28.2	0.069270	158.33	31.666	0.077784	161	32.2	0.079095
TH	128	42.6667	0.174676	112.66	37.55333	0.153742	102	34	0.139195	86	28.66666667	0.117360
TA	195	162.5	1.663181	193.33	161.1083	1.648937	158.33	131.9417	1.350418	138.33	115.275	1.179835
Ca^{2+}	62.02	82.6933	1.354181	48.65	64.86667	1.062252	44.68	59.57333	0.975569	42.32	56.42666667	0.924039
Mg^{2+}	15.86	52.8667	2.164353	15.56	51.86667	2.123413	13.93	46.43333	1.900973	10.63	35.43333333	1.450635
Cl^-	37.83	15.132	0.074340	36.4	14.56	0.071530	58.66	23.464	0.115273	70.03	28.012	0.137616
NO_3^-	3.1	6.88889	0.188020	3.13	6.955556	0.189839	4.7	10.44444	0.285062	4.06	9.022222222	0.246245
SO_4^{2-}	184.33	122.887	1.006192	191.66	127.7733	1.046204	282.33	188.22	1.541139	251	167.3333333	1.370120
DO	8.01	68.6458	16.86210	6.8	81.25	19.95817	4.6	104.1667	25.58740	6	89.58333333	22.00516
BOD	3.2	64	15.72090	3.13	62.6	15.37700	2.53	50.6	12.42933	3.46	69.2	16.99822
	$\sum W_nQ_n$=45.679 WQI=45.68			$\sum W_nQ_n$=50.986 WQI=50.99			$\sum W_nQ_n$=63.773 WQI=63.77			$\sum W_nQ_n$=59.03 WQI=59.03		

Table 5.9: Seasonal flow rate of coal mine drainages

Seasons	D1	D2	D3	D4	D5	Mean±SD
Winter	1.99±0.09	2.24±0.04	2.28±0.02	1.73±0.01	2.95±0.03	2.24±0.45
Spring	2.59±0.03	2.49±0.02	2.8±0.02	3.12±0.02	3.34±0.02	2.87±0.36
Summer	4.8±0.02	4.45±0.02	4.76±0.04	5.07±0.04	5.36±0.03	4.89±0.35
Autumn	3.38±0.02	3.6±0.01	4.09±0.01	3.73±0.04	4.43±0.02	3.84±0.41

D – drainage, all values are expressed in m^3/s

5.3 DISCUSSION

5.3.1 Spatio-temporal variations in the water physicochemical properties

pH, or "potential of hydrogen," is a measurement of hydrogen ion concentration that determines the acidity or alkalinity of water and is an essential indicator for water quality. Throughout the four seasons, the pH was acidic and did not meet the BIS/ICMR permitted range. Pyrites, the most frequent sulfide mineral in coal and a key source of sulphur, reacts with water molecules to generate sulfuric acid, which is primarily responsible for the acidity of contaminated water from coal mines (Swer and Singh, 2004). The fluctuation of river water temperature depends on the season, geographic location, sampling time and temperature of effluents entering the river (Ahipathy and Puttaiah, 2006). As observed in the present study, with the increase of atmospheric temperature during summer, water temperature also rises and drops gradually with the onset of the dry winter months. The temperature of river water is also governed by the interaction of natural environmental processes including air temperature, solar radiation and conduction from soil including anthropogenic disturbances of the natural thermal regime (Benyahya, 2008). The concentration of free CO_2 in summer (S1) was beyond the permissible limits given by WHO (2017). This could be due to the runoff litters from the forest along with agricultural, domestic sewages discharged into the river system during the rainy summer seasons. The rise in water temperature can also elevate the rate of microbial respiration and decomposition of organic matter which tends to increase free CO_2 in the water (Manjare *et al*., 2010). In all the stations, minimum free CO_2 observed during winter months could be due to inactive microbial activity as organic contents and water temperature decrease. Turbidity can be visually observed upto an extent and it determines the degree of loss in water transparency caused by the presence of suspended particulates. During the summer and autumn seasons when the Tsurang river water is muddy and yellowish-brownish in color with a pungent odour the turbidity measured in all the sampling sites were beyond the permissible limit of BIS/ICMR. Rainy season

brings debris into the river from surrounding catchment areas, which includes colloidal particles, dissolved solids, trace metals and salts of various chemicals and ions, all of which raise EC, turbidity and TDS (Semy and Singh, 2021). Such observation was recorded in all the sampling stations with the maximum concentration in S3 (Human settlement area) during the monsoon periods. However, factors such as the geological character of the watershed and the number of surface runoffs greatly determine the presence of these parameters and eventually indicate the degree of substances in the water (Driche *et al.*, 2008). In all the stations, SO_4^{2-} concentrations were relatively high and crossed the permissible limit of 150 mg/l (BIS/ICMR) throughout the four seasons. The escalated amount of sulphates is duly caused by the presence of iron sulphide (pyrite) in coal and as it reacts with water and oxygen, the compounds are chemically broken down into ions of sulfate which later runoffs into the river channel through coal mine drainages (Swer and Singh, 2004). The ability of water to neutralise acids is measured by total alkalinity. Alkaline compounds in water, such as hydroxides and carbonates, remove H^+ ions from the solution, lowering the acidity of the solution and raising the pH. In the present study, a significant amount of total alkalinity was reduced during the rainy summer and autumn months in all the stations. Such effects may be attributed to the influx of fresh water in the river system during the monsoon and post-monsoon period causing dilution (Chatterjee and Razuiddin, 2002). The hardness of water is determined by the presence of calcium and magnesium ions. As observed in the study, the mean value of calcium, magnesium and total hardness in the river water was maximum during the winter season. This can be attributed due to the surface runoff from limestone deposits, weathering of rocks and domestic sewages as reported by Radhakrishnan *et al.* (2007). Lowest concentration of these parameters were recorded from S1 and increases drastically downstream (S3) in human populated locality. The observed differences in the level of TH, Ca^{2+} and Mg^{2+} parameters from one station to the other could be caused by the rate of inputs of waste from site-specific disturbances. Chloride occurs naturally due to its high solubility and is present in most natural waters but in some cases is formed from agricultural runoffs comprising of inorganic fertilizers. The seasonal values of chloride were all within the permissible limit of 250 mg/l. However, there was a significant increase in chloride in the post-monsoon or autumn season. This may be attributed due to the discharge of municipal sewages and domestic waste containing residential water softeners, vinyl chloride, DDT (dichloro-diphenyl-trichloroethane) and the salt used for the brine which can elevate chloride levels in the river water (Singh and

Shrivastava, 2015). Nitrate concentration in river water may be due to influx of nitrogen rich floodwater that brings voluminous amount of contaminated sewages from agricultural fields; it can also be attributed due to the fixing of atmospheric nitrogen into nitrates by the nitrogen fixing microorganism which is also a significant contributor to nitrates in water (Semy and Singh, 2019). Inspite of the extensive used of nutrient fertilizer (Urea) in the agriculture fields along the catchment areas of the river, NO_3^- was detected in very low concentration throughout the four seasons. Huang and Zhang (2004) showed that low nitrate in water is due to the effect of acidic pH which rapidly reduced the compound to ammonium and dissolved it in the water system. Such explanations can be reasoned with the acidic pH of Tsurang river water caused by the coal mine drainages entering the river. Potassium is an essential element required for plants growth but in river water it naturally occurs in very low concentration unless or otherwise provided externally from different sources. In all the sampling stations, the seasonal values of potassium were all within the standard limits of 12 mg/l (WHO). However, during the summer months the concentration of potassium in the river water escalated, which could be due to the runoffs from vegetables and fruit plantation fields (cabbage, mustard, groundnuts and papaya) where potassium sulphate and potassium nitrate are used as inorganic fertilizers. Parihar *et al.* (2012) also recognized that major source of potassium in freshwater that could be associated with weathering of rocks and sediments. In all the stations, the parameter phosphorus was within the permissible limit of 0.5 mg/l. Seasonally, the rainy summer and autumn months have higher concentration of PO_4^{3-} compared to the other dry months. This could be reasoned with the common usage of phosphate fertilizers such as Mono Ammonium Phosphate Fertilizer (MAPF) and Diammonium Phosphate (DAP) in the agricultural fields along the stretch of the river which could have elevated the phosphate concentration in the river water during the monsoon period of the year. DO is a crucial parameter determining the quality of a water system be it underground or surface water. The level of DO in surface water is affected by environmental factors such as atmospheric temperature, humidity including microbial activity and has both seasonal and a daily cycle. As observed in the study, the level of DO decreases from winter>spring>autumn>summer. Cold river water tends to accumulate more DO than warm water due to their higher saturation point; with the onset of winter and early spring, the water temperature is low, and the DO concentration is high whereas in summer and fall, when the water temperature is high, the DO drops gradually (Rounds

et al., 2013). BOD indicates organic loads in the water bodies and is taken as a pollution index, especially for water bodies that are receiving organic effluent (Ndimele, 2012). Higher the BOD value, the greater is the level of organic pollution (Patel *et al*., 1983) while low BOD represents lesser organic contaminants and good water quality status. In all the stations, seasonal BOD level was consistently moderate in respect to the standard limits of 5 mg/l (WHO) which represents the presence of moderate organic waste and microbial activities throughout the year. From the analysis examined, most of the parameters falls under the permissible drinking water limits while some few parameters in particular like pH, turbidity, total alkalinity and sulfates were not within the standard limit given by BIS/ICMR.

The ANOVA and the Tukey post-hoc test on the physicochemical water properties depict the spatiotemporal variations at varying seasons during the study period. Parameters like pH, TDS and turbidity, showed that the stretch of the river including the sampling stations are gradually affected by the acidity of the coal mine drainages, discharge of solid deposits and wastewater from catchment areas at different seasons. The analysis of variance also illustrated that seasonal pattern of winter, spring, summer and autumn influenced by the proceeding pre-monsoon, monsoon and the post monsoon period of the study area greatly altered the seasonal physicochemical water variables such as free CO_2, Cl^-, TA, EC, TH, Mg^{2+}, Ca^{2+}, PO_4^{3-}, K, NO_3^-, DO, BOD and SO_4^{2-} which was in conformity with the work of Lkr *et al*. (2020a) at Doyang river, Nagaland. Since at varying seasons of the year, the water level, biogeochemical cycle and microbial activities are gradationally ever-changing therefore it affects the chemical and physical composition of the water to an extent where its concentration significantly fluctuates (Lohse *et al*., 2009). In addition, coal mine waste, sewages, forest litters, soil erosions and other domestic waste expedited by anthropogenic activities could have slowly modified the water properties. However, water temperature of Tsurang river was not significantly affected by the seasons due to the area low altitude followed by high atmospheric temperature and humidity even during the winter months.

5.3.2 Inter-relation of the seasonal WQI and flow rate of coal mine drainages

According to the WQI presented in **Fig.5.19**, winter and spring have good water quality and can be recommended for drinking, irrigation and industrial purpose, whereas summer and autumn exhibit poor water quality suitable only for irrigation and industrial

purpose. Seasonally, WQI followed a trend of summer>autumn>spring>winter which was in conformity with observations made by Sahoo *et al.* (2016) at Talcher river. As recorded, the flow rate of drainages increase in summer and decrease with the approach of winter season, so does the WQI **(Fig. 5.20)**. The high correlation between the seasonal flow rates of mine

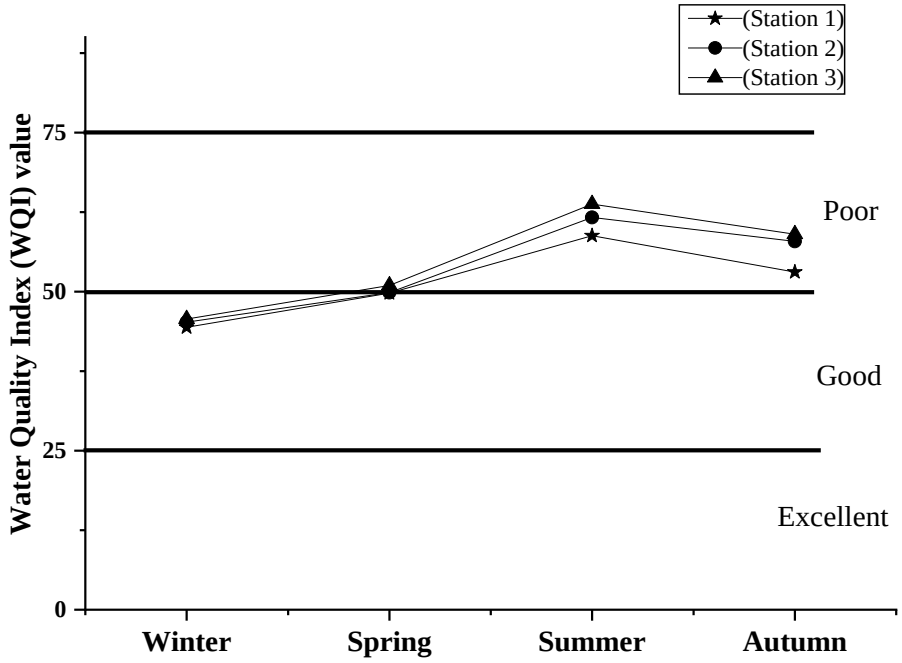


Fig. 5.19: Seasonal water quality status at the three sampling stations of Tsurang river

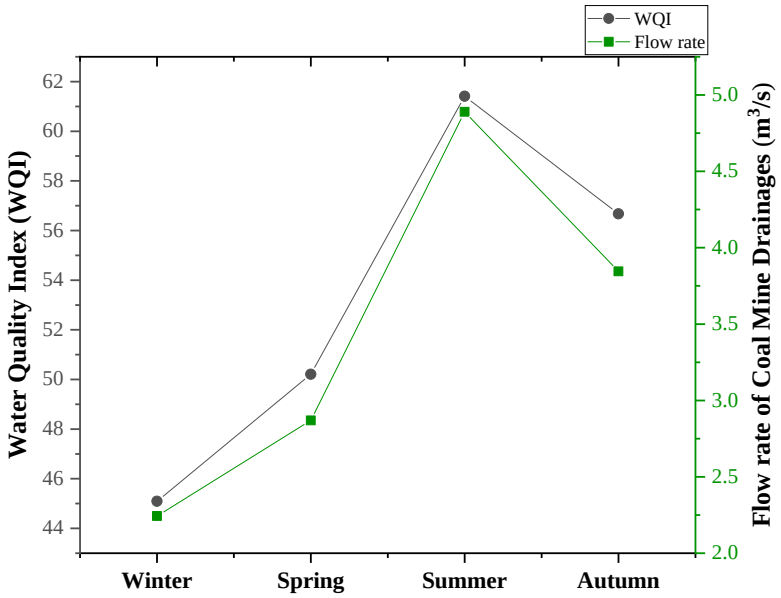


Fig. 5.20: Seasonal flow rate of coal mine drainages (m^3/s) and the water quality index (WQI)

drainages and the WQI clearly indicates that coal mine drainages are negatively impacting the Tsurang river water characteristics and its water quality, which is consistent with Lamare and Singh (2016) on their study of water quality at Lukha River in Meghalaya. The decline of water quality, on the other hand, can also be linked to runoff from various land-use regimes (Paliwal *et al*., 2007) along the river's course. According to the statistics, river water pollution rates intensify as it passes from upstream (S1) to midstream (S2) and finally downstream (S3). This is due to the accumulation of waste from upstream to downstream, such as pyrites from coal mine drainage runoff, forest litter, inorganic fertilizers from agricultural waste and domestic sewage from residential populated areas. Apart from coal mining, varied land-use patterns in the adjacent areas of S1 (plantations), S2 (sand mining) and S3 (agricultural and human settlements) have had a significant impact on water chemistry, altering physicochemical characteristics and exerting significant pressure on water quality. S3 contributed the highest WQI in all seasons due to its proximity to the state highway (Mokokchung-Mariani Road-NH 702D) connecting Nagaland (Mokokchung) and Assam (Mariani) along with developmental projects, making it more susceptible to water pollution. It can also be asserted that the degradation of water quality induced by human activity in upstream areas lowers the utility of water resources for downstream inhabitants (Fulazzaky, 2010). Yoon *et al.* (2015) reported a similar increase in pollutant level downstream in their study of upstream water resource management to address

downstream pollution issues. Polluting activities, such as the discharge of domestic, urban and other wastewaters, into the water channel and the use of chemical pesticides on agricultural land in the drainage basin are also reported by Simeonov *et al.* (2003) and Bouslah *et al.* (2017). In regards to pollution from coal mining activities, Swer and Singh (2004) and Singh *et al.* (2012) have indicated that mine drainages alter the quality of the water system to the extent where it could be detrimental for the survival of aquatic life in the stream and rivers, not only in the catchment zones by even further downstream. Research investigating water bodies affected by coal mining activities have noticed that low pH (Swer and Singh, 2003; Baruah *et al.*, 2005; Equeenuddin *et al.*, 2010), high turbidity (Tambekar *et al.*, 2012) and elevated sulphate concentrations (Rawat and Singh, 1982; Khan *et al.*, 2013; Kumar and Singh, 2016; Tiwari *et al.*, 2016) are all linked to coal mine waste. The current study also demonstrates similar trends in results and rectifies the fact that runoffs and drainages from coal mines entering the Tsurang river have an impact on the water quality status.

5.4 SUMMARY AND CONCLUSION

The present study was undertaken to evaluate the spatio-temporal variation of surface water quality variables of Tsurang river. In total, 17 physicochemical parameters were estimated to compare their seasonal values with the drinking water permissible limits of ICMR/BIS/WHO. Throughout the four seasons, S3 accumulated the highest concentration of TA, BOD, Cl^-, K, TDS, Ca^{2+} and turbidity. Majority of the parameters falls within the desirable limits while some of the properties like pH, turbidity, total alkalinity and sulphate were not in the standard limit and this poses a serious threat for the local inhabitants relying on the river water. The analysis of variance and the Tukey post-hoc test presented the spatiotemporal variations in the water physicochemical characteristics at different seasons. The pre-monsoon, monsoon and the post-monsoon which covers part of winter, spring, summer and autumn period had influence the variability of pH, TDS, turbidity, free CO_2, Cl^-, TA, EC, TH, Mg^{2+}, Ca^{2+}, PO_4^{3-}, K, NO_3^-, DO, BOD and SO_4^{2-} as rainfall greatly enhance the alteration in the physicochemical concentration in river water.

The application of WQI to determine the quality of water from the three stations of the Tsurang river reveals that winter and spring have good quality status and can be used for drinking, irrigation and industrial purposes, whereas the recorded WQI values of

summer and autumn indicate unfit status, which can be harmful, if not fatal, for the local population. As per the observation, the flow rate of coal mine drainages entering the Tsurang river has a significant impact on the WQI. With the increase of drainages flow rate during the summer seasons, the water pollution gradually rises while the probable usage decreases. The result imparted in the statistics represents that the trends of river water pollution tends to elevate as it flows from upstream (S1) to midstream (S2) and then to downstream (S3) due to carrying of organic and inorganic waste from upstream towards downstream. Overall, this study clearly defined the condition of the river according to its exclusive characteristics of water chemistry and provided crucial information of water quality status at each sampling station.

Major sources of pollution around the catchment areas of the river include coal mining, sand mining, agriculture, stone quarries, rubber plantations, picnic spots, residential area, passing highways and dumping of untreated domestic sewages into the river. These activities, if not enforced by law, could lead to further deterioration of the river water quality and may have many far reaching negative consequences on the environment. The takeaway quantitative results from this investigation will highlight information to the public and village councils or board members and impart ideas to tackle river water-related issues. In the near future, predictive model for technical and scientific applications can be developed to counteract the repercussion effect of mining on the river. However, controlling the discharge of coal mining effluents, domestic sewages and agricultural waste into the river system is nonetheless, a critical first step to reduce the pollution vulnerability of Tsurang river.

CHAPTER-6

HEAVY METALS ACCUMULATION ON COAL MINING AFFECTED AND NON-AFFECTED FOREST SOIL, TSURANG RIVER WATER AND BIOACCUMULATION ON SOME DOMINANT PLANT SPECIES

6.1 INTRODUCTION

Heavy metal can be referred to any metallic element with a relatively high density that is toxic or even poisonous at low concentrations (Nagajyoti *et al*., 2010). They are major environmental pollutants, and their toxicity is becoming more of a problem for ecological, evolutionary, nutritional and environmental reasons. Naturally occurring heavy metals in soil are generally in low amounts and typically remain in trace levels, but anthropogenic activities have resulted in massive quantities of metal being discharged into the environment, substantially increasing their concentrations (Gowd *et al*., 2010). According to Nagajyoti *et al*. (2010), heavy metals are most abundant in soil and aquatic ecosystems, with a lower fraction in the atmosphere as particulate or vapors. Currently, heavy metals are exceptional persistent pollutants and their lethality is a problem related with biological to ecological reasons, which is arguably one of the most pressing environmental challenges (Weissmannova and Pavlovsky, 2017). Moreover, mining generates 2.7 billion tonnes of waste which is significantly more than the world's total municipal trash, and is responsible for an increase in various heavy metals in soils,

sediments, surface water and groundwater reserves within the mine's impacted zones (Aucamp, 2003).

Metal contamination is becoming more widespread in India as well as in other parts of the world, with several documented occurrences of metal toxicity in mining, foundries, smelters, coal-burning power plants and agriculture. Heavy metals like cadmium, copper, lead, chromium, and mercury are substantial environmental hazards, especially in places where there is a lot of human activity. Over the past few decades, the Indian coal mining sector has seen tremendous growth in terms of coal generation; though it has been invariably witnessed with a number of environmental hazards, including the improper management of mine water, which is contaminated with a variety of heavy metals (Tiwari *et al*., 2017). Coal composition includes a variety of trace elements which when discharged in abundance causes toxicity and can be lethal for the environment. Layers of soil and rocks above the coal (overburden materials) exposed during mining extraction and processing commonly contain residues of iron, manganese, aluminium including other heavy metals. These metals can be washed into streams as silt or dissolved from mining sites through the action of leachates (Singh, 1998) and anthropogenic sources, notably, mining operations are the main sources of emissions (Nriagu, 1988). In some cases, the released metals can persist in the environment even after mining activities have stopped. Environmental pollution by heavy metals is very prominent in mining areas, and pollution reduces with an increase in the distance from the mining sites (Peplow, 1999). Moreover, quantities of metals, whether from natural sources or anthropogenic activity, can be hazardous to soil microflora (Kumar, 2016). Heavy metal contamination in water can arise from a variety of sources, including industrial discharges from coal washeries and mining activities (Keishiro, 2006). Sludge, municipal compost, pesticides, fertilizers, emissions from industrial waste incinerators, vehicle exhausts, residues of metalliferous rocks and other smelting industries also deposit heavy metals in the environment (Garbisu and Alkorta, 2003). Toxic heavy metals accumulating in soil, water and plants can have a severe impact on regional eco-safety and constitute a threat to agricultural productivity, ecology, animals, humans and plants (Yan *et al*., 2022). Through several paths, a substantial number and variety of trace elements, some of which are potentially harmful are transmitted to the surrounding environment as a result of coal extraction and burning (Reddy *et al*., 2005; Goodarzi *et al*., 2008). The negative consequences of mining activities on water resources are widely established (Nouri *et al*., 2009; Verma and Singh, 2013). In general, mine tailings and

other mining-related operations are the primary sources of pollutants in water (Conesa *et al*., 2007; Mahato *et al*., 2014). Water influx is usually an unwanted feature of coal mining, though it can sometimes be used for processing and dust suppression, and the rest may have to be pumped out. It can be contaminated by particulate matter, oil and grease, unburnt explosives, and other chemicals, and if the coal appears to be high in pyrites, the mine water may be acidic, polluting nearby stream after it is discharged (Tiwary, 2001). In particular, acid mine drainage, which is caused by the oxidation of sulphides in spoil heaps and the mobilization of potentially harmful materials, causes ecological damage (Arroyo and Siebe, 2007). Domestic effluents, consisting of untreated or solely mechanically treated wastewater, substances that have passed through the filters of biological treatment plants and waste substances passed over sewage outfalls and discharged to receiving water bodies, can also elevate metal concentrations in rivers and lakes (Nagajyoti *et al*., 2010). Heavy metal toxicity in plants varies with species, specificity of metal, concentration, chemical form, soil composition and pH. Many heavy metals including copper, manganese, cobalt, zinc and chromium are considered to be essential for plant growth and some plants may bioaccumulate specific metals but majority of plants can be classified as non-accumulator plants. Besides, it is only when metals are beyond the excessive bioavailable levels they have the potential to become lethal to plants (Millaleo *et al*., 2010). Regardless, all plants habituating in metal rich soil must cope with heavy metals for nourishment to thrive in metalliferous soils (Viehweger, 2014). As a result, they must have highly calibrated mechanisms to tolerate with even lethal heavy metals (Hall, 2002; Clemens, 2006). Disturbed mining regions are usually devoid of vegetation, and only a few adaptive species thrive and dominates the community. Plants are able to colonise such areas due to a variety of heavy metal tolerance mechanisms, and these routes offers a variety of beneficial approaches such as phytoremediation and biofortification (Viehweger, 2014). Heavy metal bioavailability in terrestrial ecosystems is influenced by their physicochemical form, growing plant species (Blanco *et al*., 2004) and soil features (Mortvedt, 1994). Irrespective of the source of heavy metals in soil; higher concentrations of metals degrade soil quality, water quality, reduce vegetation cover and also pose hazards to the ecosystems, including biological health (Blaylock and Huang, 2000). Therefore, this research aims to evaluate the heavy metals in the contaminated soil, water and dominant plant species in the coal mine-affected forest and compare their concentrations with the unaffected site including the standard permissible limits of

WHO/BIS. This study will raise environmental awareness of heavy metals in coal mining areas; trigger further work on heavy metals in Northeast India especially in the environmentally degrading coal mine regions of Nagaland and since these elements are globally considered one of the central polluting agents and is of great concern in the present scenario, the data collected will be of valuable information to academicians, researchers and policymakers.

6.2 RESULTS

6.2.1 Heavy metal concentration in soil

As shown in **Table 6.1**, 10 heavy metals (Zn, Cd, Cu, Ni, Pb, Sb, Cr, Hg, Ba and As) were estimated out of which Pb was below the detectable level in CMAF while Pb and Sb were absent in NAF. As observed, Zn was higher in CMAF (54±0.89 mg/kg) than in NAF (40±1.30 mg/kg). The recorded value of Cd in CMAF and NAF are 2.40±0.07 mg/kg and 0.82±0.09 mg/kg respectively. CMAF soil (18.41±0.78 mg/kg) presented higher Ni content than NAF (18.00±0.88 mg/kg) while no significant escalated difference was observed for Cr in CMAF (7.20±0.88 mg/kg) and NAF (7.10±0.78 mg/kg). Cu value in the soil sample of CMAF and NAF are 35.40±0.95 mg/kg and 32.81±1.4 mg/kg respectively while Sb value in CMAF was 1.21±0.55 mg/kg. The heavy metal, Hg was higher in CMAF (3.70±0.47 mg/kg) compared to NAF (1.90±0.37 mg/kg) while Ba content didn't vary much between CMAF (35.71±0.95 mg/kg) and NAF (35.21±0.99 mg/kg). Greater concentration of As was detected in CMAF (22.40±0.92 mg/kg) compared to NAF (14.30±0.84 mg/kg).

Table 6.1: Soil heavy metals (mg/kg) at the CMAF and NAF of Changki

Elements	CMAF	NAF
Zn	54 ± 0.89	40 ±1.30
Cd	2.40 ± 0.07	0.82±0.09
Cu	35.40 ± 0.95	32.81±1.4
Ni	18.41 ± 0.78	18.00±0.88
Pb	ND	ND
Cr	7.20±0.88	7.10±0.78
Sb	1.21±0.55	ND
Hg	3.70±0.47	1.90±0.37
Ba	35.71±0.95	35.21±0.99
As	22.40±0.92	14.30±0.84

ND- Not detected

Soil pollution index

To estimate the soil pollution status of CMAF in relation to the geochemical background or the considered control site (NAF), 10 heavy metals were incorporated out of which the pollution index of Pb could not validated as Pb was not detected in the soil sample. However, the PI of the CMAF shows a varied contamination value for Zn (1.35), Cd (2.92), Cu (1.08), Ni (1.02), Cr (1.00), Sb (1.20), Hg (1.94), Ba (1.00) and As (1.57). In case of PLI and NIPI the substantial values of the CMAF soil are 1.31 and 2.22 respectively.

5.2.2 Heavy metal concentration in water

Water samples from the three sampling stations of Tsurang river were analysed for As, Pb, Zn, Cr, Hg, Ba, Cd, Ni and Sb out of which Sb was below the detectable level or absent in all the samples **(Table 6.2)**. **Fig. 6.1** depicts the graphical representation of heavy metals concentration at the three sampling stations of Tsurang river. The value of As in S1,

Table 6.2: Heavy metals (mg/l) in the water samples at the three sampling stations of Tsurang river

Elements	Station 1	Station 2	Station 3	Desirable limit (WHO, 2008)	Desirable limit (BIS, 2012)
As	0.04	0.06	0.08	0.01	0.01
Pb	0.03	0.05	0.09	0.01	0.01
Zn	4.0	4.06	4.6	3.0	5.0
Cr	0.03	0.02	0.06	0.05	0.05
Hg	0.001	0.001	0.003	0.006	0.001
Ba	0.04	0.09	0.2	0.7	0.7
Sb	ND	ND	ND	0.02	0.005
Cd	0.004	0.007	0.008	0.003	0.003
Ni	0.007	0.009	0.009	0.07	0.02

S2 and S3 are 0.04 mg/l, 0.06 mg/l and 0.08 mg/l respectively. Lower concentration of Pb was detected in S1 (0.03 mg/l) followed by S2 (0.05 mg/l) and S3 (0.09 mg/l). Similarly, Zn also showed lower value in S1 (4.0 mg/l) compared to S2 (4.06 mg/l) and S3 (4.60 mg/l). Maximum Cr was estimated in S3 (0.06 mg/l) followed by S1 (0.03 mg/l) and S2 (0.02 mg/l) while Hg analysis shows a same concentration of 0.001 mg/l in S1 and S2 but with a value of 0.003 mg/l in S3. The heavy metal Ba in the water samples increases from S1 (0.04 mg/l) < S2 (0.09 mg/l) < S3 (0.20 mg/l). Such trend was also observed for Cd in

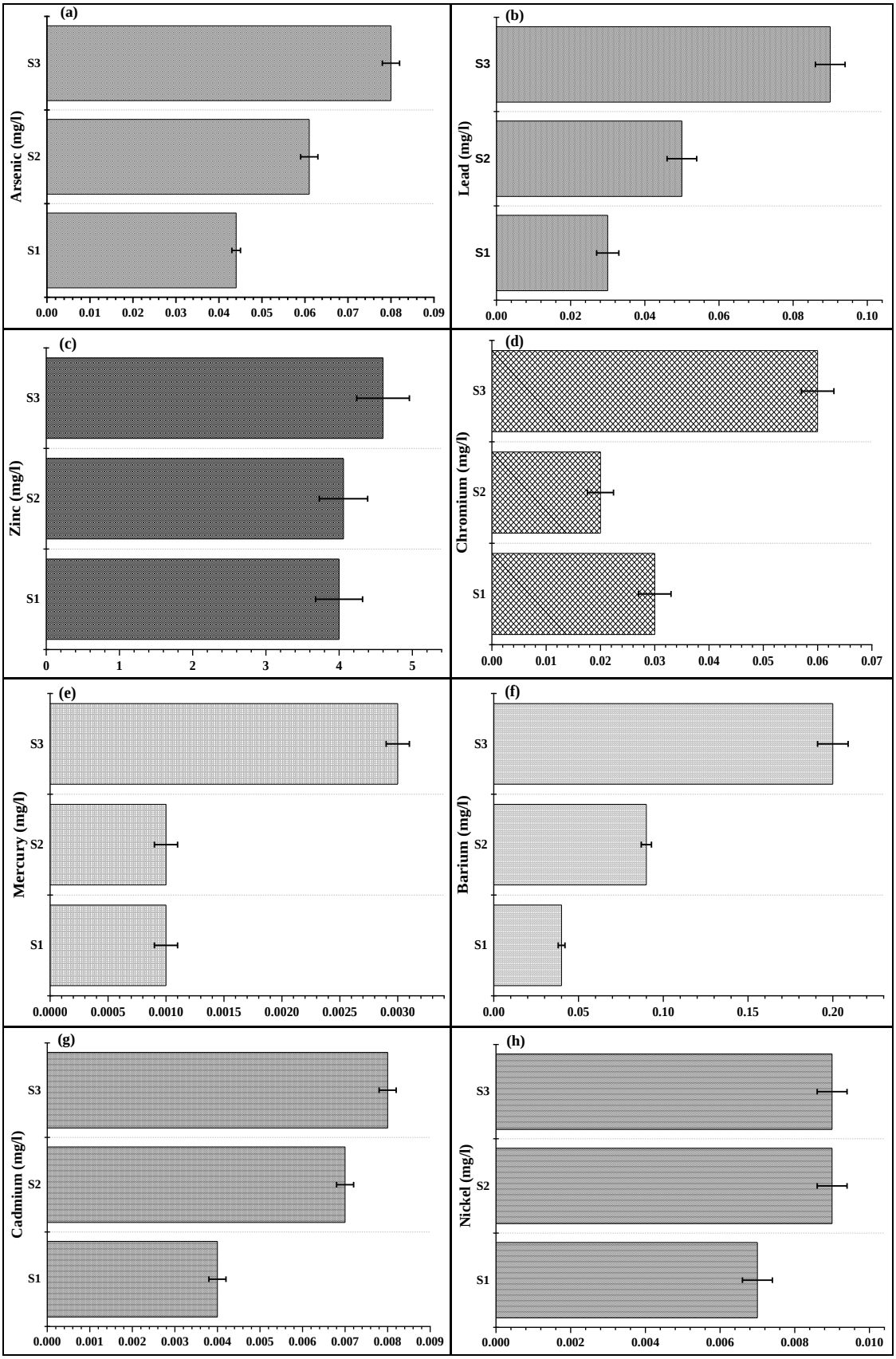


Fig 6.1: Graphical representation of heavy metals (mg/l) at the three sampling stations of Tsurang river

S1 (0.004 mg/l) < S2 (0.007 mg/l) < S3 (0.008 mg/l). Minimum Ni was detected in S1 (0.007 mg/l) while in S2 and S3 an estimated amount of 0.009 mg/l was obtained.

6.2.3 Heavy metal bioaccumulation in plants

Dominant plant species *Melastoma malabathricum, Dicranopteris linearis, Chromolaena odorata, Pteridium esculentum* and *Thysanolaena latifolia* in the study area were analysed for Zn, Cd, Cu, Ni and Pb. However, Pb was not detected in any of the plant samples as presented in **Table 6.3**. At CMAF, Cd was detected highest in *T. latifolia* (1.40±0.07 mg/kg) followed by *P. esculentum* (1.24±0.07 mg/kg) and *D. linearis* (0.91±0.06 mg/kg). While in NAF, highest Cd was recorded from *M. malabathricum* (0.02±0.001 mg/kg) followed by *C. odorata* and *T. latifolia* both with a value of 0.019 mg/kg. Zn bioaccumulation of *M. malabathricum*, *D. linearis*, *C. odorata*, *P. esculentum* and *T. latifolia* in CMAF were 4.67±0.47 mg/kg, 6.82±0.57 mg/kg, 7.60±0.66 mg/kg, 5.20±0.58 mg/kg and 6.60±0.73 mg/kg while in NAF were 3.43±0.47 mg/kg, 3.55±0.57 mg/kg, 4.91±0.66 mg/kg, 1.94±0.58 mg/kg and 2.44±0.73 mg/kg respectively. Highest Cu was recorded in *C. odorata* (15.03±0.84 mg/kg) at CMAF, while in NAF, *T. latifolia* (9.82±0.20 mg/kg) presented maximum Cu concentration value. CMAF plants has higher Ni content, with the maximum in *C. odorata* (8.40±0.28 mg/kg) followed by *T. latifolia* (6.61±0.13 mg/kg). Pearson correlation shows a positively significant relation of soil heavy metals (SHM) with heavy metals bioaccumulation in *M. malabathricum, D. linearis, C. odorata, P. esculentum* and *T. latifolia* in both the forest as presented in **Table 6.4.**

Table 6.3: Bioaccumulation of heavy metals (mg/kg) in the shoots of dominant plants

Elements	*M. malabathricum*		*D. linearis*		*C. odorata*		*P. esculentum*		*T. latifolia*		Standard limits (WHO, 1996)
	CMAF	NAF	CMAF	NAF	CMAF	NAF	CMAF	NAF	CMAF	NAF	
Zn	4.67±0.47	3.43±0.47	6.82±0.57	3.55±0.57	7.60±0.66	4.91±0.66	5.20±0.58	1.94±0.58	6.60±0.73	2.44±0.73	0.60
Cd	0.63±0.03	0.02±0.001	0.91±0.06	0.016±0.004	0.64±0.03	0.019±0.001	1.24±0.07	0.014±0.003	1.40±0.07	0.019±0.001	0.02
Cu	10.4±0.99	5±0.79	12.62±0.84	6.63±0.66	15.03±0.84	9±0.74	12.61±0.46	7.72±0.28	14.61±0.62	9.82±0.20	10
Ni	3.63±0.11	1.50±0.08	5.40±0.17	2.20±0.70	8.40±0.28	5.41±0.21	3±0.098	4.22±0.08	6.61±0.13	4.61±0.13	10
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2

Table 6.4: Pearson's correlation coefficient (r) between soil heavy metal (SHM) with heavy metals bio-accumulated in the plant samples

Forest site	*M. malabathricum*	*D. linearis*	*C. odorata*	*P. esculentum*	*T. latifolia*
Coal Mining Affected Forest (SHM)	0.627	0.977**	0.850*	0.853*	0.971**
Non-Affected Forest (SHM)	0.884*	0.800	0.761	0.514	0.533

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

6.3 DISCUSSION

6.3.1 Soil Pollution Status of CMAF

The toxicity and persistence of heavy metals accumulated in the environment as a result of diverse mining and industrial activities represent a serious issue worldwide (Demkova *et al*., 2017). In the present study, comparative analysis shows a higher escalated amount of heavy metals in CMAF than in NAF soil. Ascertain with greater accumulation of Zn, Cd, Cu, Ni, Sb, Cr, Hg, Ba and As in CMAF soil the intense active mining operation could have elevated the contamination rate which was relatable to research conducted by Agrawal *et al.* (2010); Niu *et al*. (2015); Ying *et al*. (2016) and Demkova *et al*. (2017). The undisturbed NAF soil sample considerably has fewer concentration of heavy metal since naturally occurring heavy metals are quite lesser where anthropogenic activities are limited (Gowd *et al*., 2010). The pollution status of CMAF soil is depicted in **Fig. 6.2.** In regards to soil pollution status, the PI revealed that CMAF soil conditions varied from 'very severe contamination' to 'moderate pollution'. Zn, Cu, Ni, Sb, Hg and As showed 'slight pollution' status while Cr and Ba presented 'very severely contaminated'. However, the contamination degree did not reach the 'pollution level'. The PI for Cd provides a seemingly 'moderate pollution' soil status and exhibit it as the primary potential contributor to soil pollution, which was in conformity with Niu *et al*. (2015) and Nwankwoala and Ememu (2018) in coal mining-affected soils. However, the findings contrast those of Ita and Anwana (2017) and Anwana *et al*. (2018), who estimated Cd concentrations to be minimal in comparison to other metals. Study conducted by Liu *et al*. (2019) and Yan *et al*. (2022) also shows that compared to other elements analysed, Cd and Hg showed higher ecological risk potential due to its contamination level. The degree of pollution in the area estimated through PLI and NIPI indicates that CMAF soil is 'moderately polluted' which can be attributed due to substantially rich heavy metals in the depositions of rocky materials, coal overburden dumps including untreated mine waste drainages into the forested area (Razo *et al*., 2004). Similarly, moderate soil pollution was also observed by Ukpe *et al*. (2021) at Ikwo, Ebonyi state, Nigeria including Mandal and Sengupta (2006) at Kolaghat, West Bengal, India. For the most part, an escalated amount of heavy metals at any region can alter the soil chemistry (Jung, 2001) causing soil toxicity and thus affecting the environmental quality to a great extent.

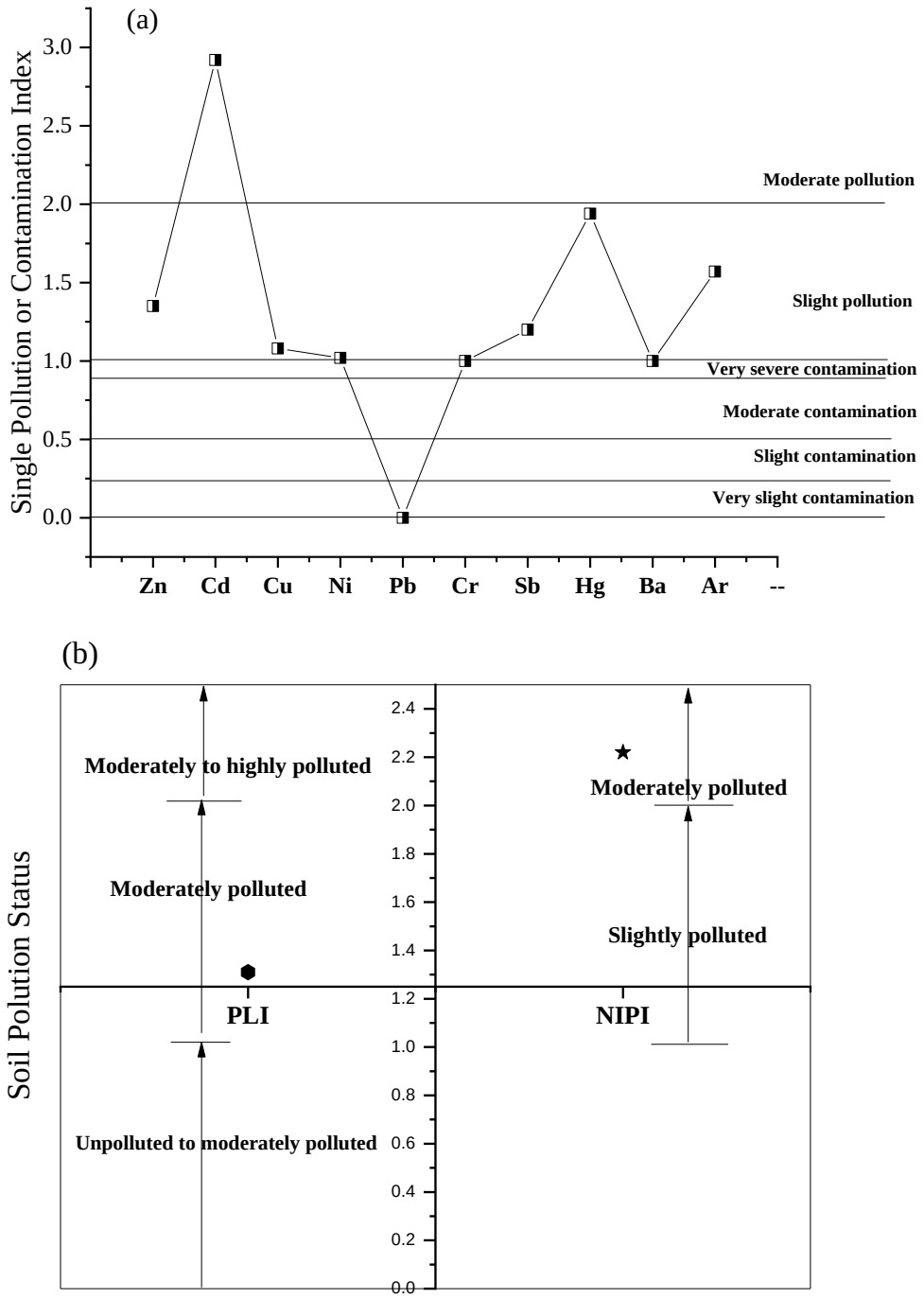


Fig. 6.2: Soil pollution status of CMAF soil a) Single Pollution Index (PI) b) Pollution Load Index (PLI) and Nemerow Integrated Pollution Index (NIPI)

Moreover, mobility of these heavy metals are caused by activity of several atmospheric events e.g., runoff water and blowing winds enhanced their accumulation in the topsoil, polluting air and water that leads to chronic disorders in living bodies inhabiting these localities (Kamran *et al*., 2017).

6.3.2 Estimated heavy metals in water in relation to standard permissible limits (BIS/WHO)

Heavy metals are known to cause varied health issues even in minute concentration and the increasing quantity of heavy metals in our water resources is currently an area of greater concern, especially since a large number of industries are discharging their metal containing effluents into fresh water without any adequate treatment (Salomons *et al*., 1995). Datas recorded from the present investigation shows that As and Pb were beyond the drinking water standard limits (>0.01 mg/l) in all the three sampling stations. High arsenic concentrations in water have resulted in a slew of health-related issues, including hyperkeratosis, loss of appetite, skin lesions in the sole and palm, and skin cancer (ATSDR US, 2005; Karim, 2000). The effects of Pb exposure on human health have been thoroughly studied by competent authorities in several countries where they specify its impact on the nervous system, urinary, cardiovascular, reproductive, including the brain (USATSDR, 2007; EFSA, 2010). In all the stations, Zn was beyond the permissible limits of 3 mg/l prescribed by WHO but within the limits of 5 mg/l set by BIS. Ingestion of large amounts of zinc leads to gastrointestinal effects, such as abdominal pain, vomiting and diarrhoea (WHO, 2017). Cr concentration in the water samples were within the permissible standards of 0.05 mg/l except in S3. Its consumption has been linked to mouth ulcers, indigestion, acute tubular necrosis, vomiting, kidney failure and even death (Beaumont *et al*., 2008). Except for S3, Hg was within the desirable limits of 0.001 mg/l (BIS); however, compared to WHO limits the water samples were all within the standard value. Certain health issues like neurological and behavioural disorders may be observed after inhalation, ingestion or dermal exposure of different mercury compounds; symptoms may include tremors, insomnia and memory loss (WHO, 2017). Ba was within the standard limits of 0.70 mg/l in all the samples. However, small doses of water-soluble barium may cause a person to experience breathing difficulties, high blood pressures, changes of heart rhythm and nerve reflexes,

stomach irritation, muscle cramp, swelling of brains and liver, kidney and heart damage (Kravchenko *et al*., 2014). The lethal metal Cd was beyond the standard concentration of 0.003 mg/l in all sampling points. According to OSHA (2013), minute Cd consumption can aggravate flu-like symptoms (chills, fever and muscle pain) along with lung damage while prolonged exposure (low levels over a long period of time) can cause kidney, bone and lung disease. In all the stations, Ni was found to be within the standard limits of BIS/WHO. As an immune-toxic and carcinogenic agent, Ni can cause a variety of health issues, such as contact dermatitis, cardiovascular disease, asthma, lung fibrosis, including respiratory tract cancer, depending on the dose and length of exposure (Chen *et al*., 2017).

The result reflected that only Ba and Ni were in the drinking water permissible standards while Sb was not detectable. Such heavy metal rich water could be due to sources from coal mining prevalent at the catchment areas. Previous studies (Tripathy, 2010; Mahato *et al*., 2014; Uugwanga and Kgabi, 2021) have also reported that high levels of metals in the water resources of mining areas are mainly associated due to leachate water from coal mines and mine drainages. As reported by Fiket *et al.* (2016) and Medunic *et al.* (2016) mining activities represent a long-term pollution risk as potential release points of various pollutants, including metal(loid)s, with the ability to severely contaminate soils, surface and groundwater in the region, even decades after their disposal. Similar to the current collected datas, Mahato *et al*. (2017) in Damodar river basin, India reported mine water are the main cause of escalated heavy metal such as Mn, Cu, Pb, Zn, Ni, As, Cd and Cr. Li *et al*. (2022) also showed pollution due to As and Cd in the surface water affected by mining waste. Apart from coal mining, household waste could also have elevated the heavy metal concentration in the river water as Angino *et al.* (1970) outlined that most domestic sewages including detergents contain trace amounts of heavy metals. In addition, land application of sewage sludge, organic waste manure, industrial by-products and irrigation with waste water are major sources of heavy metals into agricultural fields (Khan *et al*., 2013) which later affects the water bodies. Varying concentrations of Cd, Cr, Ni, Pb, and Zn are contributed predominantly by fungicides, phosphate fertilizers, and inorganic fertilizers (Kelepertzis, 2014; Toth *et al*., 2016) that significantly deteriorate the river water. Alves *et al.* (2016) also reported agricultural practices along the stretch of the river are the sources of heavy metals like Pb, Cr, As, Zn, Cd, Cu and Ni and these heavy metals gets accumulated into the river system during heavy rainfall, windy seasons or through soil erosion. Interestingly, in this

study, heavy metals concentration increases from upstream to downstream which could be due to trends of water pollution from S1 (upstream) to S3 (downstream) (Semy and Singh, 2021). As coal waste, domestic sewages and agricultural effluents from different catchment areas get accumulated and flows down the river, intensity of heavy metals also increases downstream which was similar with works on heavy metals in river system by Shanbehzadeh *et al.* (2014) and Pandey and Singh (2017).

6.3.3 Bioaccumulations of heavy metals on dominant plants

Among the plant samples in CMAF, *C. odorata* (Cu, Zn and Ni) and *T. latifolia* (Cd) has the highest bioaccumulated concentration of heavy metals which determines their progressive adaptation in the stressed environmental conditions induced by coal mining. Similar results and tolerant nature for *C. odorata* in relation to heavy metals were reported by Swapna *et al*. (2014) and Ayesa *et al.* (2018). As shown through Pearson's correlation coefficient the heavy metals present in the soil has great positive affinity with the heavy metals accumulated in the plant samples. This correlation confirms that the amount or type of heavy metals prevalent in the soil of a specific area can be the major factor regulating the heavy metals accumulated in the plants of that vicinity. Heavy metal concentration in most cases is higher in soil and water (Chen *et al*., 2006) compared to plants. Such observations were recorded in the current indagation as the amount of heavy metals (Zn, Cd, Cu and Ni) in the soil samples were considerably greater compared to their bioaccumulations in the plant samples. Comparative evaluation shows that CMAF plants have greater bioaccumulation of all the heavy metals analysed than their NAF analogue. Similar results were obtained by Deo (2004) in Orissa, India and Niu *et al*. (2017) at Huainan coalfield, China in their works of heavy metal bioaccumulation by plant species from coal mining regions. For decades, coal mining operations is practiced in the study area which has relentlessly deteriorated the vegetation quality and as observed few species like *M. malabathricum, D. linearis, C. odorata, P. esculentum* and *T. latifolia* dominates the CMAF site in large proportion proven by phytosociological studies evaluated in **Chapter-3**. Since mining tends to increase heavy metals content in soil besides other pollutants and these metals are of potential threat to living organisms on account of their extensive uptake and their biotoxicity either in combined or elemental forms (Sayel *et al*., 2014). Therefore, certain mechanisms are developed over the years of exposure to cope up in response to such pollutants or interference. Kumar (2016) reported

that plants developed various cellular and molecular adaptations necessary to tolerate heavy metal stress; the strategies adapted by plants aim to avoid accumulation of heavy metals in cytosol and preventing toxicity symptoms; this is facilitated by using various tolerance mechanisms that are present and are likely to be employed in plant homeostasis. Viehweger, (2014) addresses the mechanisms of heavy metal tolerance and toxicity in plants possessing a sophisticated network for maintenance of metal homeostasis; the key elements of general tolerance mechanisms are based on exclusion, chelation and sequestration processes which result either in removal of toxic metal from sensitive sites or conduct essential metal to their specific cellular destination. In relation to WHO (1996) permissible limits, the metal Cd and Cu in all the plant samples at CMAF were beyond its standard concentration while such surpassing value was not obtained in NAF. Since excess of heavy metal in an environment are indications of disturbances by external forces, the overall findings depicts a balanced ecosystem unaltered by anthropogenic activities in the community protected NAF which has rendered the plant to thrive under natural forest habitat while such ecological state was not validated in CMAF due to coal mining activities along with various other intermittent anthropogenic influences like stone quarries, farming and logging.

6.4 SUMMARY AND CONCLUSION

Assessing heavy metals in soil, water and vegetation is considerably a notable importance to monitor the environmental quality as heavy metals along with many other pollutants can be lethal to biological health even at low concentration due to their gradual accumulations over a period of time. This study revealed that the coal mining activities going on in Changki, Nagaland have a negative impact on the soil, water and vegetation prevailing in the area as mining operations introduces heavy metals above the threshold limits, and alters the natural environmental properties. The data assembled in the research shows a significantly higher amount of heavy metals in the anthropogenically disturbed CMAF compared to the community protected NAF. The metal Zn was recorded with the maximum value but Pb was not present in detectable concentration at both the sites. As observed, the CMAF soil was heavily contaminated due to mining oriented activities and the pollution indices such as Pollution Load Index (PLI) and Nemerow Integration Pollution Index (NIPI) has evidently marked the soil as “moderately polluted”. The Single Pollution Index (PI) or the contamination index has categorized the metals

pollution intensity as Cd>Hg>As>Zn>Sb>Cu>Ni>Cr>Ba>Pb. The PI identified Cd as the primary soil pollutant contributor followed by Hg while such result cannot be validated for Pb due to its absence in the soil. Overall, the PI portrayed the CMAF soil to be under 'very severe contamination' to 'moderate pollution' status.

Comparative assessment of heavy metals in Tsurang river water with their permissible standard limits formulated by BIS/WHO shows that the river water is contaminated by significantly rich amount of metal elements due to coal mining and other anthropogenic activities. Throughout the three sampling stations, the heavy metals As, Pb, Zn, Cr, Hg and Cd were beyond the drinking water permissible limits and an adequate amount of Ba and Ni was detected; however, Sb was undetectable in the water samples. This may poses a serious threat to the environmental quality and the biological health of the region including the local population depending on the Tsurang river water. As heavy metals consumptions in water are known to cause various human ailments such as cardiovascular diseases, lungs infection, respiratory disorder, gastrointestinal and kidney dysfunction, skin cancer, birth defects, nausea, diarrhoea, vomiting, impair brain function, brain inflammation, etc. Therefore, the river water needs to be pre-treated using modern technology tools before consumption as various diseases are borne due to drinking or domestically utilizing water from polluted source.

The study also showed higher bioaccumulation of heavy metals in plants at CMAF compared to their NAF counterparts. Maximum accumulation of heavy metals was recorded in *C. odorata* followed by *T. latifolia*. The relation of soil heavy metals in both the sites were positively significant with the amount of heavy metals in the plant samples which justifies that the presence of certain elements in the soil could be a major factor governing the availability of it in the plants. There are screening levels or regulatory limits for metal concentration in India, all set to protect humans health including crops, wildlife and aquatic fauna. In spite of these regulations, there is still uncertainty as to the nature and extent of heavy metal pollution in coal mine areas, particularly in less scientifically studied areas like the coal mining areas of Nagaland. Thus in this region, there is very little information available on the level of heavy metals in the soil, water and vegetations in places associated with mining activities. This comprehensive research conducted will highlight the effects of coal mining and its intensity in bringing about heavy metal accumulation in the environment and impart knowledge to the local inhabitants, researchers and policy makers. The processes involved in minimizing heavy metal toxicity are of great interest because understanding

how to manipulate tolerance could be useful in developing phytoremediation strategies. Therefore, this study will present reliable datas for the state government to bring about wide-ranging phyto-remediation projects and initiate mining pollution control programs in near future.

REFERENCES

Angino, E.E., Magnuson, L.M., Waugh, T.C., Galle, O.K. and Bredfeldt, J. (1970). Arsenic in detergents-possible danger and pollution hazard. *Science*. 168: 389-392.

Allen, S.E. (1989). Analysis of soils. In: Allen, S.E. (ed) Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford.

APHA (1992). Method 3500-CR: Standard Methods for the Examination of Water and Wastewater.

Anderson, J.M. and Ingram, J.S.I. (Eds.) (1993). Tropical soil biology and fertility: A handbook of methods (2^{nd} ed.). Wallingford: CAB International.

Agrawal, S.B. and Agarwal, M. (2000). Environmental pollution and plant responses. CRC Press, Boca Raton.

Andrews, S.S., Karlen, D.L. and Mitchell, J.P. (2002). A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems and Environment*. 90: 25–45.

Andrews, S.S., Flora, C.B., Mitchell, J.P. and Karlen, D.L. (2003). Grower's perceptions and acceptance of soil quality indices. *Geoderma*. 114: 187–213.

Aucamp, P. (2003). Trace-element pollution of soils by abandoned gold-mine tailings near Potchefstroom, South Africa. *Council of Geoscience*. 130:1-8.

Adewoye, O.O. (2005). Assessment of beneficiation routes of Tantalite ores from key locations in Nigeria. *Journal of Mineral Material Characterization and Engineering*. 4: 67-76.

Ang, H.H. and Lee, K.L. (2005). Analysis of mercury in Malaysian herbal preparations: A peer review. *Journal of Biomedical Sciences*. 4(1), 31-36.

APHA (American Public Health Association) (2005). Standard Methods for the Examination of Water and Wastewater, Method 1020.

ATSDR US (2005). Agency for toxic substances and diseases registry. Toxicological profile for Arsenic.

Ahipathy, M.V. and Puttaiah, E.T. (2006). Ecological characteristics of Vrishabhavathy river in Bangalore (India). *Environmental Geology*. 49(8): 1217-1222.

Arroyo, R.R.Y. and Siebe, C. (2007). Weathering of sulphide minerals and trace element speciation in tailings of various ages in the Guanajuato mining district, Mexico. *Catena*. 71: 497-506.

Agrawal, P., Mittal, A., Prakash, R., Kumar, M., Singh, T.B. and Tripathi, S.K. (2010). Assessment of contamination of soil due to heavy metals around coal fired thermal power plants at Singrauli region of India. *Bulletin of Environmental Contamination and Toxicology*. 85: 219-223.

Ahmad, I., Ahmad, M.S.A., Hussian, M. and Ashraf, M.Y. (2011). Spatio-Temporal variations in soil characteristic and nutrient availability of an open scrub type rangeland in the sub–mountainous Himalayan tract of Pakistan. *Pakistan Journal of Botany*. 43(1): 565-571.

Appiah, D.O. and Buaben, J.N. (2012). Is gold mining a bane or a blessing in Sub-Saharan Africa: The case of Ghana. *International Journal of Development and Sustainability*. 1(3): 1033-1048.

Adekunle, V.A.J., Olagoke, A. and Akindele, S.O. (2013). Tree species diversity and structure of a Nigerian strict nature reserve. Tropical Ecology. 54(3): 275-288.

Armenise, E., Redmile-Gordon, A.M., Stellacci, A. and Rubino, C.P. (2013). Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment. *Soil and Tillage Research*. 130: 91-98.

Akram, G. and Khan, I. (2014). Impacts of coal mining on vegetation and water quality. *The International Journal of Science and Technology*. 2(4): 176-182.

Adhikari, G. and Bhattacharyya, K.G. (2015). Correlation of soil organic carbon and nutrients (NPK) to soil mineralogy, texture, aggregation, and land use pattern. *Environmental Monitoring and Assessment*. 187(11): 735.

Alves, L.R., Reis, A. and Gratao, P.L. (2016). Heavy metals in agricultural soils: From plants to our daily life. *Científica*. 44(3): 346-361.

Ahirwal, J. and Maiti, S.K. (2017). Assessment of carbon sequestration potential of revegetated coal mine overburden dumps: a chronosequence study from dry tropical climate. *Journal of Environmental Management*. 201: 369-377.

Ahirwal, J., Maiti, S.K. and Singh, A.K. (2017). Changes in ecosystem carbon pool and soil CO_2 flux following post-mine reclamation in dry tropical environment, India. *Science of the Total Environment*. 583: 153-162.

Ahirwal, J. and Maiti, S.K. (2018). Development of Technosol properties and recovery of carbon stock after 16 years of revegetation on coal mine degraded lands, India. *Catena*. 166: 114-123.

Akash, N. and Bhandari, B.S. (2018). Phytosociological studies, biodiversity conservation in a sub-tropical moist deciduous forest of Rajaji Tiger reserve; Uttarakhand, India. *International Journal of Research and Analytical Reviews*. 5(3): 39-50.

Anwana, E.D., Ita, R.E. and Mbong, E.O. (2018). Spatial concentrations of heavy metals in soils and plants of a landfill site in Uyo, AkwaIbom state. *Cancer Biology*. 8(1): 144-149.

Ayesa, S.A., Chukwuka, K.S. and Odeyemi, O.O. (2018). Tolerance of *Tithonia diversifolia* and *Chromolaena odorata* in heavy metal simulated-polluted soils and three selected dumpsites. *Toxicology Reports*. 5: 1134-1139.

Ao, A., Changkija, S. and Tripathi, S.K. (2020). Species diversity, population structure, and regeneration status of trees in Fakim Wildlife Sanctuary, Nagaland, Northeast India. *Biodiversitas*. 21: 2777-2785.

Ao, A., Changkija, S. and Tripathi, S.K. (2021). Stand structure, community composition and tree species diversity of sub-tropical forest of Nagaland, Northeast India. *Tropical Ecology*. 62(4): 549.

Bentham, G. and Hooker, J.D. (1862-1883). Genera Plantarum. Volume3. London.

Bor, N.L. (1940). Flora of Assam. Volume 5.Gramineae.Government of Assam, Shillong. p. 480.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Sciences*. 59: 39-45.

Bower, C.A., Reitemeier, R.F. and Fireman, M. (1952). Exchangeable cation analysis of saline and alkali soils. *Soil Science*. 73: 251-261.

Brown, R.M., McCleland, N.I., Deininger, R.A. and Tozer, R.G. (1970). A water quality index—Do we dare? *Water and Sewage Works*. 117(10): 339-343.

Brown, R.M., McCleland, N.I., Deininger, R.A. and O'Connor, M.F. (1972). A water quality index—crashing the physiological barrier. *Indicators of Environmental Quality*. 1: 173-182.

Bussler, B.H., Byrness, W.R., Pope, .P.E. and Chaney, W.R. (1984). Properties of mine soil reclaimed for forest land use. *Soil Science Society of American Journal*. 48:178-184.

Bennet, S.S.R. (1987). Name changes in flowering plants of India and adjacent regions. Triseas Publishers, Dehradun, p. 772.

Biswas S.K., Bhasin, A.L. and Ram, J. (1994). Classification of Indian sedimentary basins in the framework of plate tectonics. Proceedings of the Second Seminar on Petroliferous basins of India. KDM Institute of Petroleum Exploration, Dehradun. 1: 1-46.

Bradshaw, A.D. (1997). The importance of soil ecology in restoration science. *Restoration ecology and sustainable development*. Cambridge University Press, UK.

Blaylock, M.J. and Huang, J.W. (2000). Phytoremediation of Toxic metals: Using plants to clean up the environment. John Wiley, New York, pp. 53-71.

Barapanda, P., Singh, S.K. and Pal, B.K. (2001). Utilization of coal mining wastes: An Overview. National Seminar on environmental issues and allied industries, Regional Engineering College, Rourkela, Orissa, India, pp. 177-182.

Bell, F.G., Bullock, S.E.T., Halbich, T.F.J. and Lindsey, P. (2001). Environment impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. *International Journal of Coal Geology*. 45: 195-216.

Brunn, A., Dittmann, C., Fischer, C. and Richter, R. (2001). Atmospheric correction of 2000 HyMAP data in the framework of the EU-project MINEO. Image and Signal Processing for Remote Sensing VII. 4541: 382-392.

Brandl, R., Eber, S. and Johst, K. (2002). Metapopulation persistence in dynamic landscapes: the role of dispersal distance. *Oikos*. 98: 263-270.

Bachan, K.H. (2003). Riparian vegetation along the middle and lower zones of the Chalakkudy river, Kerala, India. Limnological Association of Kerala, Irangalakkuda.

Bhuyan, P., Khan, M.L. and Tripathi, R.S. (2003). Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. *Biodiversity and Conservation*. 12: 1753-1773.

Blanco, P., Tomé, F.V. and Lozano, J.C. (2004). Sequential extraction for radionuclide fractionation in soil samples: a comparative study. *Applied Radiation and Isotopes*. 61: 345-350.

Bhatt, B.P. and Sachan, M.S. (2004). Firewood consumption pattern of different tribal communities in Northeast India. *Energy Policy*. 32(1):1-6.

BIS-IS 10500 (2004). Standard parameters given by Government of India.

Barajas-Gea, C.I. (2005). Evaluacion de la diversidad de la flora en el campus Juriquilla de la UNAM. *Bol-e: Organo de comunicacion electronic del Centro de Geociencias de la UNAM*. 1(2).

Baruah, B.P., Kotoky, P. and Rao, P.G. (2005). Genesis of acid mine drainage from coalfields of Assam, India. *International Seminar on Coal Science and Technology*. p. 245.

Barik, S.K., Pandey, H.N., Tiwari, B.K., Sarma, K. and Singh, B. (2006). Coal mining in Meghalaya: An environmental perspective. Regional centre, National afforestation and eco-development board, North Eastern Hill University, Shillong, India, pp. 1-21.

Boruah, D.H.P. (2006). North eastern coal and environment: An overview, Proceedings on Characterization and Gainful Utilisation of NE Coal, RRL, Jorhat, pp. 28-33.

Beaumont, J.J., Sedman, R.M., Reynolds, S.D., Sherman, C.D., Li, L.H., Howd, R.A., Sandy, M.S., Zeise, L. and Alexeeff, G.V. (2008): Cancer mortality in a Chinese population exposed to hexavalent chromium in drinking water. *Epidemiology*. 19(1): 12- 23.

Benyahya, L., Hiliare, A., Ouarda, T.M.J., Bobee, B. and Dumas, J. (2008). Comparison of nonparametric and parametric water temperature models on the Nivelle river, France. *Hydrological Sciences*. 53(3): 640-655.

Blander, M. (2010). Calculations of the influence of additives on coal combustion deposits. *Argonne National Laboratory.* IL (USA).

Bahrami, B., Olsen, K., Latham, P.E., Roepstorff, A., Rees, G. and Frith, C.D. (2010). Optimally interacting minds. *Science*. 329: 1081-1085.

Bhuiyana, L.P., Mohammad, A.H., Islam, M.A., Samuel, B. and Dampare, S.S. (2010). Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. *Journal of Hazardous Materials*. 173: 384-392.

Barzani, M.G., Ismail, B.S., Sujaul-Islam, M., Abd. Rahim, S. and Toriman, M.E. (2011). The physicochemical properties of four soil series in Tasik Chini, Pahang, Malaysia. *Asia Journal of Earth Sciences*. 4(2): 75-84

Basyal, S., Lekhak, H.D. and Devkota, A. (2011). Regeneration of *Shorea robusta*. Gaertn in tropical forest of Palpa district, Central Nepal. *Scientific World*. 9: 53-56.

Bhardwaj, A.K., Jasrotia, P., Hamilton, S.K. and Robertson, G.P. (2011). Ecological management of intensively cropped agro-ecosystems improves soil quality with sustained productivity. *Agricultural Ecosystem and Environment*. 3: 419-429.

Brzezinska, M., Sokolowska, Z., Alekseeva, T., Alekseev, A. and Hajnos, M. (2011). Some characteristics of organic soils irigated with municipal wastewater. *Land Degradation and Development*. 22: 586-595.

Balan, I.N., Shivakumar, M. and Kumar, P.D. (2012). An assessment of ground water quality using water quality index in Chennai, Tamil Nadu, India. *Chronicles of Young Scientists*. 3(2): 146-150.

BIS-IS. (2012). Indian standard drinking water specification. 2nd Edition, Standard parameters by Government of India.

Bitzer, L.Z. (2012). Chronic toxicity testing in mining influenced streams of West Virginia. Thesis submitted to the Graduate College of Marshall University.

Bora, A. and Bhattacharyya, D. (2017). Phytodiversity of Barail wildlife sanctuary, Assam, India: field-based observations—I. Trees and lianas. *Check List*. 13: 1037-1053.

Bora, M. and Goswami, D.C. (2017). Water quality assessment in terms of water quality index (WQI): Case study of the Kolong river. *Applied Water Science*. 7(6): 3125-3135.

Bouslah, S., Djemili, L. and Houichi, L. (2017). Water quality index assessment of KoudiatMedouar reservoir, northeast Algeria using weighted arithmetic index method. *Journal of Water and Land Development*. 35(1): 221-228.

Bradford, A. (2018). Deforestation: Facts, Causes and Effects. Retrieved from: https://www.livescience.com/27692-deforestation.html; Accessed on: 28/01/2019

Curtis, J.T. and McIntosh, R.P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecologia*. 31: 434-455.

Cottam, G. and Curtis, J.T. (1956). The use of distance measures in phytosociological sampling. *Ecologia*. 37: 451-460.

Curtis, J.T. (1959). The vegetation of Wisconsin: an ordination of plant communities. University of Wisconsin Press, Madison, Wisc, p 657.

Corbett, R.G. (1977). Effects of coal mining on ground and surface water quality, Monongalia County, West Virginia. *Science of the Total Environment*. 8(1): 21-38.

Chaulya, S.K. and Chakraborty, M.K. (1995). 'Perspective of New National Policy and Environ-mental Control for Mineral Sector', in G.S. Khuntia (ed.). Proceedings of National Seminar on Status of Mineral Exploitation in India, New Delhi, India, pp. 114-123.

Chatterjee, C. and Raziuddin, M. (2002). Determination of water quality index (WQI) of a degraded river in Asansol Industrial area, P.O. Raniganj, District Burdwan, West Bengal. *Nature Environment and Pollution Technology*. 1(2): 181-189.

Criddle, R.S., Church, J.N., Smith, B.N. and Hansen, L.D. (2003). Fundamental causes of the global.

Cui, L., Bai, J. and Shi, Y. (2004). Water analysis in coal mining drainage. *Acta Pedologica Sinica*. 6: 896.

Cleal, C. J. and Thomas, B.A. (2005). Palaeozoic tropical rainforests and their effect on global climates: is the past the key to the present? *Geobiology*. 3(1): 13-31.

Clemens, S. (2006). Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. *Biochimie*. 88: 1707-1719.

Chen, Y., Graziano, J.H., Parvez, F., Hussain, I., Momotaj, H. And Geen, V.A. (2006). Modification of risk of arsenicinduced skin lesions by sunlight exposure, smoking and occupational exposures in Bangladesh. *Epidemiology*. 17: 459-467.

Conesa, H.M., Faz, A. and Arnalsos, R. (2007). Initial studies for the phytostabilization of a mine tailing from the Cartagena—La Union Mining District (SE Spain). *Chemosphere*. 66: 38-44.

Chu, M. (2008). Natural revegetation of coal fly ash in a highly saline disposal lagoon in Hong Kong. *Applied Vegetation Science*. 11: 297-306.

Culas, R.J. (2009). The causes and consequences of tropical deforestation: a review. *International Journal of Climate Change: Impacts and Responses*. 1 (2): 127-139.

Chatterjee, R., Tarafder, G., and Paul, S. (2010). Ground quality assessment of Dhanbad district, Jharkand, India. *Bulletin of Engineering Geology and the Environment*. 69(1): 137-141.

Chauhan, A. and Singh, S. (2010). Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion*. 2(9): 53-61.

Castleden, W.M., Shearman, D., Crisp, G. and Finch, P. (2011). The mining and burning of coal: effects on health and the environment. *The Medical Journal of Australia*. 195(6): 333-335.

Chaulya, S.K., Kumar, A., Mandal, A., Tripathi, N., Singh, R.S., Mishra, P.K. and Bandyopadhyay, L.K. (2011). Assessment of coal mine road dust properties for controlling air pollution. *International Journal of Environmental Protection*. 1(2): 1-7.

Conant, R.T. (2011). Temperature and soil organic matter decomposition rates-synthesis of current knowledge and a way forward. *Global Change Biology*. 17: 3392-3404.

Chabukdhara, M. and Singh, O.P. (2016). Coal mining in Northeast India: an overview of environmental issues and treatment approaches. *International Journal of Coal Science and Technology*. 3(2): 87-96.

Chen, Q.Y., Brocato, J., Laulicht, F. and Costa, M. (2017). Mechanisms of nickel carcinogenesis. In: Mudipalli A., Zelikoff J.T., (eds). Essential and Non-Essential metals.Molecular and Integrative Toxicology. Springer International Publishing AG; New York, NY, USA, pp. 181-197.

Down, C.G. (1974). The relationship between colliery waste particles sizes and plant growth. *Environmental Conservation*. 1: 29-40.

Dunnette, D.A. (1979). A geographically variable water quality index used in Oregon. *Journal of Water Pollution Control Federation.* 51(1): 53-61.

Donahue, R.L., Miller, R.W. and Shickluna, J.C. (1990). Soils: An introduction to soils and plant growth. Prentice- Hall, Upper Saddle River.

Dittmann, C., Vosen, P. and Brunn, A. (2002). MINEO (Central Europe) Environment test site in Germany - Contamination/impact mapping and modelling - Final report.

Deo, B. (2004). Heavy metal accumulation by plant species from a coal mining area in Orissa. *Journal of Environmental Biology*. 25(2): 163-6.

David, L. and Mark, B. (2005). Practical conservation biology, Australia. CSIRO publishing, pp. 25-30.

Driche, M., Abdessemed, D. and Nezzal, G. (2008). Treatment of waste water by natural lagoon for its reuse in irrigation. *American Journal of Engineering and Applied Sciences*. 1(4): 408-413.

Donggan, G., Zhongke, B., Tieliang, S., Hongbo, S. and Wen, Q. (2011). Impacts of coal mining on the aboveground vegetation and soil quality: A case study of Qinxin coal mine in Shanxi Province, China. *Clean Soil Air Water*. 39: 219-225.

Devi, U., Sharma, P., Rana, J.C. and Sharma, A. (2014). Phytodiversity assessment in Sangla valley, Northwest Himalaya, India. *Check List*. 10(4): 740-760.

Dejun, Y., Zhengfu, B. and Shaogang, L. (2016). Impact on soil physical qualities by the subsidence of coal mining: a case study in Western China. *Environmental Earth Sciences*. 75: 652.

Demkova, L., Jezny, T. and Bobulska, L. (2017). Assessment of soil heavy metal pollution in a former mining area – before and after the end of mining activities. *Soil and Water Research*. 12: 229-236.

DEFCC (Department of Environment, Forest and Climate Change) (2018). Government of Nagaland, Status of forest report. https://forest.nagaland.gov.in

Devi, N.L., Singha, D. and Tripathi, S.K. (2018). Tree species composition and diversity in tropical moist forests of Mizoram, Northeast India. *Indian Journal of Ecology*. 45(3): 454-461.

Dey, S. (2018). Studies of the diversity of flowering plants of Tuensang district, Nagaland. Ph. D. thesis submitted to the department of Botany, Nagaland University, Lumami, Nagaland, India.

Elias, E.A., Cichota, R., Torraiani, H.H. and Lier, Q.D.J.V. (2004) Analytical soil temperature model: correction for temporal variation of daily amplitude. *Soil Science Society of America Journal*. 68(3): 784-788.

Espana, J.S., Enrique, L.P., Esther, S., Osvaldo, A., Jesus, R. and Daniel, B. (2005). Acid mine drainage in the Iberian Pyrite Belt (Odiel river watershed, Huelva, SW Spain): Geochemistry, mineralogy and environmental implications. *Applied Geochemistry*. 20: 1320-1356.

EFSA (2010). Panel on Contaminants in the Food Chain (CONTAM). Scientific opinion on lead in food. *European Food Safety Authority Journal*. 8(4): 1570.

Equeenuddin, S.M., Tripathy, S., Sahoo, P.K. and Panigrahi, M.K. (2010). Hydrogeochemical characteristics of acid mine drainage and water pollution at Makum Coalfield, India. *Journal of Geochemical Exploration*. 105: 75-80.

Energy Statistics (2019). Ministry of Statistics and Programme Implementation. Government of India.

Fan, Y.H., Lu, Z.H. and Cheng, J.L. (2003). Major ecological and environmental problems and the ecological reconstruction technologies of the coal mining areas in China. *Acta Ecologica Sinica*. 23(10): 2144-2152.

Fausch, K.D., Baxter, C.V. and Murakami, M. (2010). Multiple stressors in north temperate streams: lessons from linked forest- stream ecosystems in Northern Japan. *Freshwater Biology*. 55(1): 120-134.

Fulazzaky, M.A. (2010). Water quality evaluation system to assess the status and the suitability of the Citarum river water to different uses. *Environmental Monitoring and Assessment*. 168(1): 669-684.

Feiza, V., Feiziene, D., Kadziene, G., Lazauskas, S. and Deveikyte, I. (2011). Soil state in the 11^{th} year of three tillage systems application on a cambisol. *Journal of Food, Agriculture and Environment*. 9: 1088-1095.

Feng, W.T., Plante, A.F. and Six, J. (2013). Improving estimates of maximal organic carbon stabilization by fine soil particles. *Biogeochemistry*. 112: 81-93.

FAO (2015). Global forest resources assessment. FAO forestry paper No. 1. Rome. United Nation, Food and Agriculture Organization.

Fashola, M.O., Jeme, V.M.N. and Babalola, O.O. (2016). Heavy metal pollution from gold mines: environmental effects and bacterial strategies for resistance. *International Journal of Environmental Research and Public Health*. 13(11): 1047.

Frelich, L.E. (2019). Terrestrial ecosystem impacts of sulfide mining: Scope of issues for the boundary waters canoe area wilderness, Minnesota, USA. *Forests*. 10(9): 747.

FAO and UNEP (2020). The state of the world's forests. Forests, biodiversity and people, Rome. p. 214.

Forest Survey Report (2021). India state of forest report. Minister for Environment, Forest and Climate Change.

Gould , A.R. and Liberta, A.E. (1981). Effects of storage during surface mining on the viability of vesicular arbuscular mycorrhiza. *Mycologia*. 73: 914-922.

Glover, J.D., Reganold, J.P. and Andrews, P.K. (2000). Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. *Agriculture, Ecosystems and Environment*. 80: 29-45.

Ghosh, R. (2002). Land use in mining areas of India. Minenvis Monograph. No.9. Centre on Mining Environment.

Gupta, D.S., Tiwari, B.K. and Tripathi, R.S. (2002). Coal Mining in Jaintia Hills, Meghalaya: An ecological perspective. *In*: Jaintia Hills, a Meghalya Tribe: Its Environment, Land and People. Passah P.M. and A.S. Sarma A.S. (Eds), Reliance Publishing House, New Delhi, pp. 121-128.

Gahoonia, T.S. and Nielsen, N.E. (2003). Phosphorus (P) uptake and growth of root hairless barley mutant (bald root barley) and wild type in low and high-P soils. Plant, Cell and Environment. 26(10): 1759-1766.

Grogan, P. and Jonasson, S. (2003). Controls on annual nitrogen cycling in the understorey of a sub-arctic birch forest. *Ecology*. 84(1): 202–218.

Garbisu, C. and Alkorta, I. (2003). Basic concepts on heavy metal soil bioremediation. *European Journal of Mineral Processing and Environmental Protection*. 13(1): 58-66.

Ghose, M.K. (2004). Effect of open cast mining on soil fertility. *Journal of Sceintific and Industrial Research*. 63: 1006-1009.

Goswami, U. and Sarma, H.P. (2007). Study of groundwater contamination due to municipal solid waste dumping in Guwahati city. *Pollution Research*. 26(2): 211-214.

Gemici, U. (2008). Evaluation of the water quality related to the acid mine drainage of an abandoned mercury mine (Alasehir, Turkey). *Environmental Monitoring and Assessment*. 147(1): 93-106.

Goodarzi, F., Huggins, F.E. and Sanei, H. (2008). Assessment of elements, speciation of As, Cr, Ni and emitted Hg for a Canadian power plant burning bituminous coal. *International Journal of Coal Geology*. 74: 1-12.

Government of Nagaland (2009). Investment opportunities in mineral sector in Nagaland. Directorate of geology and mining, Dimapur, Nagaland.

Gairola, S.K. and Soni, P. (2010). Role of soil physical properties in ecological succession of restored mine land – A Case Study. *International Journal of Environmental Science*. 1(4): 475-480.

Gowd, S.S., Reddy, M.R. and Govil, P.K. (2010). Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga plain, Uttar Pradesh, India. *Journal of Hazardous Materials*. 174: 113-121.

Government of Nagaland (2014a). Nagaland Coal Policy (1st Amendment) Rules.

Government of Nagaland (2014b). Nagaland Coal Policy (1st Amendment) Rules.

Goswami, S. (2015). Impact of coal mining on environment. A study of Raniganj and Jharia Coal field in India. *Journal of Arts and Humanities.* 3(1).

Gajic, G., Djurdjevic, L., Kostic, O., Jaric, S., Mitrovic, M. and Stevanovic, B. (2016). Assessment of the phytoremediation potential and an adaptive response of *Festuca rubra* L. sown on fly ash deposits: native grass has a pivotal role in ecorestoration management. *Ecological Enginering*. 93: 250-261.

Gajic, G. and Pavlovic, P. (2018). The role of vascular plants in the phytoremediation of fly ash deposits in Phytoremediation: Methods, Management and Assessment, ed V. Matichenkov (New York, NY: Nova Science Publishers, Inc.). pp. 151-236.

Guo, X.M., Zhao, T.Q., Chang, W.K., Xiao, C.Y. and He, Y.X. (2018). Evaluating the effect of coal mining subsidence on the agricultural soil quality using principal component analysis. *Chilean Journal of Agricultural Research*. 78(2): 173-182.

Horton, R.K. (1965). An index number system for rating water quality. *Journal of the Water Pollution Control Federation*. 37(3): 300-306.

Hudson, T.L., Borden, J.C., Russ, M. and Bergstrom, P.D. (1997). Controls on As, Pb and Mn distribution in community soils of an historic mining district, Southwestern Colorado. *Environmental Geology*. 33: 25-42.

Herawati, N., Susuki, S., Hayasi, K., Rivai, I.E. and Koyama, H. (2000). Cadmium, copper and Zinc levels in rice and soil of Japan. *Bulletin of Environmental Contamination and Toxicology*. 64: 33-39.

Hall, J.L. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. *Journal of Experimental Botany*. 53(366): 1-11.

He, W.L. (2003). Mining subsidence and damage in mountainous region. China Science and Technology, Beijing (in Chinese).

Huang, W., Pohjonen, V., Johansson, S., Nashanda, M., Katigula, M.I.L. and Luukanen, O. (2003). Species diversity, forest structure and species composition in Tanzanian tropical forests. *Forest Ecology and Management*. 173: 11-24.

Huang, H.Y. and Zhang, T.C. (2004). Effects of low pH on nitrate reduction by iron powder. *Water Research*. 38(11): 2631-2642.

Hu, Z.Q., Wang, P.J. and Li, J. (2012). Ecological restoration of abandoned mine land in China. *Journal of Resources and Ecology*. 3(4): 289-296.

Halim, M.A., Majunder, R.K., Zaman M.N., Hossain, S., Rasul, M.G. and Sasaki, K. (2013). Mobility and impact of trace metals in Barapukuria coal mining area, Northwest Bangladesh. *Arabian Journal of Geosciences*. 6(12): 4593-4605.

Howladar, M.F., Deb P.K., Muzemder, A.T.M. and Ahmed, M. (2014). Evaluation of water resources around Barapukuria coal mine industrial area, Dinajpur, Bangladesh. *Application Water Science*. 4(3): 203-222.

Huang, Y., Tian, F., Wang, Y. and Wang, M. (2015). Effect of coal mining on vegetation disturbance and associated carbon loss. *Environmental Earth Sciences*. 73(5): 2329-2342.

ICMR (1975). Manuals of standards of quality for drinking water supplies. Indian Council of Medical Research, New Delhi.

IS (1992). Indian Standard-3025. Methods of sampling and test (physical and chemical) for water and wastewater. Water sectional committee, CDC 26:P1.

ISO (1998). International Organization for Standardization–11047, First edition. Determination of heavy metals - Flame and electrothermal atomic absorption spectrometric methods.

IS (2001). Indian Standard-9806. Methods of sampling and test (physical and chemical) for water and wastewater.

IS (2005). Indian Standard-13428. Packages natural mineral water specification (Heavy metals).

India Meteorological Department (IMD) (2017). Seasons in India: 4 Seasons, Northeast India.

Ita, R.E. and Anwana, E.D. (2017). Geochemical assessment of heavy metals contamination in rural and urban wetlands in AkwaIbom State, Nigeria. *New York Science Journal*. 10(11): 43-51.

Jackson, M.L. (1973). Soil chemical analysis, 2nd Ed. Prentice Hall, India Pvt. Ltd. New Delhi, pp. 111-182.

Jain, S.K. and Rao, R.R. (1977). A handbook of field and herbarium methods. Today and tomorrow printers and publishers, New Delhi, p. 157.

James, I., Sam, I. and Kevin, M.B. (2000). Effects of coal mine drainage on stream water quality in the Allgheny and Monogahela river basins-sulphate transport and trends, Geological survey's (USGS) National quality assessment report. United States.

Jung, M.C. (2001). Heavy metal contamination of soils and wa-ters in and around the Imcheon Au–Ag mine, Korea. *Applied Geochemistry*. 16(11-12): 1369-1375.

Jimenez, M.N., Bacchetta, G., Casti, M., Navarro, F.B., Lallena, A.M. and Fernandez-Ondono, E. (2011). Potential use in phytoremediation of three plant species growing on contaminated mine-tailings soils in Sardinia. *Ecological Engineering*. 37: 392-398.

Kjeldahl, J. (1883). A new method for the determination of Nitrogen in organic matter. *Journal of Analytical Chemistry*. 22(1): 366-383.

Kanjilal, U.N., Kanjilal, P.C., Das, A. and Purkayastha, C. (1934). Flora of Assam. Volume 1. Ranunculaceae to Elaeocarpaceae. Government of Assam, Shillong. p. 184.

Kanjilal, U.N., Kanjilal, P.C. and Das, A. (1936). Flora of Assam. Volume 2. Connaraceae to Cornaceae. Government of Assam, Shillong. p. 409.

Kanjilal, U.N., Das, A., Kanjilal, P.C. and De, R.N. (1938). Flora of Assam. Volume 3. Caprifoliaceae to Plantaginaceae. Government of Assam, Shillong. p. 578.

Kanjilal, U.N., Kanjilal, P.C., De, R.N. and Das, A. (1940). Flora of Assam. Volume 4. Nyctaginaceae to Cycadaceae. Government of Assam, Shillong. p. 377.

Keller, J., Keller, A. and Davids, G. (1998). River basin development phases and implications of closure. *Journal of Applied Irrigation Science*. 33(2): 145-163.

Karim, M. (2000). Arsenic in groundwater and health problems in Bangladesh. *Water Resources*. 34: 304-310.

Kanae, S., Oki, T. and Musiake, K. (2001). Impact of deforestation on regional precipitation over the Indochina Peninsula. *Journal of Hydrometeorology*. 2(1): 51-70.

Khan, R., Israili, S.H., Ahmed, H. and Mohan, A. (2005). Heavy metal pollution assessment in surface water bodies and its suitability for irrigation around the Neyevli lignite mines and associated industrial complex, Tamil Nadu, India. *Mine Water and the Environment*. 24(3): 155-161.

Khumbongmayum, A.D., Khan, M.L. and Tripathi, R.S. (2005). Sacred groves of Manipur, northeast India: biodiversity value, status and strategies for their conservation. *Biodiversity and Conservation*. 14(7): 1541-1582.

Keishiro, H. (2006). Mine water contamination and quality management policy in Asia. *International Review for Environmental Strategies*. 6: 291-306.

Kumar, A., Marcot, B.G. and Saxena, A. (2006). Tree species diversity and distribution patterns in tropical forests of Garo Hills. *Current Science*. 9(10): 1370-1381.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.H., Haberl, H. and Fischer-Kowalski, M. (2009). Growth in global materials use, GDP and population during the 20th century. *Ecological Economics*. 68(10): 2696-2705.

Kumar, R.N., Solanki, R. and Kumar, J.I.N. (2011). An assessment of seasonal variation and water quality index of Sabarmati river and Kharicut canal at Ahmedabad, Gujarat. *Journal of Environmental, Agricultural and Food Chemistry*. 10(5): 2248-2261.

Khan, I., Javed, A. and Khurshid, S. (2013). Physicochemical analysis of surface and groundwater around Singrauli coal field, district Singrauli, Madhya Pradesh, India. *Environmental Earth Sciences*. 68(7): 1849-1861.

Khan, M.U., Malik, R.N. and Muhammad, S. (2013). Human health risk from Heavy metal via food crops consumption with wastewater irrigation practices in Pakistan. *Chemosphere*. 93: 2230-2238.

Kelepertzis, E. (2014). Accumulation of heavy metals in agricultural soils of Mediterranean: insights from Argolida basin, Peloponnese, Greece. *Geoderma*. 221: 82-90.

Kravchenko, J., Darrah, T.H., Miller, R.K., Lyerly, H.K. and Vengosh, A. (2014). A review of the health impacts of barium from natural and anthropogenic exposure. *Environmental Geochemistry and Health*. 36(4):797-814.

Keenan, R.J., Reams, G.A., Achard, F., Freitas, J.V., Grainger, A. and Lindquist, E. (2015). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment. *Forest Ecology and Management*. 352: 9-20.

Kumar, A. and Singh, P.K. (2016). Qualitative assessment of mine water of the western Jharia coalfield area, Jharkhand, India. *Current World Environment*. 11(1): 301.

Kumar, R., Mishra, R.K., Mishra, V., Qidwai, A., Pandey, A., Shukla, S.K., Pandey, M., Pathak, A. and Dikshit, A. (2016). *Plant Metal Interaction*. 335-359.

Kamran, M.A., Bibi, S., Xu, R.K., Hussain, S., Mehmood, K. and Chaudhary, H.J. (2017). Phyto-extraction of chromium and influence of plant growth promoting bacteria to enhance plant growth. *Journal of Geochemical Exploration*.182: 269-274.

Kassambara, A. and Mundt, F. (2020). Factoextra: Extract and visualize the results of multivariate data analyses. R package version 1.0.7. https://CRAN.R-project.org/package=factoextra

Konthoujam, R., Singh, M.R. and Semy, K. (2021). Comparative assessment on riparian soil characteristic at three lateral buffer zones in riparian forest of Dikhu river. *Indian Journal of Ecology*. 48(5): 1365-1369.

Lal, R. (1994). Methods and guidelines for assessing sustainable use of soil and water resources in the tropics; Washington D.C.: USDA/SMSS Technical Monograph 21.

Lovesan, V.J., Kumar, N. and Singh, T.N. (1998). Effect of the bulk density on the growth and biomass of the selected grasses over overburden dumps around coal mining areas. In Proceedings of the 7th National Symposium on Environment, Dhanbad, Jharkhand, India. pp. 182-185.

Lacutusu, R. (2000). Appraising levels of soil contamination and pollution with heavy metals. In: J. Heinike., J.W. Eckselman. and A.J. Thomasson (Eds.), Land information systems for planning the sustainable use of land resources Luxembourg (pp. 393-402). European Soil Bureau Research.

Leelavathi, G.P., Naidu, M.V.S., Ramavatharam, N. and Sagar, G.K. (2009). Studies on genesis, classification and evaluation of soils for sustainable land use planning in

Yerpedu mandai of Chittor District, Andhra Pradesh. *Journal of the Indian Society of Soil Science*. 57(2): 109-120.

Lei, M., Feng, Q.Y., Laia, Z., Ping, L. and Jun, M.Q. (2009). Environmental cumulative effects of coal underground mining. *Procedia Earth and Planetary Science*. 1: 1280-1284.

Lohse, K.A., Brooks, P.D., McIntosh, J.C., Meixner, T. and Huxman, T.E. (2009). Interactions between biogeochemistry and hydrologic systems. *Annual Review of Environmental Resources*. 34: 65-96.

Luis, A.T., Teixeira, P., Almeida, S.F.P., Ector, L., Matos, J.X. and Ferreira da Silva, E.A (2009). Impact of Acid Mine Drainage (AMD) on water quality, stream sediments and periphytic diatom communities in the surrounding streams of Aljustrel mining area (Portugal). *Water Air and Soil Pollution*. 200: 147-167.

Ladwani, K.D., Manik. V.S. and Ramteke, D.S. (2012). Assessment of heavy metal contaminated soil near coal mining area in Gujarat by toxicity characteristics leaching procedure. *International Journal of Life Sciences and Biotechnology Pharmaceutical Research*. 1(4): 73-80.

Li, H., Liu, G., Sun, R., Chen, J., Wu, B. and Chou, C.L. (2013). Relationships between trace element abundances and depositional environments of coals from the Zhangji coal mine, Anhui Province, China. *Energy Exploration and Exploitation*. 31(1): 89-107.

Liu, Z., Zhou, W., Shen, J., Li, S. and Ai, C. (2014). Soil quality assessment of yellow clayey paddy soils with different productivity. *Biology and Fertility of Soils*. 50(3): 537-548.

Lamare, R.E. and Singh, O.P. (2016). Seasonal variation in water quality of Lukha River, Meghalaya, India. *Current World Environment*. 11(1): 101-113.

Leishangthem, D. and Singh, M.R. (2018). Tree diversity, distribution and population structure of a Riparian forest from certain zones along the Dikhu River in Nagaland, India. *Journal of Environmental Sciences*. 34: 31-45.

Liu, X., Bai, Z., Shi, H., Zhou, W. and Liu, X. (2019). Heavy metal pollution of soils from coal mines in China. *Natural Hazards*. 99: 1163-1177.

Lkr, A., Singh, M.R. and Puro, N. (2020a). Assessment of water quality status of Doyang river, Nagaland, India, using water quality index. *Applied Water Science*. 10: 46.

Lkr, A., Singh, M.R. and Puro, N. (2020b). Studies on riparian vegetation diversity and its relation with soil and water characteristics of Doyang river, Wokha, Nagaland. Ph.D. thesis submitted to the Department of Botany, Nagaland University, Lumami, Nagaland, India.

Leishangthem, D. and Singh, M.R. (2021). Physicochemical properties of riparian soil along the three zones of the Dikhu river, Nagaland, Northeast India. *International Journal of Ecology and Environmental Sciences.* 3(1): 293-300.

Li, D., Xu, Y., Zhang, X., Yang, Z., Wang, S., He, Q. and Jia, Z. (2022). Water quality, natural chemical weathering and ecological risk assessment of the contaminated area of vanadium ore in Yinhua River, China: Evidence from major ions and trace elements. *Acta Geochimica*. 41: 84-99.

Margalef, R. (1958). Information theory in ecology. *General Systems*. 3: 36-71.

Misra, R. (1968). Ecology work book. Oxford and IBH Publishing, New Delhi, p. 235.

Mengel, D.B. (1993). Fundamentals of soil cation exchange capacity (CEC). Agronomy guide AY-238. Cooperative Extension Service, Purdue University.

Mortvedt, J.J. (1994). Plant and soil relationships of uranium and thorium decay series radionuclides - a review. *Journal of Environmental Quality*. 23: 643-650.

Mishra, H.K. and Ghosh, R.K. (1996). Geology, petrology and utilization potential of some Tertiary coals of the northeastern region of India. *International Journal of Coal Geology*. 30(1-2): 65-100.

May, R.M. and Stumpf, M.P.H. (2000). Species-area relation in tropical forests. *Ecology*. 290(5499): 2084.

Moffat, A.J. (2003). Indicators of soil quality for UK forestry. *Forestry*. 76: 1-22.

Mas, J.F., H. Puig, J.L., Palacio, J.L. and Lopez, A.S. (2004). Modelling deforestation using GIS and artificial neural networks. *Environmental Modelling and Software*. 19(5): 461-471.

MoC (Ministry of Coal) (2005). The expert committee on road map for coal sector reforms, Part-I, Government of India.

Moore, T.A, Li, L., Nelson, C.M., Finkelman, R.B. and Boyd, R. (2005). Concentration of trace elements in coal beds. Metal contaminants in New Zealand. Moore, A., Black,

A., Centeno, J.A., Harding, J.S. and Trumm, D.A. (Eds.) Resolutionz Press, Christchurch.

Mandal, A. and Sengupta, D. (2006). An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India. *Environmental Geology*. 51(3): 409-420.

Maiti, S.K. (2007). Bioreclamation of coalmine overburden dumps- with special emphasis on micronutrients and heavy metals accumulation in tree species, *Environmental Monitoring and Assess*esment. 125: 111-122.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. (2008). Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. *Environmental Monitoring and Assessment*. 136: 419-435.

Mandal, U.K., Warrington, D.N., Bhardwaj, A.K., Bar-Tal, A., Kautsky, L. and Minz, D. (2008). Evaluating impact of irrigation water quality on a calcareous clay soil using principal component analysis. *Geoderma*. 144: 189-197.

Meng, L., Feng, Q.Y., Zhou, L., Lu, P. and Meng, Q.J. (2009). Environmental cumulative effects of coal underground mining. *Procedia Earth and Planetary Science*. 1: 1280-1284.

Marzaioli, R., D'Ascoli, R., De Pascale, R.A. and Rutigliano, F.A. (2010). Soil quality in a Mediterranean area of Southern Italy as related to different land use types. *Applied Soil Ecology*. 44: 205-212.

Manjare, S.A., Vhanalakar, S.A. and Muley, D.V. (2010). Analysis of water quality using physico-chemical parameters Tamdalge tank in Kolhapur district, Maharashtra. *International Journal of Advanced Biotechnology and Research*. 1(2): 115-119.

Millaleo, R., Reyes-Dıaz, M., Ivanov, A.G., Mora, M.L. and Alberdi, M. (2010). Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. *Journal of Soil Science and Plant Nutrition*. 10: 476-494.

Muhammad, F.N., Guilhem, B. and Fabienne, T. (2011). Soil compaction impact and modeling: a review. *Agronomy for Sustainable Development.* 33: 291-309.

Mukhopadhyay, S. and Maiti, S.K. (2011). Trace metal accumulation and natural mycorrhizal colonisation in an afforested coalmine overburden dump: a case study

from India. *International Journal of Mining, Reclamation and Environment*. 25(2):187-207.

Majumdar, K., Shankar, U. and Datta, B.K. (2012). Tree species diversity and stand structure along major community types in lowland primary and secondary moist deciduous forests in Tripura, Northeast India. *Journal of Forest Research*. 23: 553-568.

Mohapatra, H. and Goswami, S. (2012). Impact of coal mining on soil characterestics around lb river coalfield, Orissa, India. *Journal of Environmental Biology*. 33: 751-756.

Maiti, S.K. (2013). Ecorestoration of the coalmine degraded lands. Springer Science & Business Media.

Mahato, M.K., Singh, P.K. and Tiwari, A.K. (2014). Evaluation of metals in mine water and assessment of heavy metal pollution index of East Bokaro Coalfield area, Jharkhand, India. *International Journal of Earth Sciences and Engineering*. 7(4): 1611-1618.

Ministry of Coal (2014). Coal mine ordinance in India. Government of India.

Marbaninang, D., Das, P. and Chaturvedi, S.S. (2014). Assessment of heavy metal pollution in abandoned coal stockpile and Lime Kiln of Meghalaya using Pollution Load Index (PLI) and Geoaccumulation Index (I-Geo). *International Journal of Scientific Research*. 3(9): 886-891.

Majumdar, K. and Datta, B.K. (2015). Cachar tropical semi-evergreen forest type of Northeast India: status of species diversity, distribution and population structure. *Proceedings of the International Academy of Ecology and Environmental Sciences*. 5(4): 104-127.

Makdoh, K. and Kayang, H. (2015). Soil Physico-chemical Properties in Coal mining areas of Khliehriat, East Jaintia Hills District, Meghalaya, India. *Inernational Research Journal of Environmental Sciences*. 40 (10): 69-76.

Mukhopadhyay, S., Masto, R., Yadav, A., Joshy, G., Lal, R. and Shukla, S.P. (2015). Soil quality index for evaluation of reclaimed coal mine spoil. *Science of the Total Environment*. 542: 540-550.

McDuie-Ra, D. and Kikon, D. (2016). Tribal communities and coal in Northeast India: The politics of imposing and resisting mining bans. *Energy Policy*. 99: 261-269.

Mahato, M.K., Singh, G., Singh, P.K., Singh, A.K. and Tiwari, A.K. (2017). Assessment of mine water quality using heavy metal pollution index in a coal mining area of

Damodar River Basin, India. *Bulletin of Environmental Contamination and Toxicology*. 99(1): 54-61.

Mishra, N. and Das, N. (2017). Coal Mining and Local Environment: A Study in Talcher Coalfield of India. *Air, Soil and Water Research*. 10: 1-12.

Manna, A. and Maiti, R. (2018). Geochemical contamination in the mine affected soil of Raniganj Coalfield- A river basin scale assessment. *Geoscience Frontiers*. 9(5): 1577-1590.

Mishra, G., Marzaioli, R., Giri, K. and Pandey, S. (2018). Soil quality assessment across different stands in tropical moist deciduous forests of Nagaland, India. *Journal of Forestry Research*. 30(2): 1-7.

Mishra, G., Marzaioli, R., Giri, K. and Pandey, S. (2019). Soil quality assessment across different stands in tropical moist deciduous forests of Nagaland, India. *Journal of Forestry Research*. 30(4): 1479-1485.

Mondal, S., Palit, D. and Chattopadhyay, P. (2020). Impact of mining on tree diversity of the coal mining forest area at Raniganj coalfield area of West Bengal, India. *Ecology, Environment and Conservation*. 26: 66-72.

Mirza, A.N. and Patil S.S. (2020). Assessment of seasonal variation in physicochemical characteristics of the soil at Gautala reserve forest (M.S), India. *Current World Environment*. 15(2).

Nemerow, N.L. (1985). Stream, lake, estuary, and ocean pollution, Van Nostrand Reinhold Publishing, New York, USA.

Nriagu, J.O. (1988). A silent epidemic of environmental metal poisoning? *Environmental Pollution*. 50: 139-161.

Naicker, K., Cukrowska, E. and Mccarthy, T.S. (2003). Acid mine drainage from gold mining activities in Johannesburg, South Africa. *Journal of Environmental Pollution.* 122: 29-40.

Nagdeve, D.A. (2007). Population growth and environmental degradation in India. *Asian Pacific Journal on Environment and Development*. 14:41-63.

Nouri, J., Khorasani, N., Lorestani, B., Yousefi, N., Hassani, A.H. and Karami, M. (2009). Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. *Environmental Earth Sciences*. 59(2): 315-323.

Nagajyoti, P.C., Lee, K.D. and Sreekanth, T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters*. 8: 199-216.

Ndimele, P.E. (2012). The Effects of Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) Infestation on the Physico-Chemistry, Nutrient and Heavy Metal Content of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. *Journal of Environmental Science and Technology*. 5(2): 128-136.

Nigam, G.K., Sahu, R.K., Sinha, J. and Sonwanshi, R.N. (2015). A study on physico-chemical characteristics of open cast mine water. *Journal of Industrial Pollution Control*. 31(2): 191-200.

Niu, S., Gao, L. and Zhao, J. (2015). Distribution and risk assessment of heavy metals in the Xinzhuangzi reclamation soil from the Huainan coal mining area, China. *Human and Ecological Risk Assessment: An International Journal*. 21(4): 900-912.

NPCB (2015). Nagaland Pollution Control Board. Environmental standards. Dimapur, Nagaland.

Naidu, M.T. and Kumar, O.A. (2016). Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. *Journal of Asia-Pacific Biodiversity*. 9: 328-334.

Nabiollahi, K., Taghizadeh-Mehrjardi, R., Kerry, R. and Moradian, S. (2017). Assessment of soil quality indices for salt-affected agricultural land in Kurdistan Province, Iran. *Ecological Indicators*. 83: 482-494.

Nagaland Coal (2017). Coal mining in Nagaland. https://en.wikipedia.org/wiki/Naginimora.

Niu, S., Gao, L. and Zhao, J. (2017). Heavy metals in the soils and plants from a typical restored coal-mining area of Huainan coalfield, China. *Environmental Monitoring and Assessment*. 189(10): 1-12.

Nwankwoala, H.O. and Ememu, A.J. (2018). Contamination in-dices and heavy metal concentrations in soils in Okpoko and Environs, Southeastern Nigeria. *Journal of Environmental Science and Public Health*. 2(2): 77-95.

Nohro, S. and Jayakumar, S. (2020). Tree species diversity and composition of the Pala Wetland Reserve forest, Mizoram, Indo-Burma hotspot, India. *Biocatalysis and Agricultural Biotechnology*. 23: 101-474.

Odum, E.P. (1971). Fundamentals of ecology. 3rd edition. Philadelphia, Saunders. p. 574.

OECD (2002). Social capital and social wellbeing (Discussion Paper). http://www.oecd.org/innovation/researchandknowledgemanagement/2380806.pdf

Orem, W.H. and Finkelman, R.B. (2003). Coal formation and geochemistry. In: Mackenzie, F.T., Ed., Sediments, Diagenesis, and Sedimentary Rocks: Treatise on Geochemistry. *Coal*. 7: 191-222.

Olias, M., Nieto, J.M., Sarmiento, A.M., Ceron, J.C. and Canovas, C.R. (2004). Seasonal water quality variations in a river affected by acid mine drainage: the Odiel River (South West Spain). *Science of the total environment*. 333(1-3): 267-281.

OSHA (2013). Brief - Medical evaluation of renal effects of Cadmium exposures.

Obiri, S., Mattah, P.A.D., Mattah, M.M., Armah, F.A., Osae, S., Adu-Kumi, S. and Yeboah, P.O. (2016). Assessing the environmental and socio-economic impacts of artisanal gold mining on the livelihoods of communities in the Tarkwa Nsuaem municipality in Ghana. *International Journal of Environmental Research and Public Health*. 13(2).

Onwuka, B.M. (2016). Effects of soil temperature on some soil properties and pant growth. *Advances in Plants and Agriculture Research*. 8(1): 89-93.

Omer, M., Idowu, O.J., Ulery AL , VanLeeuwen, D. and Guldan, S.J. (2018). Seasonal changes of soil quality indicators in selected arid cropping systems. *Agriculture*. 8: 124.

Prain, D. (1903). Bengal Plants.Volume 1 and 2. Botanical Survey of India, Calcutta.

Piper, C.S. (1942). Soil and plant analysis.Laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants, University of Adelaide, Adelaide.

Pielou, E.C. (1969). An Introduction to Mathematical ecology. Wiley-Interscience. John Wiley and Sons, New York. 13(3): 219-220.

Patel, S.G., Singh, D.D. and Harshey, D.K. (1983). Pamitae (Jabalpur) sewage polluted water body, as evidenced by chemical and biological indicators of pollution. *Journal of Environmental Biology*. 4: 437-449.

Pande, P.K., Bisht, A.P.S. and Sharma, S.C. (1988). Comparative vegetation analysis of some plantation ecosystems. *Indian Forester*. 114: 379-388.

Plumlee, G.S., Smith, K., Ficklin, W.H., Meier, A.L. and Briggs, P. H. (1993). Understanding and predicting the composition of mine drainage water the importance of geologic and geochemical considerations. *Reviews in Economic Geology*. 6: 142-150.

Parthasarathi, N. and Karthikeyan, R. (1997). Biodiversity and population density of woody species in a tropical evergreen forest in Courtallum reserve forest, Western Ghats, India. *Tropical Ecology*. 38: 297-306.

Peplow, D. (1999). Environmental impacts of mining in Eastern Washington.Center for water and watershed studies fact sheet, University of Washington, Seattle.

Prescott, C., Vesterdal, L., Pratt, J., Venner, K., Montigny, L.D. and Trofymow, J. (2000). Nutrient concentrations and nitrogen mineralization in forest floors of single species conifer plantations in coastal British Columbia. *Canadian Journal of Forest Research*. 30: 1341-1352.

Passah, P.M. and Sarma, S. (2002). Jaintia Hills, A Meghalaya tribe- its Environment, land and people. New Delhi: Ranjit Nagar.

Paliwal, R., Sharma, P. and Kansa, A. (2007). Water quality modelling of the river Yamuna (India) using QUAL2E-UNCAS. *Journal of Environmental Management*. 83(2): 131-44.

Parihar, S.S., Ajit, K., Ajay, K., Gupta, R.N., Manoj, P., Archana, S. and Pandey, A.C. (2012). Physico-chemical and microbiological analysis of underground water in and around Gwalior city, MP, India. *Research Journal of Recent Sciences*. 1(6): 62-65.

Palanisamy, J. and Arumugam, R. (2014). Phytodiversity in the Madukkarai hills of South Western Ghats. *Journal of Species Lists and Distribution*. 10: 883-892.

Pandey, B., Agrawal, M. and Singh, S. (2014) Assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations and heavy metals, using cluster and principal component analysis. *Atmospheric Pollution Research.* 5: 79-86.

Pandey, J. and Singh, R. (2017). Heavy metals in sediments of Ganga River: up- and downstream urban influences. *Applied Water Science*. 7: 1669-1678.

Quinn, J. M., Davies-Colley, R. J., Hickey, W. C., Vickers, M. L. and Ryan, P.A. (1992). Effects of clay discharges on streams. *Hydrobiologia*. 248(3): 235-247.

Rawat, N.S. and Singh, G. (1982). The role of micro-organisms in the formation of acid mine drainage in the north eastern coal field of India. *International Journal of Mine Water*. 2: 29-36.

Rathore, C.S. and Wright, R. (1993). Monitoring environmental impacts of surface coal mining. *International Journal of Remote Sensing*. 14(6): 1021-1042.

Rai, R.K. (2002). Implication of coal mining on environment in Jaintia Hills, Meghalaya. In: Passah PM, Sarma AK, editors. Jaintia Hills, A Meghalaya tribe: Its environment, land and people. Reliance Publishing House. New Delhi, pp. 113-119.

Razo, I., Carrizales, L., Castro, J., Díaz-Barriga, F. and Monroy, M. (2004). Arsenic and heavy metal pollution of soil, water and sediments in a semi-arid climate mining area in Mexico. *Water, Air, and Soil Pollution*. 152: 129-152.

Roy, A., Tripathi, S.K. and Basu, S.K. (2004). Formulating diversity vector for ecosystem comparison. *Ecological Modelling*. 179(4): 499-513.

Reddy, M.S., Basha, S., Joshi, H.V. and Jha, B. (2005). Evaluation of the emission characteristics of trace metals from coal and fuel oil fired power plants and their fate during combustion. *Journal of Hazardous Materials*. 123: 242-249.

Radhakrishnan, R., Dharmaraj, K. and Kumari, R. (2007). A comparative study on the physico-chemical and bacterial analysis of drinking, borewell and sewage water in the three different places of Sivakasi, *Journal of Environmental Biology*. 28(1): 105-108.

Ramakrishnaiah, C.R., Sadashivaiah, C. and Ranganna, G. (2009). Assessment of water quality index for the groundwater in TumkurTaluk, Karnataka State, India. *European Journal of Chemistry*. 6(2): 523-530.

Rai, A.K., Paul, B. and Singh, G. (2010). Assessment of top soil quality in the vicinity of subsided area in Jharia Coalfield, Dhanbad, Jharkhand. *Report and Opinion*. 2(9): 1-6.

Rao, C.S., Rao, B.S., Hariharan, A.V. and Bharathi, N.M. (2010). Determination of water quality index of some areas in Guntur district Andhra Pradesh. *International Journal of Applied Biology and Pharmaceutical Technology*. 1(1): 79-86.

Reza, R. and Singh, G. (2010). Heavy metal contamination and its indexing approach for river water. *International Journal of Environmental Science and Technology*. 7: 785-792.

Rai, A.K., Paul, B. and Singh, G. (2011). A study on the bulk density and its effect on the growth of selected grasses in coal mine overburden dumps, Jharkhand, India. *International Journal of Environmental Sciences*. 1(6): 1350-1360.

Rounds, S.A., Wilde, F.D. and Ritz, G.F. (2013). Dissolved oxygen (ver. 3.0): U.S. Geological Survey Techniques of Water C Resources Investigations. 9(A6): 2.

Randjelovic, D., Cvetkovic, V., Mihailovic, N. and Jovanovic, S. (2014). Relationship between edaphic factors and vegetation development on copper mine wastes: a case study from Bor (Serbia, SE Europe). *Environmental Management*. 53: 800-812.

Rayo, I., Herrera, E., Moreno, C.H. and Plazola, R.G. (2017). Soil quality indicators to evaluate soil fertility. *Agrociencia*. 51: 813-831.

Ritchie, H. and Roser, M. (2018). CO_2 emissions by fuel. Our World in Data.

Raj, D., Kumar, A. and Maiti, S.K. (2019). Evaluation of toxic metal(loid)s concentration in soils around an open-cast coal mine (Eastern India). *Environment Earth Sciences. 78*(22): 1-19.

Resilience (2020). Dethroning king coal-how a once dominant fuel source is falling rapidly from favour. Resilience. 24th January 2020. https://www.resilience.org/stories/2020-01-24/dethroning-king-coal-how-a-once-dominant-fuel-source-is-falling-rapidly-from-favour/

Sorensen, T. (1948). A method of establishing groups of amplitude in plant Sociology based on similarity of species content and its application to analyses of the vegetation on Danish Commons. Kongelige Danske Videnskabernes Selskab. *Biologiske Skrifter*. 5: 1-34.

Simpson, E.H. (1949). Measurement of diversity. *Nature*. 163(4148): 688.

Shannon, C.E. and Wiener, W. (1963). The Mathematical theory of communities. University of Illinois Press, Urbana. p. 125.

Singh, G. and Rawat, N.S. (1985). Removal of trace elements from acid mine drainage. *International Journal of Mine Water*. 4(1): 17-23.

Singh, G. (1988). Impact of coal mining on mine water quality. *International Journal of Mine Water*. 7(3): 49-59.

Shaw, A.J. and Diane, W.E. (1989). Heavy metal tolerance in plants: Evolutionary aspects. *Library of Congress Cataloging in Publication Data*. 1: 89-297.

Singh, J., Agrawal, M. and Narayan, D. (1994). Effect of power plant emissions on plant community structure. *Ecotoxicoloy*. 3(2): 110-122.

Salomons, W., Forstner, U. and Mader, P. (1995). Heavy Metals: Problems and Solutions. Berlin, Germany: Springer.

Singh, G. (1998). Impact of coal mining on mine water quality. *International Journal of Mine Water*. 7(3): 49-59.

Sams, J. I. and Beer, K.M. (2000). Effects of coal-mine drainage on stream water quality in the Allegheny and Monongahela river basins-sulfate transport and trends. *Water-Resources Investigations Report*. 99: 4208.

Sundarapandian, S.M. and Swamy, P.S. (2000). Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. *Journal of Tropical Forest Science*. 12: 104-123.

Sarma, K. (2002). Coal mining and its impact on environment of Nokrek biosphere reserve, Meghalaya. Ph. D. thesis submitted to Department of Geography, North Eastern Hill University, Shillong.

Six, J., Conant, R.T., Paul, E.A. and Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil*. 241: 155-176.

Sagar, R., Raghubanshi, A.S. and Singh, J.S. (2003). Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *Forest Ecology and Management*. 186(1-3): 61-71.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D. and Anthemidis, A. (2003). Assessment of the surface water quality in Northern Greece. *Water Research*. 37(17): 4119-4124.

Swer, S. and Singh, O.P. (2003). Coal mining impacting water quality and aquatic biodiversity in Jaintia hills district of Meghalaya. *Bulletin Himalayan Ecology*. 11: 26-33.

Swer, S. and Singh, O.P. (2004). Status of water quality in coal mining areas of Meghalaya, India. *Proceedings of the national seminar on environmental engineering with special emphasis on mining environment*. pp. 19-20.

Sikdar, P. K., Chakraborty, S., Adhya, E. and Paul, P. K. (2004).Land use/Land cover changes and groundwater potential zoning in and around Raniganj coal mining area, Bardhaman District, West Bengal - A GIS and Remote Sensing Approach. *Journal of Spatial Hydrology*. 4(2): 1-24.

Sharma, K.L., Mandal, U.K., Srinivas, K., Vittal, K.P.R., Mandal, B. and Grace, J.K. (2005). Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil and Tillage Research*. 83: 246-259.

Sarma, K. (2005). Impact of coal mining on vegetation: a case study in Jaintai Hills district of Meghalaya, India. M.Sc desertation, International Institute for Geo Information Science and Earth Observation (ITC), Enschede the Netherlands.

Sun, H.Y., Li, X.J., Hu, Z.Q., Liu, X.R. and Zhong, W.J. (2008). Variance of reclamation soil quality in Majiata open cast mine region. *Transactions of the Chinese Society of Agricultural Engineering*. 24(12): 205-209.

Sahney, S., Benton, M.J. and Falcon-Lang, H.J. (2010). Rainforest collapse triggered Pennsylvanian tetrapod diversification in Euramerica. *Geology*. 38 (12): 1079-1082.

Sarma, K., Kushwaha, S.P.S. and Singh, K.J. (2010). Impact of coal mining on plant diversity and tree population structure in Jaintai Hills district of Meghalaya, North East India. *New York Science Journal*. 3(9): 79-85.

Singh, A.K., Mahato, M.K., Neogi, B. and Singh, K.K. (2010). Quality Assessment of mine waer in the Raniganj coalfield area, India. *Mine Water and the Environment*. 29(4): 248-262.

Sarma, K. and Barik, S.K. (2011). Coal mining impact on vegetation of the Nokrek Biosphere, Meghalaya, India. *Biodiversity*. 12(3): 154-164.

Semiromi, F.B., Hassani, A.H., Torabian, A., Karbassi, A.R. and Lotfi, F.H. (2011). Water quality index development using fuzzy logic: A case study of the Karoon river of Iran. *African Journal of Biotechnology*. 10(50): 10125-10133.

Sharma, D. and Kansal, A. (2011). Water quality analysis of river Yamuna using water quality index in the national capital territory, India (2000-2009). *Applied Water Sciences*. 1(3): 147-157.

Sadhu, K., Adhikari, K. and Gangopadhyay, A. (2012). Effect of mine spoil on native soil of Lower Gondwana coal fields: Raniganj coal mines areas, India. *International Journal of Environmental Sciences*. 2 (3): 1675-1687.

Sahu, S.C., Dhal, N.K. and Mohanty, R.C. (2012). Tree species diversity and soil nutrient status in a tropical sacred forest ecosystem on Niyamgiri Hill range, Eastern Ghats, India. *Tropical Ecology*. 53: 163-168.

Singh, A.K., Mahato, M.K., Neogi, B., Tewary, B.K. and Sinha, A. (2012). Environmental geochemistry and quality assessment of mine water of Jharia coalfield. *Environmental Earth Sciences*. 65(1): 49-65.

Sarkar, M. and Devi, A. (2014). Assessment of diversity, population structure and regeneration status of tree species in Holloongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. *Tropical Plant Research*. 1(2): 26-36.

Sayel, H., Joutey, N.T., Bahafid, W. and Ghachtouli, N.E. (2014). Chromium resistant bacteria: impact on plant growth in soil microcosm. *Archives of Environmental Protection*. 40(2): 81-89.

Shanbehzadeh, S., Dastjerdi, M.V., Hassanzadeh, A, and Kiyanizadeh, T. (2014). Heavy Metals in Water and Sediment: A Case Study of Tembi River. *Journal of Environmental and Public Health*. 3: 758-720.

Sharma, N. and Kant, S. (2014). Vegetation structure, floristic composition and species diversity of woody plant communities in sub-tropical Kandi Siwaliks of Jammu, J&K, India. *International Journal of Basic and Applied Sciences*. 3(4): 382.

Singh, G. and Kamal, R.K. (2014). Application of water quality index for assessment of surface water quality status in Goa. *Current World Environment*. 9(3): 994-1000.

Swapna, K.S., Shackira, A.M., Abdussalam, A.K. and Puthur, J.T. (2014). Accumulation Pattern of Heavy Metals in Chromolaena odorata (L.) King and Robins. Grown in Nutrient Solution and Soil. *Journal of Stress Physiology and Biochemistry*. 10 (2): 297-314.

Singh, P.K. and Shrivastava, P. (2015). Analysis of water quality of river Narmada. *International Journal of Current Research*. 7(12): 24073-24076.

Singh, S.H.B., Mishra, B.P. and Tripathi, S.K. (2015). Recovery of plant diversity and soil nutrients during stand development in subtropical forests of Mizoram, Northeast India. *Biodiversitas*. 16: 205-212.

SRWE (Statistical Review of World Energy) (2015). Center for Strategic and International Studies, Rhode Island Avenue, Washington, DC 20036.

Sahoo, M., Mahananda, M.R. and Seth, P. (2016). Physico-chemical analysis of surface and groundwater around Talcher coal field, district Angul, Odisha, India. *Journal of Geoscience and Environment Protection*. 4: 26-37.

Shotyk, W., Bicalho, B., Cuss, C.W., Duke, M.J.M., Noernberg, T., Pelletier, R., Steinnes, E. and Zaccone, C. (2016). Dust is the source of "heavy metals" to peat moss (Sphagnum fuscum) in the bogs of the Athabasca Bituminous sands region of northern Alberta. *Environment International*. 92: 494-506.

Singh, R.K.B., Singh, T.C. and Singh, T.R. (2016). Assessment of water quality index of Nambul river, Imphal, Manipur, India. *International Research Journal of Engineering and Technology*. 3(12): 1462-1467.

Shah, K.A. and Joshi, G.S. (2017). Evaluation of water quality index for river Sabarmati. *Applied Water Sciences*. 7: 1349-1358.

Shameem, S.A., Mushtaq, H., Wani, A.A., Ahmad, N. and Hai, A. (2017). Phytodiversity of herbaceous vegetation in disturbed and undisturbed forest ecosystems of Pahalgam Valley, Kashmir Himalaya, India. *British Journal of Environment and Climate Change*. 7: 148-167.

Shi, P.L., Zhang, Y.X., Hu, Z.Q., Ma, K., Wang, H. and Chai, T.Y. (2017). The response of soil bacterial communities to mining subsidence in the west China aeolian sand area. *Applied Soil Ecology*. 121: 1-10.

Saravanan, R., Sujana, K.A. and Kannan, D. (2019). Phytodiversity analysis of tree species of Kuldiha Wildlife Sanctuary (KWLS), Odisha, India. *Journal of Applied Life Sciences International*. 22(4): 1-4.

Siregar, M., Helmanto, H. and UlieRakhmawati, S. (2019). Vegetation analysis of tree communities at some forest patches in North Sulawesi, Indonesia. *Biodiversitas*. 20(3): 643-655.

Semy, K. and Singh, M.R. (2019). Assessment on the water quality of Tsurangriver, Nagaland affected by coal mining drainage. *Indian Journal of Ecology*. 46(4): 845-849.

Semy, K. and Singh, M.R. (2021). Quality assessment of Tsurang riverwater affected by coal mining along the Tsurangkong range, Nagaland, India. *Applied Water Science*. 11:115.

Semy, K., Singh, M.R. and Vats, N. (2021). Evaluation of soil quality of a coal mine affected forestat Changki, Nagaland, India. *Journal of Environmental Engineering and Landscape Management*. 29(4): 381-390.

Semy, K., Singh, M.R., Walling, M., Temjen, W., Jangir, A. and Mishra, G. (2022). Qualitative soil assessment of coal mine disturbed and undisturbed tropical forest in Nagaland, India. *Proceedings of the National Academy of Sciences, India - Section B: Biological Sciences*.

Thomilson, D.C., Wilson, D.J. and Harris, C.R. (1980). Problem in heavy metals in estuaries and the formation of pollution index. *Helgolander Meeresunters*. 33: 566-575.

Trivedy, R.K. and Goel, P.K. (1986). Chemical and Biological method for water pollution studies. *Environmental Publication*. 6: 10-12.

Trivedi, R.K. (2000). Pollution and biomonitoring of Indian rivers. (First Edition), Ashish Publishing House, New Delhi, India: p. 447.

Tiwary, R.K. (2001). Environmental Impact of coal mining on water regime and its management. *Water, Air and Soil Pollution.* 132: 185-199.

Taylor, G., Howse, R., Dulvenvoorden, L. and Vicente-Beckett, V. (2002). Downstream flow event sampling of acid mine drainage from the historic Mt Morgan Mine. *Water Science and Technology*. 45(11): 29-34.

Tripathy, D.P. (2010). Determination of trace elements concentration and trace elements index in mine water in some fire and non-fire affected areas of Jharia coalfield, India. *Pollution Research*. 29: 385-390.

Tynsong, H. and Tiwari, B.K. (2011). Diversity and population characteristics of woody species in natural forests and Areca nut agroforests of south Meghalaya, Northeast India. *Tropical Ecology*. 52: 243-252.

Tambekar, P., Batra, R.J. and Weginwar, R.G. (2012). Assesment of water quality from Hindustan Lalpeth coal mine, Chandrapur. *Journal of Chemical and Pharmaceutical Research*. 4(8): 3813-3821.

Tao, S., Fang, J. and Zhao, X. (2015). Rapid loss of lakes on the Mongolian plateau. *Sustainability science*. 112 (7).

Tapadar, S.A. and Jha, D.K. (2015). Influence of open cast mining on the soil properties of Ledo Colliery of Tinsukia district of Assam, India. *International Journal of Scientific and Research Publications*. 5(3): 1-5.

Talukdar, B., Kalita, H.K., Basumatary, S. and Sarma, D. (2016) .Impact of coal mining on soil characteristics of Simsang river, Meghalaya, India. *Journal of Fundamental Renewable Energy*. 6(6): 45-86.

Tiwari, A.K., Singh, P.K. and Mahato, M.K. (2016). Environmental geochemistry and a quality assessment of mine water of the west Bokaro coalfield, India. *Mine Water and the Environment*. 35: 525-535.

Tiwary, M. and Singh, J.N. (2016). Impact of open cast coal mining on medicinal plants - A case study of Jharia coalfields. *International Journal Impact of Mining for Exchange of Knowledge*. 2 (1): 109-110.

Tóth, G., Hermann, T., Da Silva, M.R. and Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. *Environmental Pollution*. 88: 299-309.

Tiwari, A.K., Singh, P.K. and Mahato, M.K. (2017). Assessment of metal contamination in the mine water of the West Bokaro Coalfield, India. *Mine Water Environment*. doi:10.1007/s10230-017-0440-x

Triantafyllidis, V., Kosma, A.K.C. and Patakas, A. (2018). An assessment of the soil quality index in a Mediterranean agro ecosystem. *Emirates Journal of Food and Agriculture*. 30(12): 1042-1050.

USEPA (1986). Effects of lead on the environment. www.lead.org.au/lanv1n2/lanv1n2-8.html.

Upadhaya, K., Pandey, H.N., Law, P.S. and Tripathi, R.S. (2003). Tree diversity in sacred groves of the Jaintia hills in Meghalaya, Northeast India. *Biodiversity and Conservation*. 12: 583-597.

USAID (United States Agency for International Development) (2007). Freedom of Information Act/Privacy Act. Annual report. http://www.usaid.gov/about/foia

USATSDR (United States Agency for Toxic Substances and Disease Registry) (2007). Toxicological profile for lead. US Department of Health and Human Services. Available at: http://www.atsdr.cdc.gov/toxfaqs/tfacts13.pdf. Accessed: August 2015.

Urik, M. and Nemcek, K.L. (2012). Soil moisture and its effect on bulk density and porosity of intact aggregates of three Mollic soils. *Indian Journal of Agricultural Science*. 82(2): 172-176.

Upadhyay, N., Verma, S., Singh, A.P., Devi, S., Vishwakarma, K., Kumar, N., Pandey, A., Dubey, K., Mishra, R., Tripathi, D.K., Rani, R. and Sharma, S. (2016). Soil ecophysiological and microbiological indices of soil health: a study of coal mining site in Sonbhadra, Uttar Pradesh. *Journal of Soil Science and Plant Nutrition*. 16(3): 778-800.

USEPA (2017). Rad Town USA. http://www.epa.gov/radtown/coal-plant.html.

USIA (2017*)*. US Energy Information Administration. Archived *from the original on*. Retrieved 13 November 2017.

Uugwanga, M. and Kgabi, N. (2021). Heavy metal pollution index of surface and groundwater from around an abandoned mine site, Klein Aub. *Physics and Chemistry of the Earth Parts*. 124(6).

Ukpe A.E., Akhionbare, S.M.O. and Ihejirika, C.E. (2021). The effects of mining activities on the soil quality of Ikwo, Ebonyi state Nigeria. *International Journal of Advanced Academic Research*. 7(12): 88-99.

Valente, T.M. and Gomes, C.L. (2007). The role of two acidophilic algae as ecological indicators of acid mine drainage sites. *Journal of Iberian Geology*. 33(2): 283-294.

Veziroglu, T.N. and Sahin, S. (2008). 21st century's energy: hydrogen energy system. *Energy Conversion and Management*. 49: 1820-1831.

Varol, M., Gokot, B., Bekleyen, A. and Sen, B. (2012). Water quality assessment and apportionment of pollution sources of Tigris river (Turkey) using, multivariate statistical techniques - a case study. *River Research and Applications*. 28: 1428-1438.

Verma, A.K. and Singh, T.N. (2013). Prediction of water quality from simple field parameters. *Environmental Earth Sciences*. 69(3): 821-829.

Venkatramanan, S., Chung, S.Y., Lee, S.Y. and Park, N. (2014). Assessment of river water quality via environmentric multivariate statistical tools and water quality index: A case study of Nakdong River Basin, Korea. *Carpathian Journal of Earth and Environmental Sciences*. 9(2): 125-132.

Viehweger, K. (2014). How plants cope with heavy metals. *Botanical Studies*. 55: 35.

Vasu, D., Singh, S.K., Ray, S.K., Duraisami, V.P., Tiwary, P., Chandran, P., Nimkar, A.M. and Anantwar, S.G. (2016). Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India. *Geoderma*. 282: 70-79.

Vishwakarma, A.K., Behera, T., Rai, R., Sonkar, A.K., Singh, A.P. and Shrivastva, B.K. (2020). Impact assessment of coal mining induced subsidence on native soil of South Eastern Coal Fields: India. *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*. 6(1): 1-21.

Walkley, A.J. and Black, I.A. (1934). Estimation of soil organic carbon by the chromic acid titration method. *Soil Sciences*. 37: 29-38.

WHO (World Health Organization) (1996). Permissible limits of heavy metals insoil and plants. Geneva,Switzerland.

Wong, M.H. (2003). Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Chemosphere*. 50: 775-780.

Wang, L., Wei, S.P. and Wang, Q.J. (2008). Effect of coal exploitation on groundwater and vegetation in the Yushenfu Coal Mine. *Journal of China Coal Society*. 33(12): 1408-1414.

WHO (2012). World health statistics. WHO Library Cataloguing-in-Publication Data (NLM classification: WA 900.1.

Wiryono, L. and Siahaan, A.B. (2013). Species composition of understory vegetation in coal mined land in Central Bengkulu, Indonesia. *Biodiversitas*. 14(1): 31-36.

Woodworth, M.D. (2015). China's coal production goes west: assessing recent geographical restructuring and industrial transformation. *The Professional Geographer*. 67: 630-640.

Wang, Y.C., Bian, Z.F., Lei, S.G. and Zhang, Y. (2017). Investigating spatial and temporal variations of soil moisture content in an arid mining area using an improved thermal inertia model. *Journal of Arid Land*. 9: 712-726.

Weissmannova, H.D. and Pavlovsky, J. (2017). Indices of soil contamination by heavy metals - methodology of calculation for pollution assessment (Mini review). *Environmental Monitoring Assessment*. 189(12).

WHO (2017).Guidelines for drinking-water quality, 4th edition, World Health Organisation, Geneva.

Xia, H.P. and Cai, X.A. (2002). Ecological restoration technologies for mined lands: a review. *Chinese Journal of Applied Ecology*. 13: 1471-1477.

Yeboah, J.Y. (2008). "Environmental and health impact of mining on surrounding communities: a case study of Anglogold Ashanti in Obuasi", Thesis submitted to the Department of Geography and Rural Development, Kwame Nkrumah University of science and Technology, Ghana. http://www.dailypioneer. com/state-editions/talcher-angul-ib-valley-critically-polluted-zones.html.

Yimer, F., Messing, I., Ledin, S. and Abdelkadir, A. (2008). Effects of different land-use types on infiltration capacity in a catchment in the highlands of Ethiopia. *Soil Use and Management*. 24: 344-349.

Yogendra, K. and Puttaiah, E.T. (2008). Determination of water quality index and suitability of an urban waterbody in Shimoga town, Karnataka. In: Sengupta M, Dalwani R (Eds.) Proceedings of Taal 2007: The 12th world lake conference, pp. 342-346.

Yisa, J. and Jimoh, T. (2010). Analytical studies on water quality index of river Landzu. *American Journal of Applied Sciences*. 7(4): 453-458.

Yuan, L., Qin, Y. and Cheny, Y.P. (2013). Scenario predication for medium-long term scale of coal mine methane drainage in China. *Journal of China Coal Society*. 38: 529-534.

Yadav, R.S., Pandya, I.Y. and Jangid, M.S. (2015). Estimating status of soil organic carbon in tropical forests of Narmada. *International Research Journal of Environmental Sciences.* 4(1): 19-23.

Yoon, T., Rhodes, C. and Shah, F.A. (2015). Upstream water resource management to address downstream pollution concerns: A policy framework with application to the Nakdong river basin in South Korea. *Water Resources Research*. 51(2): 787-805.

Yang, D.J., Bian, Z.F. and Lei, S.G. (2016). Impact on soil physical qualities by the subsidence of coal mining: a case study in Western China. *Environmental Earth Sciences*. 75: 652.

Ying, L., Shaogang, L. and Xiaoyang, C. (2016). Assessment of heavy metal pollution and human health risk in urban soils of a coal mining city in East China. *Human and Ecological Risk Assessment: An International Journal*. 22(6): 1359-1374.

Yu, P.J., Liu, S.W., Zhang, L., Li, Q. and Zhou, D.W. (2018). Selecting the minimum data set and quantitative soil quality indexing of alkaline soils under different land uses in northeastern China. *Science of the Total Environment*. 616: 564-571.

Yan, T., Zhao, W., Yu, X., Li, H., Gao, Z., Ding, M. and Yue, J. (2022). Evaluating heavy metal pollution and potential risk of soil around a coal mining region of Tai'an City, China. *Alexandria Engineering Journal*. 61: 256-2165.

Zhang, C.X., Xu, L. and Zhou, X.C. (2007). Land suitability assessment of vegetation restoration of the coal Gangue pile of Fuxin mine area. *Soil Water Conservation*. 14(3): 246-248.

Zhang, D., Fan, G., Ma, L., Wang, A. and Liu, Y. (2009). Harmony of large scale underground mining and surface ecological environment protection in desert district-a case study in Shendong mining area, northwest of China. *Proceedings Earth and Planetary Science*. 1: 1114-1120.

Zaimes, Z., Iakovoglou, V., Emmanouloudis, V.D. and Gounaridis, D. (2010). Riparian areas of Greece: Their definition and characteristics. *Journal of Engineering and Technology Review.* 3(1): 176-183.

Zuo, C., Ma, F. and Hou, J. (2014). Representatives of mining subsidence analysis visualization of China. Liaoning Gongcheng Jishu Daxue Xuebao (Ziran Kexue Ban). *Journal Liaoning Technical University* (*Natural Science Edition*). 33: 788-792.

Appendix I

Monthly value of the soil physicochemical properties recorded from Coal Mining Affected Forest (CMAF) and Non-Affected Forest (NAF)

(September, 2018 – August, 2019).

Physical soil properties of CMAF

Parameters	Soil depth (cm)	Autumn		Winter			Spring			Summer			
		Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
Sand (%)	0-10	57.79	58.93	58	60.8	60.13	61.61	56.37	59.97	60	61.38	61.67	60.97
	10-20	58.16	60.63	60.77	61.5	61.91	64.74	56.28	59	63.94	61	62.13	61.20
	20-30	59.25	61	61.63	62.32	62.93	65.38	58.93	59.34	64.17	62.27	62.47	61.95
Silt (%)	0-10	20.67	22.25	20.97	20.37	21.44	22.67	21.94	19.46	21	19.54	20.86	21.37
	10-20	20.97	20.56	19.84	22	19.56	19.76	20.15	20.75	21.18	22.25	22	21
	20-30	21.12	21	20.23	21.71	20.53	19.35	22.70	23	20.94	22.37	22.52	22.3
Clay (%)	0-10	21.37	21.63	21.23	17.91	19.31	16.22	22.84	19.86	18.67	16.15	16.56	19.74
	10-20	18.95	21	19.57	16.53	18.63	15.68	21.71	20.34	15.18	16.84	15.95	17.82
	20-30	18	19.75	18.20	16	16.65	15.46	18.40	17.70	15	15.50	15.20	15.8
BD (g/cm^3)	0-10	1.33	1.30	1.39	1.45	1.51	1.56	1.41	1.37	1.43	1.38	1.37	1.35
	10-20	1.37	1.33	1.46	1.48	1.53	1.60	1.47	1.41	1.45	1.43	1.42	1.39
	20-30	1.39	1.34	1.53	1.56	1.62	1.64	1.53	1.45	1.51	1.50	1.47	1.42
SP (%)	0-10	0.46	0.45	0.42	0.41	0.4	0.39	0.4	0.46	0.42	0.44	0.41	0.48
	10-20	0.43	0.44	0.42	0.38	0.38	0.39	0.38	0.45	0.41	0.41	0.39	0.45
	20-30	0.40	0.42	0.41	0.37	0.37	0.38	0.36	0.45	0.37	0.40	0.38	0.43

Physical soil properties of NAF

Parameters	Soil depth (cm)	Autumn		Winter			Spring			Summer			
		Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
Sand (%)	0-10	50.18	48.33	57.41	59.54	58.48	60.83	50.48	58.31	57.63	55.61	51.54	57.13
	10-20	51.35	49.18	60.37	60.94	59.14	62.78	52.23	58.70	60.78	59.78	53.73	58.64
	20-30	51.70	50.31	60.97	63.24	61.90	63	54.77	60.14	61.96	61	54.27	58.83
Silt (%)	0-10	19.74	23	21.56	16.62	21.57	19.32	23.24	18.4	21.92	23.77	22.24	18.94
	10-20	20.62	26.14	20.4	20	23.24	19.82	25.52	20.52	20.54	20.22	22.74	20.12
	20-30	21.64	26.47	22.24	18.54	21	20.15	24.84	18.85	20.14	20.75	24.13	22
Clay (%)	0-10	30.27	28.72	21.15	23.95	20.15	19.97	26.45	23.36	20.57	20.76	26.33	24
	10-20	28.16	24.81	19.38	19.17	17.71	17.56	22.31	20.87	18.81	20.1	23.67	21.37
	20-30	26.75	23.86	16.91	18.36	17.16	16.98	20.58	20.11	18	18.38	21.78	19.28
BD (g/cm^3)	0-10	1.02	1.11	1.25	1.41	1.43	1.21	1.32	1.20	1.18	1.19	1.17	1.14
	10-20	1.06	1.16	1.29	1.43	1.47	1.27	1.39	1.26	1.21	1.25	1.19	1.16
	20-30	1.09	1.24	1.35	1.46	1.49	1.36	1.43	1.27	1.24	1.28	1.25	1.17
SP (%)	0-10	0.57	0.53	0.5	0.46	0.43	0.48	0.47	0.5	0.52	0.48	0.49	0.56
	10-20	0.54	0.52	0.49	0.46	0.42	0.47	0.46	0.49	0.51	0.45	0.49	0.54
	20-30	0.54	0.51	0.48	0.45	0.41	0.44	0.46	0.49	0.48	0.45	0.47	0.54

Chemical soil properties of CMAF

Parameters	Soil depth (cm)	Autumn		Winter			Spring			Summer			
		Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
SM (%)	0-10	32.19	28.52	27.10	18.72	16.90	18.32	21.35	29.92	36.25	38.28	33.50	35.58
	10-20	35.30	24.77	25.32	18.10	14.72	16.32	19.85	27.40	33.15	39.38	32.72	32.60
	20-30	36.81	26.10	22	16.70	14.13	15.16	18.17	25.12	31.90	35.12	31.12	28.15
Temp. (°C)	0-10	36.3	30.	27.1	24	22.3	22.7	25.1	29.3	32.7	35.8	36.6	36.9
	10-20	35.9	30.5	26.4	24	20.9	22.4	24.3	28.5	32.3	35.6	36.2	36.3
	20-30	35.4	29.8	26	23	20.1	21.8	24	28.1	32	34.3	35.8	36.1
SOC (%)	0-10	1.26	1.92	1.17	1.59	0.96	1.44	1.47	1.05	1.02	0.96	1.18	1.26
	10-20	1.17	1.86	1.05	1.32	0.87	1.38	0.87	1.30	1.38	1.17	0.93	1.05
	20-30	0.84	1.77	1.08	1.2	0.81	1.20	0.93	1.50	1.5	1.26	1.14	0.96
pH	0-10	4.1	4.1	3.2	2.8	2.9	3.1	3	3.5	3.6	4.2	3.8	3.5
	10-20	4.2	4.1	3.4	2.9	3.1	3.3	3.1	3.5	3.8	4.3	3.8	3.6
	20-30	4.2	4.3	3.4	3	3	3.3	3.1	3.5	3.9	4.5	3.91	3.9
EC (µS/cm)	0-10	289.14	286.13	272	267.33	279.10	294.85	310	328.10	337	347.32	334.7	309.88
	10-20	284.78	283.38	270.50	265.67	268.32	288.27	302.13	318.62	331.10	344.91	330.64	304.80
	20-30	280	280.72	269.22	263.50	263.42	280.81	294	313.20	329.57	338.53	328	291.26
CEC	0-10	31.06	35.50	22.83	17.51	19.87	21.62	25.20	26.95	22.20	29.38	24.61	30.66
(meq/100g)	10-20	31.68	35.20	21.05	15.73	17.50	19.21	24	26.33	20.43	27.52	22.83	30.20
	20-30	29.33	32.82	19.28	15.10	16.34	21.05	24.62	24.01	17.50	26.95	22.23	29.76
P (Kg/ha)	0-10	8	7.48	6.23	5.97	5.62	6.22	7.84	6.53	7.20	8	9.75	8.24
	10-20	8.81	7.62	6	6.12	5.90	6.83	7.40	6.30	7	7.62	9.22	8
	20-30	7.67	6.88	5.86	5.64	5.27	6	7	6	6.42	7	8.67	7.82
K(Kg/ha)	0-10	186.94	178	168	158.50	153	159.58	161.93	166	170.82	177.42	169	170.42
	10-20	177.48	166.90	159.20	149.50	140.52	151.80	153.60	158.42	1637	169.76	158.50	168.34
	20-30	172.55	168	150	142.98	137.32	147.50	151.50	156.73	159.54	168.52	154.66	160.98
TN (Kg/ha)	0-10	0.92	1.14	1.07	0.99	0.79	0.74	0.86	0.89	0.99	0.93	0.98	0.84
	10-20	0.82	1.11	1.02	0.96	0.72	0.71	0.80	0.82	0.91	0.92	0.87	0.77
	20-30	0.8	1.08	1.01	0.92	0.70	0.69	0.776	0.81	0.84	0.88	0.81	0.71
N (Kg/ha)	0-10	100.34	103.86	83.82	76.28	62.76	75.24	79.20	83.81	95.28	102.33	120.41	112.85
	10-20	85.22	96.34	77.21	63.70	60.74	73.20	69.74	77.28	92.73	99.33	117.86	107.37
	20-30	83.70	79.20	68.75	55.54	53.13	63.73	50.16	67.77	85.26	87.88	105.37	88.84

Chemical soil properties of NAF

Parameters	Soil depth (cm)	Autumn		Winter			Spring			Summer			
		Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
SM (%)	0-10	45.99	39.23	35.54	27.33	25.30	23.30	34.26	42.86	38.93	44.12	47.57	46.58
	10-20	37.45	32.76	31.50	26.18	24.83	21.15	31.54	42.29	35.97	43.74	46.14	45.92
	20-30	31	28.20	30.10	24.91	23.10	20.60	30.40	41.50	35	42.58	46	45
Temp. (°C)	0-10	33.7	27.5	25	22	21.1	21.7	23.2	26.4	28.6	33.3	35.3	35.9
	10-20	33.3	27.2	24.6	22	20.7	21.6	22.9	26.1	28.3	32.8	34.3	35.7
	20-30	33.2	26.8	24.1	21	20	21.3	22.5	25.1	27.5	32.3	34.1	34.9
SOC (%)	0-10	3.06	3	2.16	1.83	2.1	1.26	3	2.37	2.07	2.25	1.38	2.61
	10-20	3.03	2.79	1.92	1.77	1.59	1.20	2.61	2.16	1.48	1.92	1.59	2.82
	20-30	2.91	2.76	1.83	1.65	1.50	1.05	2.49	2.34	1.65	1.80	1.98	2.43
pH	0-10	5.2	4.9	4.6	4.5	4.3	4.7	4.5	4.6	5.3	5.2	5.5	5.1
	10-20	5.3	4.9	4.7	4.6	4.5	4.8	4.5	4.6	5.4	5.4	5.6	5.3
	20-30	5.5	5	4.9	4.8	4.5	4.8	4.6	4.8	5.5	5.4	5.7	5.1
EC (µS/cm)	0-10	239.74	232.86	227.32	222.44	213.85	239.32	246.56	249.22	246	238.58	228.52	230.75
	10-20	237.72	228.80	222.50	218.38	217.34	235.64	239.17	247.87	241.63	224.90	219.22	237.52
	20-30	229.53	221.10	217.80	211.82	214.10	236.10	231.70	240.22	231.91	220.30	210.32	235.91
CEC	0-10	42.93	39.90	35.52	33.72	29.93	28.74	38.82	37.60	31.51	29.96	33.74	30.22
(meq/100g)	10-20	39.98	37.61	33.36	31.50	27.56	26.90	37.66	33.40	30.63	29.33	31.56	29.75
	20-30	39.39	37	32.47	30.62	28.15	27.52	35.10	31.11	30.22	27.52	30.23	29.34
P (Kg/ha)	0-10	8.92	8.63	7.22	7.40	7.21	7.82	8.22	9.82	10.80	10.22	11.72	10.66
	10-20	9.21	8	7.61	7.83	7	7.20	7.80	9.45	10.41	10	11.22	10.82
	20-30	8.82	7.43	6.87	7.21	6.82	7	7.60	9	9.60	9.82	10.83	10
K(Kg/ha)	0-10	281.80	272.21	262.92	244.42	235.81	243.92	252.43	253.70	264.42	278.83	271.30	263.42
	10-20	272.20	268.40	259.44	239.81	233.94	237.50	247.92	248.91	255.41	269.15	266.64	253.94
	20-30	270.72	263.93	249.76	235.91	226.42	228.96	243.43	244.82	250.94	262.16	268	251.41
TN (Kg/ha)	0-10	1.96	1.92	1.76	1.73	1.65	1.63	1.74	1.77	1.75	1.80	1.89	1.90
	10-20	1.74	1.71	1.72	1.65	1.54	1.60	1.66	1.73	1.69	1.77	1.84	1.88
	20-30	1.70	1.63	1.67	1.62	1.50	1.59	1.61	1.64	1.60	1.75	1.80	1.83
N (Kg/ha)	0-10	213	194.12	168.12	160.32	147	125.42	127.8	148	163	175	188.10	200.70
	10-20	201.73	188.13	165	152.36	138.43	112.84	122.82	135.42	150.50	163	170	178.13
	20-30	192.12	177.92	163	150.53	133.42	109.33	112.8	120.84	148.50	158.50	163	170.9

Appendix II

Monthly value of the water physicochemical properties recorded from the three sampling stations of Tsurang River (September, 2018 – August, 2019).

Sampling station 1 (S1)

Parameters	Autumn			Winter			Spring			Summer		
	Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
pH	4.30	4.72	5.14	6	6.40	6.71	5.60	5.22	4.81	3.90	3.32	3.41
Turbidity	8.62	5.60	3.40	2.11	2.40	2.60	3.82	3.90	8.61	9.30	9.33	8.20
WT	23	20.03	20	18	22.06	23.08	20	20.01	23.03	22.04	23	22
EC	201.13	190	175.08	177	193.03	201	194	189.1	213.04	229.30	249.17	227
TDS	152.09	143.12	124	111.04	105	107.23	123	141.11	138.40	148	158	147.32
TH	76.10	88.05	114	134.06	128.19	124	102.11	110.08	112	94.06	72	78
Free CO_2	17.67	22.09	11	8.80	6.60	13.21	15.43	22	24.24	24.20	28.61	26.40
TA	120.09	130.16	175	180.08	210.16	205.22	180	175.14	165	155.70	130.01	125
Ca^{2+}	36.40	54	56.17	60.02	58.03	59.95	35.91	46	60	44.03	28.02	32
Mg^{2+}	9.62	10.70	14.12	18.05	13.92	15.62	16.14	15.60	12.61	12.10	10.70	11.23
DO	6.40	6.82	7.86	9.20	8	6.25	83	6.66	5.42	4.20	4	5.60
BOD	4.31	3.24	3.80	3.22	3.66	4.05	3.84	3.20	2.20	2.20	2.42	3.21
Cl^-	66.70	62	42.62	31	28.47	31.20	34	38.32	56.80	49.71	62.44	71
SO_4^{2-}	275.20	253.09	225.27	197	175.08	186.40	197.12	220.09	275.21	297.32	308.09	286.03
NO^-_3	3.29	3.72	3.30	2.14	2.25	2.80	2.30	3.33	4.21	4.40	3.72	4.30
PO_4^{3-}	0.35	0.28	0.26	0.24	0.20	0.22	0.21	0.28	0.34	0.38	0.39	0.32
K	7.50	6.21	4.41	3.10	2.23	4.08	5.38	6.60	7.10	8.83	8.42	6.60

All the parameters are expressed in mg/l except for pH, turbidity (NTU), WT (°C) and EC (µS/cm)

Sampling station 2 (S2)

Parameters	Autumn		Winter			Spring			Summer			
	Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
pH	4.41	4.90	5.22	6.10	6.45	6.92	5.84	5.31	4.95	3.92	3.30	3.90
Turbidity	8.72	5.84	3.50	2.32	2.61	2.90	3.90	3.92	8.84	9.40	9.62	8.81
WT	24.10	21.04	21.09	18	23.11	24	21.09	21.12	24.02	23.01	24	23.03
EC	188.16	178.60	188.82	189.03	183	196.14	186.74	168.61	209.10	210.50	236.37	217.81
TDS	166.12	155.09	138.12	121.07	112.09	121.14	145.50	157.10	148	159.20	168.01	162
TH	80.01	96.10	108.11	138	138.07	126.05	98	114	124.15	102.11	80.16	82.09
Free CO_2	19.81	15.40	13.21	6.60	8.80	11.23	13.21	19.85	22	19.80	24.21	22
TA	135.03	145.16	180	190.31	215.09	200.01	195.23	190.05	170.12	165.09	140.21	135.04
Ca^{2+}	40.03	50.03	58	68.08	62.02	64.06	37.91	44.01	58	46.03	30.02	36.92
Mg^{2+}	9.72	11.20	12.12	17	18.51	15.15	14.62	17	16.15	13.62	12.10	11
DO	6	6.20	7.43	9.05	7.60	7	7.21	6.23	5.02	4.45	4.41	5.83
BOD	3.60	3	3.62	3.42	3.07	3.40	3.62	2.45	2	2.60	3.02	3.80
Cl^-	71	63.92	44.03	38.32	31.20	34	35.51	39.75	61	51.12	63.90	75.20
SO_4^{2-}	258.03	242.11	214.09	175.01	164.13	175.29	192	208.07	264.01	286.12	297	253.04
NO^-_3	3.50	3.93	3.82	2.81	2.70	3.22	2.50	3.70	4.80	5	4.31	4.84
PO_4^{3-}	0.46	0.37	0.32	0.28	0.25	0.23	0.23	0.36	0.40	0.48	0.47	0.44
K	8.40	5.71	4	3.53	2.71	4.40	4.91	6.22	7.90	9.21	8.80	7.12

Sampling station 3 (S3)

Parameters	Autumn			Winter			Spring			Summer		
	Sept. 2018	Oct.	Nov.	Dec.	Jan. 2019	Feb.	Mar.	April	May	June	July	August
pH	4.70	4.91	5.41	6.34	6.61	6.82	5.90	5.41	4.93	4.01	3.40	3.91
Turbidity	8.91	6.22	3.70	2.43	2.70	3.20	4.22	4	9.34	9.82	10	8.91
WT	24.03	22.08	21.10	17	23.04	24	21.01	22.03	22.01	23.15	24.03	23.11
EC	192.06	171.17	194.22	182.09	171.41	188.60	177.01	170.60	197.02	200.43	222.70	203.11
TDS	183.12	171.33	156.12	138.04	123.30	127.01	134.01	163.20	172.07	168.30	177.11	179.09
TH	82.14	100.20	122.30	136.02	142.11	132.52	112.22	122.09	118.33	106.04	82.02	84.11
Free CO_2	22.20	19.80	15.41	8.82	11.21	13.20	11.04	15.42	19.82	17.62	22.09	19.80
TA	140.14	155.10	195.90	200.37	230.06	215.09	205.25	190.01	180.45	170.41	155.60	145.15
Ca^{2+}	46.03	58	48.01	70.04	67.91	70.04	41.90	52	55.90	54.04	46.03	44.13
Mg^{2+}	8.77	10.20	18	16.09	18.07	15.13	17.11	14.62	15.15	12.60	8.72	9.72
DO	6.80	6.61	6.20	8.25	8.22	6.04	7.06	6.40	4.81	5.10	4.80	6.10
BOD	4.42	4.03	3.42	3.61	3.80	3.20	3.41	2.90	2.30	3.03	3.62	4.06
Cl^-	76.62	68.10	52.03	42.60	35.51	38.32	39.70	41.10	69.51	55.35	68.13	79.52
SO_4^{2-}	244.14	231.20	201.08	164.13	158.08	164.46	181.47	208.31	253.31	275.06	264.09	242.15
NO^-_3	3.90	4.20	3.64	2.31	2.90	3.61	2.83	3.90	4.61	4.90	3.93	4.40
PO_4^{3-}	0.43	0.34	0.30	0.25	0.23	0.25	0.27	0.39	0.42	0.46	0.43	0.41
K	8.82	6.60	4.94	4.04	3.10	5.31	5.72	7.50	8.42	9.71	9.22	7.90

Appendix III

Descriptive ANOVA between groups (BG) and Tukey post-hoc test of the seasonal water physicochemical parameters

Soil Parameters	ANOVA	Station-1		Station-2		Station-3	
		F-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Turbidity	BG	30.487	<.001	31.435	<.001	38.613	<.001
	Win-Spr		.751		.773		.662
	Win-Sum		<.001		<.001		<.001
	Win-Aut		.001		.001		.001
	Spr-Sum		<.001		<.001		<.001
	Spr-Aut		.004		.003		.002
	Sum-Aut		.261		.306		.179
pH	BG	6.078	.018	6.268	.017	7.350	.011
	Win-Spr		1.00		.998		.999
	Win-Sum		.055		.046		.025
	Win-Aut		.077		.113		.070
	Spr-Sum		.055		.036		.029
	Spr-Aut		.076		.089		.083
	Sum-Aut		.996		.916		.878
WT	BG	1.563	.272	1.583	.268	1.398	.312
	Win-Spr		.855		.784		.574
	Win-Sum		.231		.225		.354
	Win-Aut		.580		.525		.354
	Spr-Sum		.580		.656		.969
	Spr-Aut		.951		.963		.969
	Sum-Aut		.858		.893		1.000
EC	BG	6.278	.017	3.462	.071	2.750	.112
	Win-Spr		.691		.993		.983
	Win-Sum		.013		.109		.180
	Win-Aut		.237		.910		.931
	Spr-Sum		.061		.076		.110
	Spr-Aut		.771		.796		.779
	Sum-Aut		.234		.267		.386
TDS	BG	7.177	.012	5.616	0.023	7.081	.012
	Win-Spr		.684		.394		.996
	Win-Sum		.022		.041		.058
	Win-Aut		.025		.028		.029
	Spr-Sum		.108		.394		.079
	Spr-Aut		.120		.287		.039
	Sum-Aut		1.00		.994		.958
TH	BG	10.843	.003	3.552	.067	7.507	.010
	Win-Spr		.184		.669		.700
	Win-Sum		.014		.279		.063
	Win-Aut		.003		.053		.011
	Spr-Sum		.306		.851		.286
	Spr-Aut		.062		.261		.048
	Sum-Aut		.661		.641		.592

Soil Parameters	ANOVA	Station-1		Station-2		Station-3	
		F-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Free CO_2	BG	12.417	.002	7.322	.011	8.667	.007
	Win-Spr		.095		.337		.872
	Win-Sum		.002		.010		.064
	Win-Aut		.009		.040		.008
	Spr-Sum		.067		.120		.185
	Spr-Aut		.361		.455		.022
	Sum-Aut		.616		.736		.474
TA	BG	11.644	.003	13.642	.002	14.091	.001
	Win-Spr		.999		.998		.967
	Win-Sum		.065		.035		.028
	Win-Aut		.005		.003		.002
	Spr-Sum		.078		.044		.053
	Spr-Aut		.006		.004		.004
	Sum-Aut		.275		.305		.278
Ca^{2+}	BG	1.241	.357	2.181	.168	.816	.520
	Win-Spr		.681		.427		.824
	Win-Sum		.493		.244		.659
	Win-Aut		.334		.169		.489
	Spr-Sum		.985		.967		.989
	Spr-Aut		.901		.884		.922
	Sum-Aut		.986		.993		.989
Mg^{2+}	BG	11.313	.003	3.937	.054	10.576	.004
	Win-Spr		.980		.998		.661
	Win-Sum		.047		.683		.036
	Win-Aut		.007		.061		.004
	Spr-Sum		.028		.778		.661
	Spr-Aut		.006		.289		.185
	Sum-Aut		.651		.289		.017
DO	BG	12.381	.002	1.941	.202	8.180	.008
	Win-Spr		.201		.998		.277
	Win-Sum		.001		.398		.005
	Win-Aut		.046		.907		.277
	Spr-Sum		.022		.480		.072
	Spr-Aut		.762		.837		1.000
	Sum-Aut		.097		.169		.072
BOD	BG	10.270	.004	1.940	.202	5.533	.024
	Win-Spr		.965		.998		.536
	Win-Sum		.010		.398		.252
	Win-Aut		.995		.907		.376
	Spr-Sum		.005		.480		.915
	Spr-Aut		.895		.837		.057
	Sum-Aut		.013		.169		.023

Soil Parameters	ANOVA	Station-1		Station-2		Station-3	
		F-value	*P*-value	*F*-value	*P*-value	*F*-value	*P*-value
Cl^-	BG	24.227	<.001	25.323	<.001	20.244	<.001
	Win-Spr		1.000		.989		.896
	Win-Sum		.006		.008		.017
	Win-Aut		.001		.001		.002
	Spr-Sum		.007		.006		.007
	Spr-Aut		.001		<.001		.001
	Sum-Aut		.203		.008		.271
SO_4^{2-}	BG	18.807	.001	20.446	<.001	18.496	.001
	Win-Spr		.999		.958		.892
	Win-Sum		.001		.001		.001
	Win-Aut		.008		.009		.008
	Spr-Sum		.002		.001		.002
	Spr-Aut		.009		.016		.020
	Sum-Aut		.536		.226		.355
NO_3^-	BG	5.912	.020	5.527	.024	5.420	.025
	Win-Spr		.924		1.000		.654
	Win-Sum		.028		.036		.028
	Win-Aut		.092		.241		.075
	Spr-Sum		.067		.040		.145
	Spr-Aut		.216		.264		.368
	Sum-Aut		.831		.556		.891
PO_4^{2-}	BG	12.245	.002	9.264	.006	8.105	.008
	Win-Spr		.999		.995		.712
	Win-Sum		.004		.019		.010
	Win-Aut		.057		.045		.043
	Spr-Sum		.005		.014		.043
	Spr-Aut		.068		.033		.193
	Sum-Aut		.267		.922		.712
K	BG	12.591	.002	17.426	.001	15.074	.001
	Win-Spr		.137		.179		.100
	Win-Sum		.002		.001		.001
	Win-Aut		.012		.006		.007
	Spr-Sum		.040		.009		.026
	Spr-Aut		.355		.141		.264
	Sum-Aut		.428		.253		.398

The mean difference is significant at the 0.05 level.

Note: Win-Winter; Spr-Spring; Sum-Summer; Aut-Autumn

Abbreviations

Short form	Expanded form
AN	Available nitrogen
As	Arsenic
A/F	Abundance-Frequency ratio
BA	Basal area
Ba	Barium
BIS	Bureau of Indian Standard
BD	Bulk density
BOD	Biological oxygen demand
CMAF	Coal mining-affected forest
CEC	Cation exchange capacity
Cd	Cadmium
Cu	Copper
Cr	Chromium
Ca^{2+}	Calcium
Cl^{-}	Chloride
D	Drainage
DO	Dissolved oxygen
EC	Electrical conductivity
FQ	Frequency
Hg	Mercury
IVI	Important Value Index
ICMR	Indian Council of Medical Research
K	Potassium
Mg^{2+}	Magnesium
MDS	Minimum data set
Mn	Manganese
NO_3^{-}	Nitrate
NAF	Non-affected forest
ND	Not detected
NIPI	Nemerow Integrated Pollution Index
Ni	Nickel
OC	Organic carbon
PI	Single pollution index
PLI	Pollution Load Index
P	Phosphorus
PCA	Principal component analysis
PO_4^{3-}	Inorganic phosphorus
Pb	Lead
R.D	Relative density
R.F	Relative frequency
R.Dom	Relative dominance
SD	Standard deviation
S1	Station 1
S2	Station 2
S3	Station 2
SQI	Soil Quality Index

SP	Soil porosity
SHM	Soil heavy metals
Sb	Antimony
SO_4^{2-}	Sulphate
SM	Soil moisture
TN	Total nitrogen
TDS	Total dissolved solids
TA	Total alkalinity
TH	Total hardness
WAI	Weighted Arithmetic Index
WT	Water temperature
WHO	World Health Organization
WQI	Water Quality Index
Zn	Zinc

Units

Meq/100g	Milliequivalents per 100 grams
µS/cm	MicroSiemens per cm
%	Percentage
Kg	Kilogram
Ha	Hectare
°C	Degree Celsius
L	Litre
NTU	Nephelometric turbidity units
m^3/s	Meter cube per second
g/cm^3	Gram per centimeter cube
mg/l	Milligram per litre
mg	Milligram
mg/kg	Milligram per kilogram
gm	Gram
cm	Centimeter
ml	Millimeter

नागालैण्ड विश्वविद्यालय
NAGALAND UNIVERSITY
(संसद द्वारा पारित अधिनियम 1989, क्रमांक 35 के अंतर्गत स्थापित केंद्रीय विश्वविद्यालय)
(A Central University established by the Act of Parliament No.35 of 1989)
मुख्यालय : लुमामी, जुन्हेबोटो (नागालैण्ड), पिन कोड – 798627
Headquarters: Lumami, Dist: Zunheboto, (Nagaland), Pin Code-798 627

PLAGIARISM FREE UNDERTAKING

Name of Research Scholar/Student	Mr. Khikeya Semy
Ph.D./M. Phil. Registration Number	Ph. D./BOT/00072
Title of Ph.D. thesis/M. Phil. Dissertation	Ecological studies on the affected and non-affected forest in coal mining areas of Changki in Mokokchung district, Nagaland
Name & Institutional Address of the Supervisor/ Joint Supervisor	Dr. M. Romeo Singh
Name of the Department and School	Department of Botany
Date of submission	18/3/2022
Date of plagiarism check	18/3/2022
Percentage of similarity detected by the **URKUND** software	7%

I hereby declare/ certify that the Ph.D. Thesis/ M. Phil. Dissertation submitted by me is complete in all respect, as per the guidelines of Nagaland University (NU) for this purpose. I also certify that the Thesis/ Dissertation (soft copy) has been checked for plagiarism using **URKUND** similarity check software. It is also certified that the contents of the electronic version of the thesis/dissertation are the same as the final hardcopy of the thesis /dissertation. Copy of the Report generated by the **URKUND** software is also enclosed.

(Name & Signature of the Scholar)

Date:
Place:

Name & Signature of the Supervisor:
with seal

Name & Signature of the Joint Supervisor (if any):
with seal

LIST OF PAPER PUBLICATIONS, PRESENTATIONS, TRAININGS AND ATTENDED CONFERENCES

Papers publications

1. **Semy, K**., Singh, M.R. and Vats, N. (2021). Evaluation of soil quality of a coal mine affected forest at Changki, Nagaland, India. *Journal of Environmental Engineering and Landscape Management* 29(4): 381-390.
2. **Semy, K**. and Singh, M.R. (2021). Quality assessment of Tsurang river water affected by coal mining along the Tsurangkong Range, Nagaland, India. *Applied Water Science* 11:115.
3. **Semy, K**. and Singh, M.R. (2021). Assessment of soil physico-chemical properties and heavy metals bioaccumulation on plants at a coal mining affected forest of Changki, Nagaland. *Environment and Ecology* 39 (1A): 192-199.
4. **Semy, K**., Singh, M.R., Walling, M., Temjen, W., Jangir, A. and Mishra, G. (2022). Qualitative soil assessment of coal mine disturbed and undisturbed tropical forest in Nagaland, India. *Proceeding of the National Academy of Sciences, India: B. Biological Sciences*. 1-6.
5. Konyak, P.A., **Semy, K.** and Puro, N. (2021). Non-timber forest products as a means of livelihood in Mon district, Nagaland, India. *Current Science*. 121(6): 837-840.
6. Konthoujam, R., Singh, M.R. and **Semy, K.** (2021). Comparative Assessment on Riparian Soil Characteristics at Three Lateral Buffer Zones in Riparian Forest of Dikhu River. *Indian Journal of Ecology*. (2021) 48: 1365-1369.
7. Temjen, W., Singh, M.R., Ajungla, T., Chophi, K.Z. and **Semy, K.** (2021). Fungal diversity and physicochemical parameters of rhizospheric soil from banana plantation sites at Nagaland, India. *Agricultural Science Digest*. DOI:10.18805/ag.D-5274.
8. Das, M., **Semy, K**. and Kuotsu, K. (2022). Seasonal monitoring of algal diversity and spatiotemporal variation in water properties of Simsang river at South Garo Hills, Meghalaya, India. *Sustainable Water Resources and Management*. 8(16).

Book Chapter's published:

1. **Semy, K**. and Singh, M.R. (2021). Correlation studies among the water physico-chemical properties of Tsurang river, Nagaland. *Bioresources and Sustainable Livelihood of Rural India*. pp. 127-136. ISBN-13: 978-93906925761.

Papers presented

1. Presented a paper with the title "*Assessment on water quality status of Tsurang river, Mokokchung district, Nagaland affected by the coal mining drainage*" at International conference on "Chemical Ecology, Environment and Human Health: Emerging Frontiers and Synthesis (ICCEEHH 2019), Organized by Department of Zoology, Sikkim University on August 9^{th} – 10^{th}, 2019.

2. Presented a paper with the title "*Evaluation of heavy metals using pollution indices and transfer factor on coal mining affected soil and plants at Changki, Nagaland, India*" at Virtual International Conference on Energy, Environment and Health (VICEEH-2020), Organized by Internal Quality Assurance Cell (IQAC) & IETE student forum of Sree Ayyappa college. 11^{th} – 12^{th} September, 2020.

3. Presented a paper with the title "*Evaluation of soil quality on the coal mining affected and non-affected forest at Changki, Nagaland*" at International Conference of Biotechnology and Biological Sciences, Biospectrum, 19^{th} – 21^{st} November, 2020.

4. Presented a paper with the title "*Assessment on soil physico-chemical properties of a forest affected by coal mining at Changki, Nagaland*" at National e-seminar on Chemistry in Emerging Trends of Interdisciplinary Research (NeSCETIR-2020), Organised by Department of Chemistry, Nagaland University, DST-FIST supported, 18^{th} – 20^{th} November, 2020.

5. Presented a paper with the title "*Correlation studies among the water physicochemical properties of Tsurang river, Nagaland*" at National e-conference on Bioresources and sustainable livelihood of Rural India, Organised by Department of Botany, Nagaland University, 28^{th} – 29^{th} September, 2020.

6. Presented a paper with the title "*Soil quality status of a coal mine affected and non-affected forest in Nagaland, India*" at 2^{nd} International Conference on Environment, Agricultural, Chemical and Biological Sciences in support of United Nations SDGs

organized by Voice of Indian Concern for the Environment (VOICE), 24-26th January, 2021

7. Presented a paper with the title "*Weighted arithmetic index as a means to assess the water quality of Tsurang River in Nagaland, India affected by coal mining"*. International Conference on Environment, Agriculture, Human and Animal Health. World Environment Day, 5th -7th June, 2021.

8. Presented a paper with the title "*Seasonal soil quality assessment in a tropical semi-deciduous forest of Nagaland, India*". Biospectrum, 18th-20th November, 2021.

9. Presented a paper with the title "*Additive and weighted soil quality index as an approach to evaluate coal mine affected tropical forest stands of Nagaland*". International Conference on Environmental, Agricultural and Biological Sciences. 22nd-26th January, 2022.

Participation in seminars/conferences

1. Short-term skill development training program in biotechnology for students of North-East India. Skill development training program on "Orchid propagation" jointly organized by Biotech Park, Lucknow and Institutional Biotech Hub, Nagaland University. 16th November – 15th December, 2017.

2. Participated in the workshop "Skill and entrepreneurial development of the tribal youth" with the theme "Value-additions to rich bio-resources with special reference to medicinal and aromatic plants" at Nagaland University, Lumami, 25th – 28th July, 2018.

3. Hands on training on "Genomics and gene expression analysis" organized & sponsored by Department of biotechnology, Govt. of India sponsored Advance level institutional biotech hub, Nagaland University, Lumami, 18th – 23rd July, 2018.

4. Participated at the "National conference of stakeholders on conservation, cultivation, resource development and sustainable utilization of medicinal plants of North-eastern India" jointly organized by Department of Botany, Nagaland University & Society for conservation and resource development of medicinal plants (SMP), New Delhi. 6th – 7th March, 2019.

5. Hands on training on "Molecular taxonomy of microbes and higher plants" organized & sponsored by Department of biotechnology, Govt. of India sponsored Advance level institutional biotech hub, Nagaland University, Lumami, 17th – 23rd July, 2019.