EFFECT OF SUBSIDENCE ON THE PHYSICO-CHEMICAL PROPERTIES OF SOIL IN A COAL MINING AREA OF MADHYA PRADESH

THESIS SUBMITED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Science (Agriculture)
in
Soil Science and Agricultural Chemistry

Supervisor
Prof. A. P. Singh

Submitted by
Tusarkanta Behera

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Tusarkanta Behera

2018

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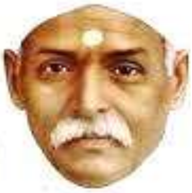

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CERTIFICATE

To,
The Registrar (Academic)
Banaras Hindu University,
Varanasi-221005 (India)

Through: The Head,
Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University,
Varanasi-221005 (India)

Dear Sir,

I have great pleasure in forwarding the thesis **"Effect of Subsidence on the Physico-Chemical Properties of Soil in a Coal Mining Area of Madhya Pradesh "**submitted by *Mr. Tuarkanta Behera,* (I.D. No. 16SSC 24), in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)**in **Soil Science and Agricultural Chemistry**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and original. No part of the work has been submitted for any other degree or distinction.

Thanking you,

Forwarded by

(Prof. A. P. Singh)
Supervisor

(Head)

EFFECT OF SUBSIDENCE ON THE PHYSICO-CHEMICAL PROPERTIES OF SOIL IN A COAL MINING AREA OF MADHYA PRADESH

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Varanasi – 221 005 (INDIA)

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Before I start inking let me truly admit that, it is practically impossible to mention all the worthy support, kind cooperation and directional guidance stretched out by my honourable teachers, supportive friends and loving relatives and all of my well-wishers in just two pages. However I am trying to document all worth-mentioning hereunder.

With a deep sense of devotion I bow and pray to the feet of ***Lord Viswanath*** *who provided me choicest, everlasting blessing to get an opportunity to satisfy in Banaras Hindu University, Varanasi.*

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Before I conclude, I confess that I do not know how to acknowledge the help and co-operation of my Supervisor, members of advisory committee, family members and relatives, seniors, juniors, colleagues but above feelings come from the core of my heart in the shape of words and as gospel truth.

Date:
Place: *Varanasi* ***(Tusarkanta Behera)***

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Chapter I

INTRODUCTION

Coal mining in India began in 1774 and its commercial exploitation started in the Raniganj Coalfield along the western bank of Damodar river. India has the fifth largest coal reserves in the world and is the fourth largest producer of coal in the world, producing 662.79 million metric tons in 2016-17. As on 31 March 2017, India had 315.14 billion metric tonnes of the resource. (https://en.wikipedia.org/wiki/Coal mining in India, accessed 30/04/2018). As a consequence of increased demand for coal, more and more coal is being mined and processed. The underground coal mining has caused a large amount of land subsidence leading to farmland losses and undulation of land surface.

What is subsidence?

Subsidence is the movement of a surface (usually, the earth's surface) as it shifts downward relative to a datum such as sea level due to various natural and man-made activities. The opposite of subsidence is uplift, which results in an increase in elevation.

Causes of subsidence

Subsidence is amalgamation of various natural and human made consequences which are depicted as under mentioned:

1. **Natural phenomena**

   The natural phenomena that cause subsidence are volcanism, folding, fault, continental drift, tectonic movement, dissolution of lime stone etc. Volcanism is the phenomenon of eruption of molten rock (magma) onto the surface of the Earth where lava and volcanic gases erupt through a break in the surface leads to subsidence. In geological folding, one or a stack of originally flat and planar surface such as sedimentary strata, are bent or curved as a result of permanent deformation which cause subsidence. In geology, a fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement as a result of rock-mass movement. Large faults within the Earth's crust result from the action of plate tectonic forces which lead to subsidence. Dissolution of limestone by fluid flow in the subsurface causes formation of voids. If the roof of these voids becomes too weak, it can collapse and the overlying rock and earth will fall into the space, causing subsidence at the surface.

2. **Man-made**

The subsidence as a result of man-made activities includes natural gas removal, underground extraction for mining, overuse of ground water etc. If natural gas is extracted from a natural gas field the initial pressure (up to 60 MPa) in the field will drop over the years. The gas molecules help in supporting the soil layers above the field. If the gas is extracted, the overburden pressure sediment compacts and may lead to subsidence at the ground level. Underground extraction for mining causes the extracted void to collapse will result in surface subsidence. when large amounts of water are pumped, the subsoil compacts, the volume of soil decreases and causes subsidence.

Mine subsidence

It can be defined as movement of the ground surface as a result of readjustments of the overburden due to collapse or failure of underground mine workings. Surface subsidence features usually take the form of either sinkholes or troughs.

Sinkhole subsidence is common in areas overlying shallow room-and-pillar mines. Sinkholes develop from the fall of the mine rooftop into a mine opening, bringing about giving in of the overlying strata and an abrupt depression in the ground surface. The majority of sinkholes usually develop where the amount of cover (vertical distance between the coal seam and the surface) is less than 50 feet. This type of subsidence is generally localized in extent, affecting a relatively small area on the overlying surface. However, structures and surface features affected by sinkhole subsidence tend to experience extensive and costly damages. Subsidence trough induced by room-and-pillar mining can happen over dynamic or deserted mines. The resultant surface effects and damages can be comparable, however the mechanisms that trigger the subsidence are significantly different. In deserted mines, troughs for the most part occur when the overburden hangs descending due to the failure of the leftover mine pillars, or by punching of the pillars into a delicate mine floor or rooftop.

A coal seam is a dark brown or black banded deposit of coal that is visible within layers of rock. These seams are located underground and can be mined using either deep mining or strip mining techniques depending on their proximity to the surface. Most coal seams are too deep underground for opencast mining and require underground mining. Room and pillar mining is the most common method of underground mining. The roof of the mine is supported by areas or columns of coal (pillars) spaced out at regular intervals in rooms from which the coal is mined. The two types of room and pillar mining are conventional and continuous mining.

According to Ministry of Environment and Forest, Govt. of India guidelines, all the underground coal mining industries situated below forest land will have to quantify the impact of subsidence due to mining under the forest land. In addition to this the underground coal mining has caused a large amount of land subsidence, which has led to farmland losses and caused severe conflicts between farming and mining.

The mining land use problems and conflicts are:

- Conflicts that arise when two or more proponents compete for the same parcel of land; for example, coal strip mining and agriculture.
- When a particular land use on one parcel of land adversely affects the use of adjacent land then conflicts at that time arise. This usually raises the question of compatibility or incompatibility of users; for example the impact of metallic mine wastes on the use of neighbouring water resources.
- Conflicts that arise between those who wish to develop a particular mineral or energy resource and those who desire the maintenance of environment through conservation and protection; for example the establishment of gardens, parks etc.

Subsidence effects on agriculture land have been documented in Illinois, U.S.A (Darmody *et al*., 2014), United Kingdom (Selman, 1986), China (Donggan *et al.*, 2011), South Africa (Bell *et al*., 2000), and Australia (Thompson *et al*., 2010). These effects include soil erosion, disruption of surface and subsurface drainage, wet or ponded areas, and reduction of crop yields. Large cracks that develop at the soil surface after subsidence can pose a hazard and may alter soil hydrology. Landscapes with erosive soils on long slopes may be subject to increased erosion potential because of slope increase or displacement of erosion control structures. Although many studies have been carried out to address the issue of mine subsidence in China, Australia, United Kingdom etc. very few of them have been done in India. Further studies available on impact of mine subsidence on changes in nutrient status in soil and plants are very few and fragmented.

Keeping in view the above, it was considered desirable to study the impact of underground mining subsidence on the land characteristics with particular reference to availability of different nutrients and whether the wasteland of mining areas could be used for cultivation of crops.

To address afore mentioned issues, the present investigation was undertaken with the following objectives:

- To study the effect of subsidence on the physico-chemical properties of soils of coal mining areas.

  To study the subsidence effect on depth wise variation of soil nutrient elements of coal mining areas.

Chapter II

REVIEW OF LITERATURE

This chapter presents some of reviews relating to the research work entitled “Effect of subsidence on the physico-chemical properties of soil in a coal mining area of Madhya Pradesh”.

Darmody *et al.* (1989) did an experiment on effects of coal mining subsidence on corn yields as damage done by subsidence to structures has been documented, but the effects on agricultural productivity were undocumented. This study was conducted to (i) determine the extent of measurable subsidence effects associated with planned subsidence mining, (ii) measure the impact of subsidence on corn (*Zea mays* L.) yield, and (iii) compare the effects of longwall and high extraction retreat mining methods. Five locations in southern Illinois were included in the 3 years of the study. A total of 4605 ha in 1985, 6747 ha in 1986, and 7764 ha in 1987 were involved. These areas represented unmined control areas as well as longwall (LW) and high extraction retreat (HER) types of mines. Aerial photographs of the study locations were taken in the spring of each year. Subsidized areas were identified, classified, and measured on the photos. The average per cent of the study area with measurable subsidence effects was 7.5% for LW mining and 3.3% for HER mining. Corn was harvested each year on selected subsided and nearby unsubsidized reference areas. The weighted average reduction in corn yield on land above the mines was calculated by multiplying the affected area by the associated yield reduction. The weighted average yield reduction was 4.7% for LW mining and 1.8% for HER mining. Results for the individual years varied with the weather: the greater the precipitation, the greater the yield reductions. The results also reflected the yearly variation in mining activity, crop sample areas, and overall study areas. In addition, the mitigation of subsidence effects in place at the time of the study also influenced the results, but the potential for mitigation for either mining type was not included in the research.

Jobbagy *et al.* (2001) studied the distribution of soil nutrients with depth. To understand the importance of vertical distributions of soil nutrients, they explored nutrient distributions in the top meter of soil for more than 10,000 profiles across a range of ecological conditions. They stated that vertical nutrient distributions are dominated by plant cycling relative to leaching, weathering dissolution, and atmospheric deposition. Nutrients strongly cycled by plants, such as P and K, were more concentrated in the topsoil (upper 20 cm) than were nutrients usually less limiting for plants such as Na and Cl. The topsoil concentrations of all nutrients except Na were higher in the soil profiles, where the elements were more scarce. Along a gradient of weathering-leaching intensity, total base saturation decreased but the relative contribution of exchangeable K^+ to base saturation increased. These patterns are difficult to be explained without considering the upward transport of nutrients by plant uptake and cycling. Shallower distributions for P and K, together with negative associations between abundance and topsoil accumulation, support the idea that plant cycling exerts a dominant control on the vertical distribution of the most limiting elements for plants (those required in high amounts in relation to soil supply). Plant characteristics like tissue stoichiometry, biomass cycling rates, above- and belowground allocation, root distributions, and maximum rooting depth may all play an important role in shaping nutrient profiles. Such vertical patterns yield insight into the patterns and processes of nutrient cycling through time.

Deo *et al.* (2004) made an ecological survey on metal contamination (Cu, Fe, Al, Cr) of vegetation (tree, shrub and herb) collected from the overburden soil of South Bolanda, Talcher, Odisha. Stem and leaf parts of the trees and shrubs, and whole plant of the herbs were analysed. Concentrations of metals were maximum in leafy part of trees and shrub samples. Among the various heavy metals studied, Fe concentration in plant parts was the highest and Cu concentration was the lowest.

Ghose *et al*. (2004) described the deterioration of soil quality due to stockpiling in coal mining areas. In the process of opencast mining, the area was to be stripped of vegetation to remove the overburden. Several changes occured in the physical, chemical and microbiological properties of soil as a result of mining and storage. One large opencast coal project of Eastern Coalfields Ltd (ECL) was investigated to assess the deterioration in soil quality. The study revealed a major qualitative deterioration in the excavated soil when dumped over a long period of time. This inability to preserve topsoil is one of the basic hindrances to restoration of mined land and overburden dumps. Hence the topsoil should be stockpiled only when it is impractical to redistribute promptly over the affected areas.

Xiaoling *et a*l. (2006) conducted an experiment on the growth of plant in reclaiming substrates for coal mine subsidence land. Fly ash was mixed separately with sewage sludge and distillers' grains in a ratio of 4:1 to produce new(reclaiming) substrates. Pot experiments were conducted using these substrates to evaluate the growth of *Medicago sativa*, cotton, *Festuca arundinacea*, *Poa pratensis* as well as the characteristics of the substrates. The plants grew well in the substrates. The chlorophyll content of the plant in the substrates exceeded that of the plant in the soil, few changes were observed in the organic matter content in the substrates. Available nutrient content was reduced because of the leaching by irrigation and rainwater, although the new substrates still had higher nutrient contents compared with their contents in soil. The salt content reduced obviously in the substrates. It was concluded that the substrates could basically sustain plant growth, but only non-edible type of plants should be grown.

Sharma *et al.* (2007*)* carried out a study *on* biodiversity loss due to refuses of thermal power station at Bokaro, India. They examined vegetation pattern and various plant species between Bokaro Thermal Power Station (BTPS) and Kathara coalfield area which is situated along Konar river, an important tributary of Damodar. A number of mining activities and various industries have been installed along the basin of Damodar river. BTPS and Kathara coalfield areas have been representing a typical tropical forest type of vegetation with much biodiversity in the plant community. But after establishment of BTPS, the vegetation is being changed due to various pollutants released by thermal power activities. The pollutants are in all the three forms i.e, solid, liquid and gases which are directly added to the river without recycling. Fly ashes released by the BTPS are allowed to settle in a tank and water is finally discharged into the river which pollute both river water and soil ultimately affecting the whole vegetation. Large number of air pollutants in the form of poisonous gases, oils and greases which are released into the atmosphere are also creating alarming situation by adversely affecting the flora and fauna. These pollutants have hazardous effect causing severe ecological problems like change in topography, deterioration of quality of top soil, loss of top soil and subsidence water logging etc. During the survey and documentation of various plant species in the existing vegetation of BTPS revealed that the original vegetation had been replaced by new exotic species such as *Lantana* sp., *Parthenium* sp., *Solanum* sp. etc. The vegetation also showed that there were some plant species which were on the verge of disappearance and some of them disappeared completely. This proves the seriousness of the load of pollution.

Hui *et al*. (2008) conducted an experiment on ecological damage prediction and restoration in Hulun Buir grassland in Wumuchang coal mine. The project region was divided into five parts, including subsidence region, surface plant, gangue field, transportation region and linear project region according to seat of settlement and land utilization. Settlement happened in half of the region, which converted into the terrestrial ecosystem from aquatic ecosystem, the other parts of the region subsidized and cracked. These damaged lands could be restored by regulating land and planting trees and grass. The area of uninfluenced region would be 1393.58 km^2, including four parts besides the settlement region. It would destroy the plant cover and exacerbate soil and water loss. In addition to measures of protection some other methods like land restoration and water and soil conservation also be adopted.

Tripathi *et al*. (2009) assessed the effect of post-mining land subsidence on fine root biomass and root tips count; plant available nutrient status, microbial biomass N (MBN) and N-mineralization rates of a southern tropical dry deciduous forest of Singareni Coalfields of India. The changes were quantified in all the three (rainy, winter and summer) seasons, in slope and depression microsites of the subsided land and an adjacent undamaged forest microsite. Physio-chemical characteristics were found to be altered after subsidence, showing a positive impact of subsidence on soil moisture, bulk density, water holding capacity, organic carbon content, total N and total P. The increase in all the parameters was found in depression microsites, while in slope microsites, the values were lower. Fine root biomass and root tips count increased in the subsided depression microsites, as demonstrated by increases of 62% and 45%, respectively. Soil nitrate N and phosphate-P concentrations were also found to be higher in depression microsite, showing an increase of 35.68% and 24.74%, respectively. Depression microsite has also shown the higher MBN value with an increase over control. Net nitrification, net N-mineralization and MBN were increased in depression microsite by 29.77%, 25.72% and 34%, respectively. There was a positive relation of microbial N with organic C, fine root biomass and root tips.

Petkova *et al.* (2009) found that while coal production makes an important contribution to economies in many countries, there is often significant conflict between farming communities and mining interests where arable land and coal co-occur in Australia.

Sankar *et al.* (2009) studied on vertical distribution of available macro and micro nutrients cation in red soils of Tamil Nadu. Vertical distributions of available macro and micro nutrients cations in soil pedons (Sivagangai, Melapoongudi, Tamarakki and Keelapoongudi series) from red soil region (Kutturavupatti village, Sivagangai district, Tamilnadu) were studied. The soil texture varied from loamy sand to clay and bulk density ranged from 1.11 to 1.33 Mgm-3. Organic carbon was more in surface than subsurface and pH of soil ranged from

5.5 to 8.3. The available nitrogen in soil was low (<280 kg ha^{-1}) in all the pedons which ranged from 28 to 117 kg ha^{-1} and its distribution was found decreasing with increasing depth. The available phosphorus (5.3 to 25.2 Kg ha^{-1}) and potassium (K) content (987 to 574 Kg ha^{-1}) in soil was low to high in all the pedons. The available Fe, Mn, Zn and Cu contents in soil ranged from 6.2 to 71.8, 2.6 to 15.4, 0.8 to 11.5 and 1.6 to 29.2 ppm, respectively. The available micronutrients content of these soils were in the order of Fe> Mn> Zn >Cu.

Jobbagy *et al.* (2001) studied the distribution of soil nutrients with depth. To understand the importance of vertical distributions of soil nutrients, they explored nutrient distributions in the top meter of soil for more than 10,000 profiles across a range of ecological conditions. They stated that vertical nutrient distributions are dominated by plant cycling relative to leaching, weathering dissolution, and atmospheric deposition. Nutrients strongly cycled by plants, such as P and K, were more concentrated in the topsoil (upper 20 cm) than were nutrients usually less limiting for plants such as Na and Cl. The topsoil concentrations of all nutrients except Na were higher in the soil profiles, where the elements were more scarce. Along a gradient of weathering-leaching intensity, total base saturation decreased but the relative contribution of exchangeable K^+ to base saturation increased. These patterns are difficult to be explained without considering the upward transport of nutrients by plant uptake and cycling. Shallower distributions for P and K, together with negative associations between abundance and topsoil accumulation, support the idea that plant cycling exerts a dominant control on the vertical distribution of the most limiting elements for plants (those required in high amounts in relation to soil supply). Plant characteristics like tissue stoichiometry, biomass cycling rates, above- and belowground allocation, root distributions, and maximum rooting depth may all play an important role in shaping nutrient profiles. Such vertical patterns yield insight into the patterns and processes of nutrient cycling through time.

Mohapatra *et al*. (2012) assessed the impact of coal mining on soil characteristics around IB river coalfield, Odisha. They analysed the soils of five opencast coal projects of IB river coalfield during pre-monsoon (March), monsoon (July) and post monsoon (November) periods of successive three years (i.e., 2006, 2007 and 2008). Sampling of soil was done from the vertical surface of the overburden at successive depths of 0-5 ft, 5-10 ft and at 10-15 ft. The different physical (soil texture, soil moisture, particle density, bulk density and porosity) and chemical (pH, organic carbon, nitrogen, phosphorus and potassium) parameters were analysed. The soil texture of the study area was found to be loamy sand to loam, loam to silty loam and clay loam to silty clay loam in the depth of 0-5 ft, 5-10 ft and at 10-15 ft, respectively. The moisture content and porosity of the soil in the study area decreased gradually from the surface to greater depth. However, the particle density and the bulk density in this region increased from surface to the deeper region of the soil. The organic carbon, nitrogen and phosphorus level of the soil decreased with increasing depth of the soil. However, the content of potassium increased gradually from the surface to the greater depth. Analysis of variance was computed to infer the variation in the concentration of parameters in different opencast coal projects and in various depths of the study area.

Biwe *et al.* (2012) made an assessment on status and distribution of available micronutrients along a toposequence at Gubi Bauchi, North Eastern Nigeria. A study was carried out to determine the status and distribution of extractable Zn, Cu, Fe and Mn along a toposequence at Gubi Bauchi. Four profile pits were dug along the toposequence at the upper slope, middle slope, lower slope and valley bottom positions and soil samples taken from identified horizons were subjected to laboratory analysis. The results showed that the mean values were 0.26, 0.36, 44.75 and 47.50 mg/kg for Zn, Cu, Fe and Mn, respectively. Zn and Cu were generally “low” to “medium” in all the horizons of the pedons, and also below the critical limits for arable crop production. The crops will benefit from supplementary application of these micronutrients for maximum productivity. Fe and Mn values were “high” and above the critical limits for arable crop production in all the horizons of the pedons. The soils will not require supplementary application of Fe and Mn.

Yang *et al.* (2013) studied the effect of ground surface subsidence on ecological environment and on soil nutrients in the Bulianta (sandstorm-subsidence area) and Yujialiang (loess-subsidence area) coal mine, Shenfu-Dongsheng coal field. The characteristics of soil nutrients in non-collapse area and the effect of collapse on soil nutrients were studied systematically by field sampling and laboratory analysis. The results showed that with increasing soil depth, total soil nutrient content gradually decreased in both study areas, while in Sandstorm-subsidence area, total nitrogen and total phosphorus increased with soil depth. The total nitrogen and total phosphorus in sandstorm-subsidence area was lower than those in loess-subsidence area, but the total K was higher than that in loess-subsidence area. The effect of coal mining subsidence on total soil nutrients in both the areas was on the small side.

Chaudhuri *et al.* (2013) stated that mining and in particular coal mining is one of the key drivers of land degradation worldwide both in developed nations such as Spain, the USA, England and Australia.

Cheng *et al.* (2014) studied the soil properties in reclaimed farmland by filling subsidence basin due to underground coal mining with mineral wastes in China. Reclaimed mining-induced subsidence area soils (RMSs) could restore soil quality and crop productivity in coal mining area. This study was conducted to evaluate the effects of mineral-processing wastes as backfill substrates on soil chemical and microbial properties in mining-induced subsidence area. A general higher water holding capacity (WHC) and pH had been observed in fly ash than coal gangue reconstructed soil. Soil microbial biomass nitrogen (MBN), soil microbial biomass C (MBC), MBC/TOC (total organic carbon) ratio were higher under the influence of the fly ash, while contents of As, Cr, C:N ratio, the basal respiration per unit of microbial biomass (Q_{CO2}) were higher under the coal gangue reconstructed mode in 0–10, 10–20, 20–50 cm layers. The microbial basal respiration was higher in 0–10, 10–20, 0–50 cm layers. The same was lower in 20–50 cm layer under fly ash than that of coal gangue reconstructed mode. The lower Q_{CO2} of fly ash mine soil suggested the lower maintenance energy requirement of the microbial community. Moreover, the contents of metals may possibly have negative implications for soil microbial and enzyme activities in reconstructed soil.

Llori *et al.* (2015) described on depth-wise distribution of micronutrient cations in Charnockitic soils. This study was to determine the status and distribution of extractable micronutrient cations in profile of soils developed on charnockite at Ado, Ijan, Ijesa-Isu, Ikere, Ire and Osin-Itapa, in Ekiti State, Nigeria. The soils were loamy sand to sand texture at the surface horizons with sandy loam to sandy clay loam sub-surface horizons. The clay content increases proportionately with depth confirming the presence of argillic Bt-horizons in charnockitic soils. Soil pH ranged from 5.6 to 7.5. Total N and available P were critically low. The extractable Mn range was 0.01 to 2.72 mg kg-1 in the soils with the Ap-horizons having the highest contents. The extractable Cu ranged from 0.04 to 12.96 mg kg^{-1} and higher in most of the subsurface soils than the surface soils. The extractable Fe was generally high in the Ap-horizons of the soils, ranging from 0.57 to 1163.90 mg kg^{-1}. Extractable Zn was critically low in the soils having the highest value of 0.31 mg kg^{-1}. The micronutrient cations followed an irregular distribution pattern; the extractable Fe and Cu were adequately available but the extractable Mg and Zn were critically deficient in charnockitic soils.

Tian *et al.* (2017) studied the vertical patterns and controls of soil nutrients in alpine grassland and nutrient cycling in high-altitude ecosystems. They examined vertical distributions of soil nutrients and their influencing factors within the upper 1 m of soil, using data of 68 soil profiles surveyed in the alpine grassland of the eastern Qinghai-Tibet Plateau. Soil organic carbon (SOC) and total nitrogen (TN) stocks decreased with depth in both alpine meadow (AM) and alpine steppe (AS), but remained constant along the soil profile in alpine swamp meadow (ASM). Total phosphorus, Ca^{2+}, and Mg^{2+} stocks slightly increased with depth in ASM. K^+ stock decreased with depth, while Na^+ stock increased slightly with depth among different vegetation types; however, SO_4^{2-} and Cl^- stocks remained relatively uniform throughout different depth intervals in the alpine grassland. Except for SOC and TN, soil nutrient stocks in the top 20 cm soils were significantly lower in ASM compared to those in AM and AS. Correlation analyses showed that SOC and TN stocks in the alpine grassland positively correlated with vegetation coverage, soil moisture, clay content, and silt content, while they were negatively related to sand content and soil pH. However, base cation stocks revealed contrary relationships with those environmental variables compared to SOC and TN stocks. These correlations varied between vegetation types. In addition, no significant relationship was detected between topographic factors and soil nutrients. Their findings suggested that plant cycling and soil moisture primarily control vertical distributions of soil nutrients (e.g. K) in the alpine grassland and highlight that vegetation types in high-altitude permafrost regions significantly affect soil nutrients.

Wang *et al*. (2017) worked on the effects of land subsidence and rehabilitation on soil hydraulic properties in a mining area in the loess plateau of China. To analyse the effects of land subsidence and rehabilitation on soil hydraulic properties, he took four plots including one unmined plot (UMP), two subsided plots (SPI and SPII) and one rehabilitated plot (RHP), and 16 sampling points were located in each plot. The bulk density (BD), soil moisture retention curve (SMRC), field capacity (FC), saturated hydraulic conductivity (K_s) and soil disintegration rate (SDR) at the depths of 0–20 cm, 20–40 cm, 40–60 cm and 60–80 cm at each sampling point were measured, and soil pore size distribution (PSD) based on soil moisture retention curve (SMRC) was analysed. The correlation analysis among soil hydraulic properties and the path analysis of effects of subsided cracks on the hydraulic properties were carried out in this study. Land subsidence increased the variability of soil hydraulic properties; whereas, they became relatively uniform after land rehabilitation. Land subsidence significantly altered soil hydraulic properties, increasing bulk density(BD), saturated hydraulic conductivity(K_s), soil disintegration rate(SDR) and soil micropores and decreasing FC; however, land rehabilitation can improve soil hydraulic properties and increase the use efficiency of soil water, decreasing BD, K_s, SDR and increasing FC and soil macro pores. The cracks related to subsidence and vegetation had significant effects on soil hydraulic properties, especially BD; the crack width and vegetation coverage had a marked effect on BD.

Jing *et al.* (2017) studied the effects of land subsidence resulted from coal mining on soil nutrient distributions in a loess area of China. He took a total of 64 soil sampling points from 4 different plots (one unmined plot, two subsided plots and one reclaimed plot) of Anjialing underground coal mine (No.3) in the loess area of China. Soil organic matter(SOM) and total nitrogen (TN) at the depths of 0–20cm, 20–40cm, 40–60cm and 60–80 cm in these sampling plots were measured. The classical statistics and geo-statistics were used to analyse the vertical and horizontal spatial variability of SOM and TN. The mechanisms of the effects of coal mining subsidence on soil nutrient distribution were revealed based on the distribution of the surface cracks of subsided plots. All the values of SOM and TN at the depth of 0–20 cm in subsided plots were less than those in unmined plot. Below the depth of 20 cm, TN in subsided plots were higher than those in unmined plot and SOM were less than those in unmined plot. SOM in reclaimed plot were higher than those in subsided plots; however, TN did not exhibit a clear regularity. Land subsidence increased horizontal spatial heterogeneity of SOM and TN distributions. The crack width, crack depth and the distance between sampling point and edge of crack were the main influence factors resulting in horizontal spatial heterogeneity of SOM and TN.

Chapter III

MATERIALS AND METHODS

The present investigation entitled “Effect of subsidence on the physicochemical properties of soil in a coal mining area of M.P’’ involved detailed laboratory analyses of the soil. Samples were drawn from a coal mining area of Jamuna & Kotma, M.P. and analysed in the Dept. of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The details of materials used and methods employed are presented in this chapter.

3.1 General Description of the Area

3.1.1 Location

The study site (P-19) is located in Jamuna & Kotma mining area of Anuppur District in M.P., India. It falls under SECL (South Eastern Coalfields Limited) region of CIL (Coal India Limited). It is situated at the latitude in between 23 ^{0}0’N and 23 ^{0}15’ N and longitude in between 81^{0} 45’ E and 82^{0} 05’ E. The area is gently undulating with the general slope towards river Kewai. The surface attains maximum and minimum elevation of 573.47 and 512.42 m, respectively from mean sea level (MSL).

3.1.2 Climate

The climate of the region is humid subtropical and divisible in to 3 distinct seasons, namely rainy (mid June to October), winter (November to February) and hot summer (March to mid June). The summers here have a good deal of rainfall, while the winters have very little. Average annual rainfall is 1210 mm. Precipitation is highest in August and lowest in the month of November. The average temperature in Anuppur is 24.3°C. Generally maximum temperature is attained in the month of May and minimum temperature in December.

3.1.3 Land use pattern

Using support vector machine classification method, it can be classified into six land-use types: water, agriculture, Forest, mining, settlement and waste land. An area of 6800 ha is covered with forest. Water bodies have increased due to the mining activities. In the year 2000 mining area was 4700 ha and in 2009 mining area had increased up to 6400 ha. The agricultural land is 8800 ha and an area of 9300 ha falls in to the category of waste land. (Garg *et al*., 2013). The forest is dominated by Sal tree (*Shorea robusta*).

3.1.4 Panel description

A panel is an area demarcated for the excavation of coal. The studied panel was P-19. Panel size was 130 x 75 m^2. The excavation of coal was started on 26.08.2016 and was closed on 19.03.2017. The maximum size of panel cover is 62m and minimum 55m. The pillar size is 23x23m^2. The maximum angle of draw is 35^0 and minimum 25^0.

3.2 Collection of soil samples

Samples were collected from Panel-19. Six sites were marked for the said study. These were the adjacent unaffected site, crack-1, slope-1, Maximum subsidence, crack-2 and slope-2 under panel-19. The samples were collected from 4 sub-spots under each site in a zig zag manner. With the help of spade, khurpi small portions of soil were collected from each sub-spot from 0-15 cm, 15-30 cm and 30-45 cm depth. The bulk soil was reduced to 500g by quartering process. Each sample was labelled with thick paper with proper identification mark. A diagram about site and subsites is shown below.

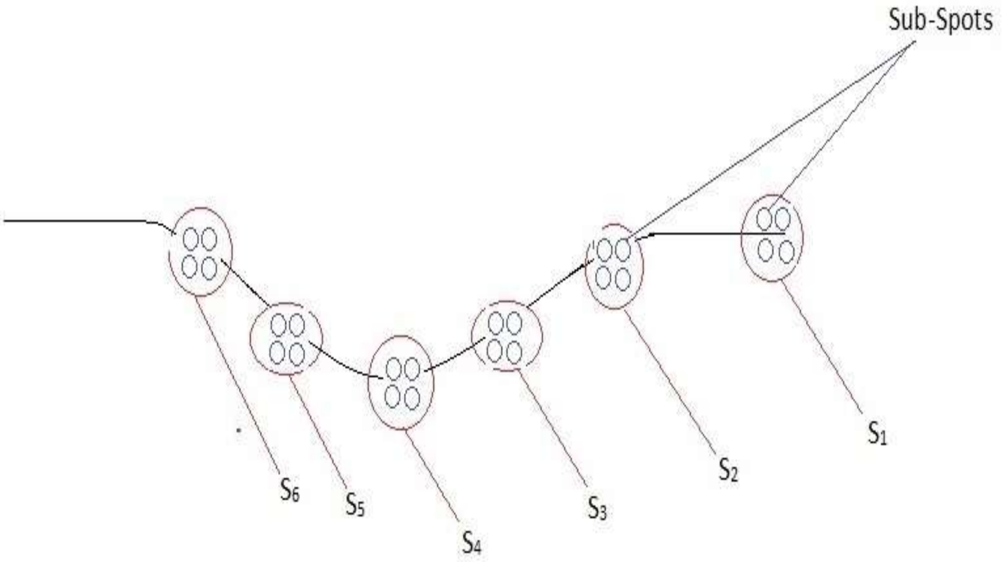


Fig 3.1 Schematic diagram of soil sampling spots

Where S_1 = unaffected site

S_2 = crack-1

S_3 = slope-1

S_4 = maximum subsidence

S_5 = slope-2

S_6 = crack-2

3.3 Processing of soil samples

Collected soil samples were brought in to the laboratory, dried in shade at room temperature and ground on wooden plank with wooden roller and passed through a 2 mm sieve. Thereafter, homogenized soil samples were stored in polythene bags for further analysis of selected physico-chemical properties of soil. For chemical analysis soil samples were further ground and passed through a 0.5mm sieve.

3.4 Analysis of soil Samples

3.4.1 Soil pH

A soil water suspension was prepared in the ratio of 1:2.5 (10 g soil with 25 mL of distilled water) and pH was recorded with the help of glass electrode pH meter (Chopra and Kanwar, 1982).

3.4.2 Electrical Conductivity

The soil water suspension prepared for determination of pH was used to estimate the electrical conductivity of soil. Soil suspension was allowed to settle till supernatant become clear. Electrical conductivity was measured with the help of EC meter and expressed as dSm^{-1} (Chopra and Kanwar,1982).

3.4.3 Textural analysis

Textural analysis of the soil was done by Bouyoucos hydrometer method (Bouyoucos,1962). Fifty gram of soil sample was taken in a beaker and 50 mL of 6%H_2O_2 was added to it. The beaker was covered by watch glass and heated on heating plate until the organic matter not oxidized. The content was transferred into a dispersing cup with about 400 mL of distilled water. Then, 100 mL of 5% calgan solution was added to it and the suspension was stirred with the help of an electric stirrer for 10 minutes. The suspension was transferred into a measuring cylinder and volume was made up to 1L. It was then shaken vigorously for 5 minutes with the help of plunger. The hydrometer was placed into suspension and readings were recorded exactly after 4 seconds and also after 2 hours. The sand, silt and clay content were calculated and textural class was determined with the help of Textural Triangle.

Corrected hydrometer reading=R+(T^0 F-67) × 0.2

Where,

R=Hydrometer reading

T=temperature of suspension

% silt+ clay= (Corrected hydrometer reading at 4 seconds/weigh of the soil) ×100

%Clay= (Corrected hydrometer reading at 2 hours/weight of the soil) ×100

% sand =100-%(silt + clay)

3.4.4 Bulk density

Bulk density of sample was determined with the help of Pycnometer. A clean Pycnometer was air dried and weighted on electrical balance. It was filled with soil up to the brim and was tapped gently and the vacant space was again filled. Weight of the Pycnometer with soil was taken. Soil was then removed from Pycnometer. The Pycnometer was filled with water up to the brim with the help of a burette. The reading of the burette was recorded to give the actual volume of Pycnometer.

$$Bulk\ density\left(\frac{Mg}{m3}\right) = \frac{Weight\ of\ soil}{volume\ of\ solid\ and\ pores}$$

3.4.5 Water holding capacity

Keen boxes were cleaned, dried and weighed. A Whatman No.1 filter paper was cut out and placed at the bottom of the box and filled ¾ of it with processed soil by repeated tapping (20-30 times) on the top of a table for complete and uniform packing. The soil surface was levelled with a spatula and weighed. The box was placed in a soaking tray and gradually tray was filled with water from the side till the water level was about 1 cm above the base of box. It was kept for overnight for equilibrium which was confirmed by a continuous and shining film of water at the soil surface. The box was carefully removed from water and dried from outside with filter paper and weighed. The soil of keen box was dried in oven at 105^0 C till constant weight was achieved. A blank (only with keen box and filter paper) was also carried out to find the weight of water absorbed by the filter paper alone (Chopra and Kanwar, 1982).

$$Water\ holding\ capacity(\%) = \frac{Water\ held\ by\ soil}{Oven\ dry\ weight\ of\ soil} \times 100$$

3.4.6 Organic Carbon (Walkley and Black, 1934)

0.5g of soil was taken in a 500 mL conical flask.10 mL of 1N $K_2Cr_2O_7$ solution was added and mixed. 20 mL of conc. $H_2S_2O_4$ was added, flask was swirled the flask 2-3 times and allowed to stand for 30 minutes in a dark place. The suspension was diluted with 200 mL of distilled water. 10mL of ortho phosphoric acid and 1mL of diphenylamine indicator were added and contents were titrated against 0.5 N ferrous ammonium sulphate solution, till colour changed from violet to bright green. A blank titration was also carried out simultaneously.

% oxidizable organic carbon = $\frac{(B-T)\times 0.003\times 10\times 100}{B\times W}$

Where,

B = volume of 0.5N ferrous ammonium sulphate solution used for blank titration

S = volume of 0.5N ferrous ammonium sulphate solution used for sample titration.

3.4.7 Available nitrogen

Available nitrogen content in soil was determined using Kjeltec Semi-Auto Nitrogen Analyzer by alkaline potassium permanganate method as proposed by Subbiah and Asija (1956). Five gram of soil sample was weighed and transferred to a distillation tube. Twentyfive mL of 0.32% KMnO4 was added to it and the distillation tube was set in to the instrument. In a 250 mL conical flask, 20 mL of 2% boric acid mixed indicator was taken and placed under the receiver tube. Twentyfive mL of 2.5% NaOH was sucked and added to the distillation tube. Then it was put on distillation for 9 min. During this process the N released in the form of ammonia is trapped in the boric acid, which develops green colour. The flask containing the distillate was removed. The distillate was then titrated against 0.02 N H_2SO_4 until pink colour developed**.**

$$Mineralizable\ N(Kg/ha) = \frac{(S-B)\times 0.02\times 14\times 10^{6}\times 2.24}{5\times 1000}$$

Where,

S= Sample titrating value (mL)

B= Blank titrating value (mL)

3.4.8 Available phosphorus

Available phosphorus was determined by BrayP1 extractant (0.03N NH4F+ 0.025N HCl). In this method 5g soil was shaken with 50 mL of extracting solution for 5 minutes. The suspension was then filtered and 5mL of filtrate was taken in a 25 mL volumetric flask. To this 5 mL of ammonium molybdate was added, shaken to mix and diluted to 20mL.1 mL of stannous chloride reagent was added and volume was made up to 25 ML. The intensity of blue colour was measured using spectrophotometer at the wavelength 660nm. (Bray and Kurtz, 1945).

$$Available\ phosphorus(Kg/ha) = \frac{Absorbance\times dilution\ factor\times 2.24}{Slope\ of\ the\ standard\ curve}$$

3.4.9 Available potassium

Available potassium content of soil was determined by Flame Photometer (1 *N* ammonium acetate extract) method (Hanway and Heidel, 1952). Five g soil was transferred to a 100 mL conical flask and 25 mL of 1 N ammonium acetate solution was added and it was shaken for 5 minutes. The suspension was then filtered through Whatman No. 1 filter paper and potassium concentration in the filtrate was measured using flame photometer. First standard reading was taken followed by sample reading.

Available potassium(Kg/ha) =C× dilution factor × 2.24

Where C=flame photometer reading

3.4.10 Available calcium and magnesium

Available calcium and magnesium determined using versenate titration method. When Ca is treated with the EDTA, a very stable complex is formed. Mg ion forms similar complex which is far less stable than Ca complex. For the combined determination of Ca and Mg, Erichrome Black-T (EBT) is used as indicator. The optimum pH for formation of complex is 10 and this is maintained using a buffer solution. 2.5 g of soil was taken in a 100 mL conical flask and 25 mL 1N NH_4OAc was added to it and shaken for 5 minutes on a mechanical shaker. Suspension was then filtered through Whatman No. 42 filter paper. 5 mL of this filtrate was transferred to 100 mL conical flask and diluted to about 10 mL. The pH of this solution was adjusted to 10 by adding 15 mL buffer solution. 10 drops of EBT indicator was added to it and titrated with 0.01N EDTA till colour changed from wine-red to blue. A blank titration was also carried out with above said procedure without soil.

$$Available\ Ca\ and\ Mg(me/100g) = \frac{(F.B.R - I.B.R) \times 0.01 \times V}{W \times V_1} \times 100$$

Where,

F.B.R = Final burette Reading

I.B.R = Initial burette Reading

V= Volume of extractant used (mL)

V_1= Volume of aliquot taken

W= Weight of soil sample taken

3.4.11 Available sulphur

Available sulphur in soil was determined by turbidity method (Chesnin and Yien, 1950). In this method, 5 g of soil was extracted with 25 mL of 0.15% $CaCl_2$ solution. Turbidity was developed by using $BaCl_2$ and gum acacia and measured spectrophotometrically at 440nm.

$$Available\ sulphur\ in\ soil\ (ppm) = \frac{Absorbance\ \times dilution\ factor}{Slope\ of\ standard\ curve}$$

3.4.12 DTPA extractable micronutrients (Fe, Cu, Mn, Zn)

Available micronutrients (Fe, Cu, Mn, Zn) were extracted with the help of DTPA extracting solution (0.005 M DTPA+ 0.01 M $CaCl_2$ an+ 0.1 M TEA), pH adjusted to 7.3 as per the procedure described by Lindsay and Norvell (1978).

10g of soil was taken in 150 mL conical flask and 20 mL of DTPA solution was added to it. It was shaken for two hours on a horizontal shaker. It was then filtered through Whatman no. 42 filter paper. The concentration of micronutrients was determined by atomic absorption spectrophotometer.

Element concentration (ppm) = AAS reading X dilution factor

Chapter IV

RESULT AND DISCUSSION

4. Effect of subsidence on the physio chemical properties of soil

4.1 pH

Soil reaction is generally measured in terms of hydrogen ion activity in soil water suspension (1:2.5). Reaction of the soil samples collected from different sites in the mining area subjected to subsidence was found to be slightly acidic to neutral in range. Upon going through the data (table 4.1 and fig. 4.1) effect of subsidence was found to be significant on the pH of soils in mining area at all the three depths i.e., depths of 0-15 cm, 15-30 cm and 30-45 cm.

At 0-15 cm depth, the pH was found to be highest in the soils of unaffected site (6.18) and lowest in the soils subjected to maximum subsidence (5.23). The pH was on a decreasing trend from soils of crack-1 to maximum subsidence. The pH of soils recorded in slope-2 and crack-2 was more than the pH of soils of maximum subsidence. Similar trend was found in soils of all the depths up to 45 cm.

Lowest pH in the soils of maximum subsidence site could be attributed to higher organic carbon content which lowers the pH of soil by producing various organic acids. Lower pH might also be due to higher presence of sesquioxides in the maximum subsidence site.

Tripathi *et.al.* (2004) reported similar results.

4.2 Electrical Conductivity

Electrical conductivity is a measure of total soluble salts in soil. So more the number of ions in soil, more will be the conduction of electricity. Data pertaining to electrical conductivity given in table 4.2 and fig. 4.2 revealed that the electrical conductivity of soils in unaffected site was less than the electrical conductivity of soils in maximum subsidence site at the depths of 0-15 cm, 15-30 cm, 30-45 cm. At 0-15 cm depth the maximum subsidence site

Table 4.1: Effect of subsidence due to coal mining activities on pH of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
			0-15 cm depth		
unaffected	6.24	6.32	6.2	5.96	**6.18**
crack 1	5.73	5.68	5.41	5.59	**5.60**
slope 1	5.49	5.5	5.51	5.46	**5.49**
max sub	5.12	5.21	5.32	5.27	**5.23**
slope 2	5.49	5.43	5.48	5.47	**5.47**
crack 2	5.63	5.53	5.74	5.76	**5.67**
SE(m±)	**0.052**				
CD ($P_{0.05}$)	**0.154**				
			15-30 cm depth		
unaffected	6.14	6.34	6.17	6.16	**6.20**
crack 1	5.67	5.65	5.63	5.54	**5.62**
slope 1	5.5	5.3	5.35	5.39	**5.39**
max sub	5.17	5.12	5.26	5.14	**5.17**
slope 2	5.53	5.38	5.49	5.39	**5.45**
crack 2	5.47	5.45	5.73	5.56	**5.55**
SE(m±)	**0.043**				
CD ($P_{0.05}$)	**0.129**				
			30-45 cm depth		
unaffected	6.21	6.13	6.1	5.98	**6.11**
crack 1	5.83	5.38	5.53	5.65	**5.60**
slope 1	5.32	5.42	5.31	5.43	**5.37**
max sub	5.1	5.13	5.23	5.23	**5.17**
slope 2	5.51	5.32	5.63	5.32	**5.45**
crack 2	5.43	5.42	5.39	5.64	**5.47**
SE(m±)	**0.061**				
CD ($P_{0.05}$)	**0.184**				

Table 4.2: Effect of subsidence due to coal mining activities on EC(dSm^{-1}) of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	0.023	0.018	0.024	0.015	**0.020**
crack 1	0.027	0.029	0.065	0.026	**0.037**
slope 1	0.022	0.071	0.043	0.068	**0.051**
max sub	0.061	0.078	0.056	0.063	**0.065**
slope 2	0.027	0.025	0.026	0.019	**0.024**
crack 2	0.017	0.015	0.013	0.018	**0.016**
SE(m±)	**0.006**				
CD ($P_{0.05}$)	**0.019**				
			15-30 cm depth		
unaffected	0.018	0.016	0.021	0.019	**0.019**
crack 1	0.025	0.027	0.035	0.026	**0.028**
slope 1	0.023	0.025	0.029	0.025	**0.026**
max sub	0.055	0.052	0.045	0.037	**0.047**
slope 2	0.023	0.029	0.025	0.025	**0.026**
crack 2	0.019	0.014	0.015	0.009	**0.014**
SE(m±)	**0.002**				
CD ($P_{0.05}$)	**0.007**				
			30-45 cm depth		
unaffected	0.026	0.016	0.018	0.017	**0.019**
crack 1	0.029	0.023	0.03	0.026	**0.027**
slope 1	0.014	0.028	0.025	0.024	**0.023**
max sub	0.045	0.039	0.042	0.027	**0.038**
slope 2	0.022	0.024	0.022	0.02	**0.022**
crack 2	0.009	0.017	0.016	0.008	**0.013**
SE(m±)	**0.003**				
CD ($P_{0.05}$)	**0.008**				

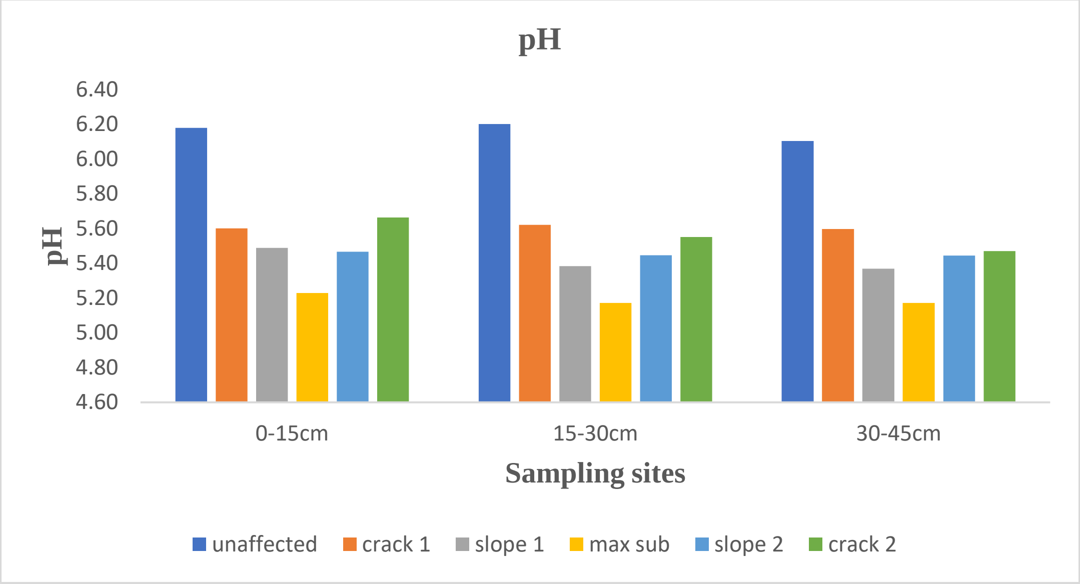


Fig 4.1: Effect of subsidence due to coal mining activities on pH of soil.

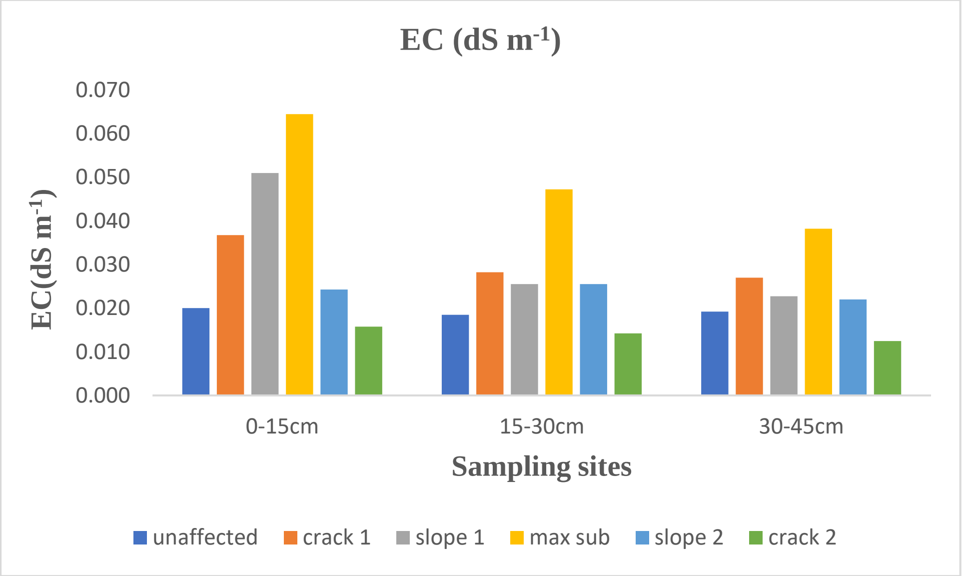


Fig 4.2: Effect of subsidence due to coal mining activities on EC (dSm^{-1}) of soil.

had the highest EC value (0.065 dSm^{-1}) whereas the crack-2 site had the least EC value (0.016 dSm^{-1}). The similar result also found at depth of 15-30 cm, 30-45 cm.

The EC value of soils of maximum subsidence site at 0-15 cm was more (0.065 dSm^{-1}) than the EC value of soils of maximum subsidence site at 15-30 cm (0.047 dSm^{-1}) followed by the same at 30-45 cm (0.038 dSm^{-1}).

Significant variation in EC of soils was found at all sites in mining area at depth of 0-15 cm,15-30 cm, 30-45 cm.

The EC of soils in maximum subsidence site was highest because of leaching of salts from elevated site across slope to maximum subsidence site and resulting in accumulation of salts at that site.

4.3 Soil Texture

Data presented in the table 4.3.1 clearly indicates that maximum subsidence had lowest sand percentage (59.55%) and slope-1 had highest sand percentage (66.8%) whereas clay percentage was found to be lowest (21.43%) in crack-2 site and highest (28.43%) in maximum subsidence site at depth of 0- 15 cm. It was revealed from the result that there was a significant variation in sand percentage and clay percentage among all sites of mining area and insignificant variation in silt percentage among all sites in mining area at the 0-15 cm depth.

Table 4.3.2 depicted that at the15-30 cm depth effect of subsidence was found to be significant on the sand and clay percentage in all sites of mining areas. The maximum subsidence site had highest clay percentage (30.93%) and lowest sand percentage (60.8 %). There was an insignificant variation in silt percentage among all sites of mining area. The crack-1 site had highest silt percentage (12.02%) and maximum subsidence site had lowest silt percentage (8.27%).

It is also evident from table 4.3.3 that there was an insignificant variation in sand and silt percentage among all sites of mining area at the depth of 30-45 cm whereas significant variation was found in clay percentage among all sites of mining area. At 30-45 cm depth slope-1 site had highest sand percentage (67.05%) and maximum subsidence had lowest sand percentage (62.05%). Clay percentage found to be highest (31.6%) in soils of maximum subsidence site and lowest (24.18%) in soils of slope-1 site.

Table 4.3.1: Effect of subsidence due to coal mining activities on soil texture at the depth of 0-15cm.

	0-15 cm depth														
	Sand (%)					Silt (%)					Clay (%)				
	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean
unaffected	64.8	62.8	63.8	65.8	**64.3**	11.28	11.6	11.28	9.6	**10.94**	23.92	25.6	24.92	24.6	**24.76**
crack 1	65.8	64.8	67.8	66.8	**66.3**	11.28	11.6	10.6	10.6	**11.02**	22.92	23.6	21.6	22.6	**22.68**
slope 1	67.8	63.8	66.8	68.8	**66.8**	10.6	15.28	10.6	9.28	**11.44**	21.6	20.92	22.6	21.92	**21.76**
max sub	61.8	58.8	59.8	57.8	**59.55**	10.28	11.6	12.6	13.6	**12.02**	27.92	29.6	27.6	28.6	**28.43**
slope 2	62.8	67.8	59.8	65.8	**64.05**	14.28	8.6	20.6	12.6	**14.02**	22.92	23.6	19.6	21.6	**21.93**
crack 2	64.8	61.8	65.8	59.8	**63.05**	14.6	15.6	15.6	16.28	**15.52**	20.6	22.6	18.6	23.92	**21.43**
SE(m±)	**1.132**						**1.207**				**0.673**				
CD ($P_{0.05}$)	**3.389**						**NS**				**2.015**				

Table 4.3.2: Effect of subsidence due to coal mining activities on soil texture at the depth of 15-30cm.

Sampling sites	**15-30cm depth**														
	Sand (%)					Silt (%)					Clay (%)				
	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean
unaffected	62.8	61.8	63.8	65.8	**63.55**	10.6	10.6	10.28	6.28	**9.44**	26.6	27.6	25.92	27.92	**27.01**
crack 1	64.8	62.8	65.8	62.8	**64.05**	10.28	12.6	12.6	12.6	**12.02**	24.92	24.6	21.6	24.6	**23.93**
slope 1	63.8	64.8	66.8	67.8	**65.8**	13.6	13.6	9.6	8.6	**11.35**	22.6	21.6	23.6	23.6	**22.85**
max sub	59.8	58.8	60.8	63.8	**60.8**	11.6	10.6	7.6	3.28	**8.27**	28.6	30.6	31.6	32.92	**30.93**
slope 2	61.8	63.8	68.8	69.8	**66.05**	11.6	12.6	5.6	6.6	**9.1**	26.6	23.6	25.6	23.6	**24.85**
crack 2	66.8	65.8	64.8	66.8	**66.05**	8.6	11.6	12.6	7.6	**10.1**	24.6	22.6	22.6	25.6	**23.85**
SE(m±)	**1.099**						**1.364**					**0.707**			
CD ($P_{0.05}$)	**3.291**						**NS**					**2.118**			

Table 4.3.3: Effect of subsidence due to coal mining activities on soil texture at the depth of 30-45cm.

Sampling site	**30-45 cm depth**														
	Sand (%)					Silt (%)					Clay (%)				
	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean	R1	R2	R3	R4	Mean
unaffected	66.8	64.8	63.8	61.8	**64.3**	6.6	6.6	10.6	7.6	**7.85**	26.6	28.6	25.6	30.6	**27.85**
crack 1	64.8	60.8	62.8	65.8	**63.55**	10.6	13.6	13.6	8.6	**11.6**	24.6	25.6	23.6	25.6	**24.85**
slope 1	68.8	66.8	67.8	64.8	**67.05**	5.6	9.6	9.6	10.28	**8.77**	25.6	23.6	22.6	24.92	**24.18**
max sub	62.8	59.8	61.8	63.8	**62.05**	6.6	7.6	9.6	1.6	**6.35**	30.6	32.6	28.6	34.6	**31.6**
slope 2	65.8	63.8	64.8	60.8	**63.8**	10.6	8.6	10.6	16.6	**11.6**	23.6	27.6	24.6	22.6	**24.6**
crack 2	67.8	61.8	65.8	62.8	**64.55**	4.6	14.28	12.6	13.6	**11.27**	27.6	23.92	21.6	23.6	**24.18**
SE(m±)	**1.067**							**1.554**				**1.025**			
CD ($P_{0.05}$)	**N/S**							**NS**				**3.069**			

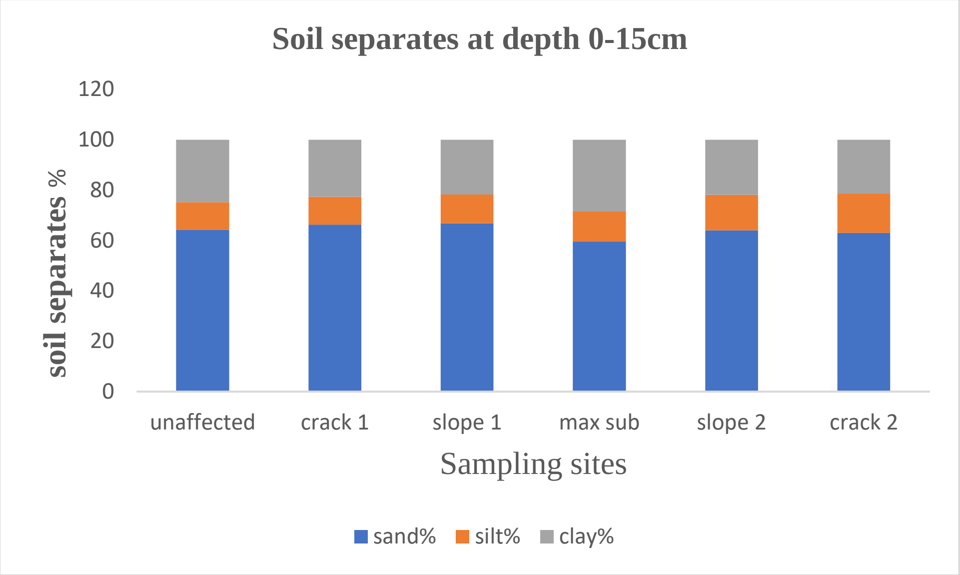
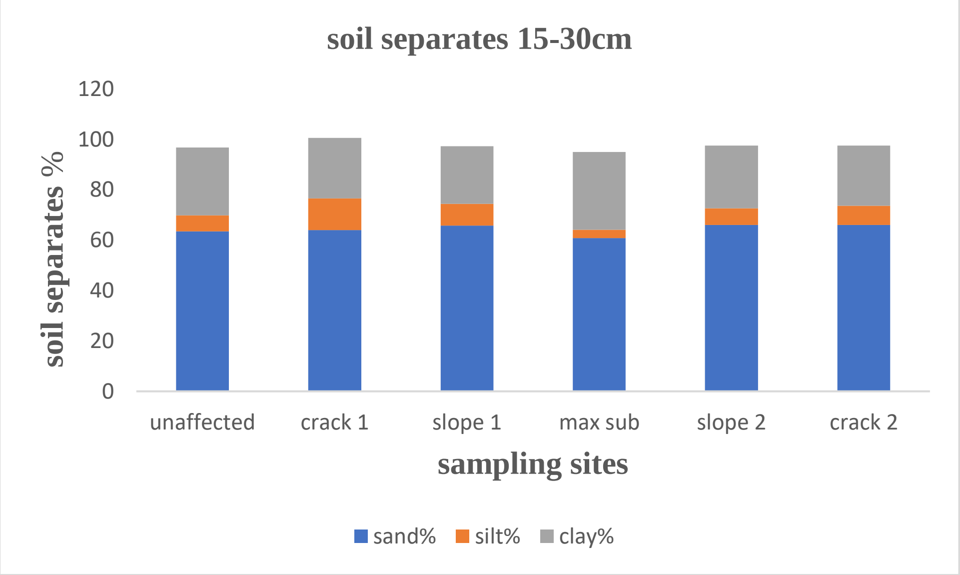


Fig 4.3.1: Effect of subsidence due to coal mining activities on soil texture at depth 0-15 cm.



The soil texture was sand clay loam at all the three depths of soil. Fine fractions of soil from upper sites move towards lower sites across the slope. As a result, clay percentage increased in soils of maximum subsidence site.

4.4 Bulk Density

The bulk density is the ratio of the mass of oven dried soil solid particles to the total volume of the soil. Data pertaining to bulk density given in table 4.4 and fig. 4.4 revealed that there was a significant variation among the bulk density of soils of all sites in mining area.

It is evident from the perusal of the data that maximum subsidence site had the lowest bulk density (1.19 Mg m^{-3},1.22 Mg m^{-3}, 1.24 Mg m^{-3}) and slope-1 had the highest bulk density (1.44 Mg m^{-3}, 1.49 Mg m^{-3}, 1.50 Mg m^{-3}) at the depths of 0-15 cm,15-30 cm, 30-45 cm respectively. With increase in depth the bulk density increased in case of maximum subsidence site.

The reason behind lowest bulk density in maximum subsidence site could be attributed to high organic matter content in maximum subsidence site with increased porosity. With increase in bulk density with increase in depth could be attributed to low organic matter content and high solid matter in lower profile.

4.5 Water holding capacity

Perusal of the data presented in table 4.5 and fig. 4.5 made it clear that the water holding capacity of soils had increased from crack-1 to maximum subsidence site at the depths of 0-15 cm and 15-30 cm. Whereas same pattern was not followed at the depth of 30-45 cm. The water holding capacity of soils had also increased from crack-2 to maximum subsidence through slope -2 at the depth of 0-15 cm, 15-30 cm and 30-45 cm.

The water holding capacity of soils was found to be highest (38.16%) in maximum subsidence site and lowest (26.49%) in crack-2 site at the depth of 0-15 cm. At the depth of 15-30 cm, the water holding capacity of soils was found to be highest (37.59%) in maximum subsidence site and lowest (26.02%) in crack-2 site, whereas at the depth of 30-45 cm, the water holding capacity of soils was found to be highest in maximum subsidence site (36.18 %) and lowest in crack-2 site (25.99 %)

Table 4.4: Effect of subsidence due to coal mining activities on BD (Mg m^{-3}) of soil

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	1.31	1.38	1.39	1.35	**1.36**
crack 1	1.38	1.34	1.25	1.36	**1.33**
slope 1	1.41	1.47	1.44	1.43	**1.44**
max sub	1.22	1.19	1.15	1.21	**1.19**
slope 2	1.45	1.45	1.42	1.38	**1.43**
crack 2	1.34	1.29	1.32	1.28	**1.31**
SE(m±)	**0.018**				
CD ($P_{0.05}$)	**0.055**				
			15-30 cm depth		
unaffected	1.35	1.39	1.43	1.41	**1.40**
crack 1	1.33	1.41	1.34	1.21	**1.32**
slope 1	1.45	1.49	1.48	1.52	**1.49**
max sub	1.24	1.18	1.25	1.22	**1.22**
slope 2	1.47	1.51	1.42	1.39	**1.45**
crack 2	1.37	1.26	1.32	1.34	**1.32**
SE(m±)	**0.025**				
CD ($P_{0.05}$)	**0.074**				
			30-45 cm depth		
unaffected	1.42	1.38	1.4	1.36	**1.39**
crack 1	1.34	1.28	1.39	1.37	**1.35**
slope 1	1.53	1.48	1.51	1.46	**1.50**
max sub	1.25	1.23	1.27	1.2	**1.24**
slope 2	1.49	1.55	1.46	1.42	**1.48**
crack 2	1.35	1.32	1.29	1.38	**1.34**
SE(m±)	**0.02**				
CD ($P_{0.05}$)	**0.059**				

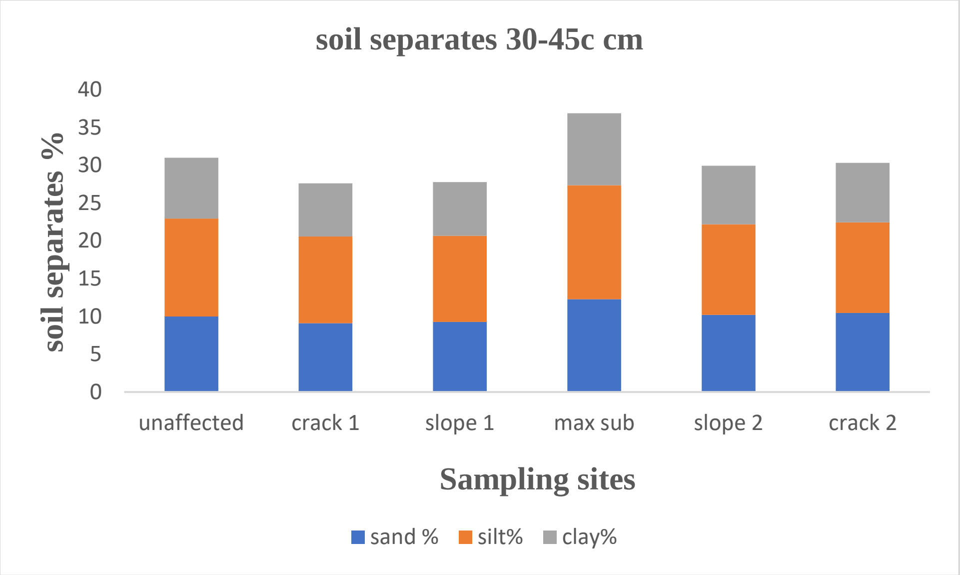


Fig 4.3.3: Effect of subsidence due to coal mining activities on soil texture at depth 30-45 cm

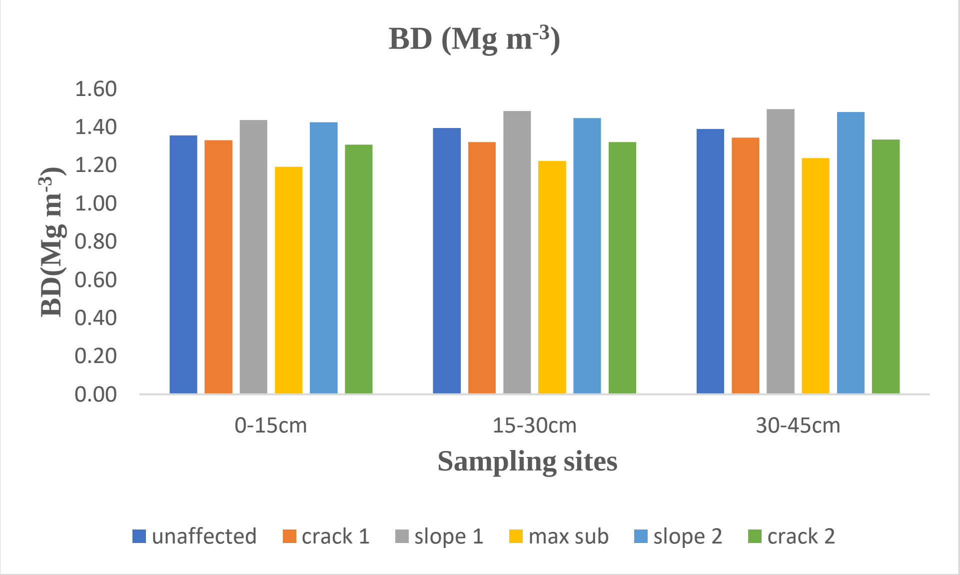


Fig 4.4: Effect of subsidence due to coal mining activities on BD (Mg m^{-3}) of soil.

Table 4.5: Effect of subsidence due to coal mining activities on WHC (%) of soil.

Sampling site	R1	R2	R3	R4	Mean
	0-15 cm depth				
unaffected	31.81	34.42	32.82	30.8	**32.46**
crack 1	30.27	28.96	27.96	22.84	**27.51**
slope 1	28.44	32.64	30.86	24.86	**29.20**
max sub	37.11	40.64	38.42	36.46	**38.16**
slope 2	26.78	29.68	27.82	26.8	**27.77**
crack 2	28.64	25.84	26.62	24.84	**26.49**
SE(m±)	**1.157**				
CD ($P_{0.05}$)	**3.465**				
	15-30 cm depth				
unaffected	32.54	32.42	31.64	29.64	**31.56**
crack 1	29.64	26.94	27.32	23.24	**26.79**
slope 1	28.32	31.92	29.78	23.68	**28.43**
max sub	36.84	38.62	39.64	35.24	**37.59**
slope 2	25.84	27.98	26.42	25.42	**26.42**
crack 2	28.96	26.64	24.62	23.86	**26.02**
SE(m±)	**1.141**				
CD ($P_{0.05}$)	**3.417**				
	30-45 cm depth				
unaffected	30.86	31.98	29.64	27.94	**30.11**
crack 1	27.95	27.96	26.12	24.74	**26.69**
slope 1	27.92	28.86	24.86	22.32	**25.99**
max sub	35.64	37.82	36.82	34.42	**36.18**
slope 2	27.82	27.42	25.23	28.92	**27.35**
crack 2	28.12	23.84	25.32	26.98	**26.07**
SE(m±)	**0.967**				
CD ($P_{0.05}$)	**2.894**				

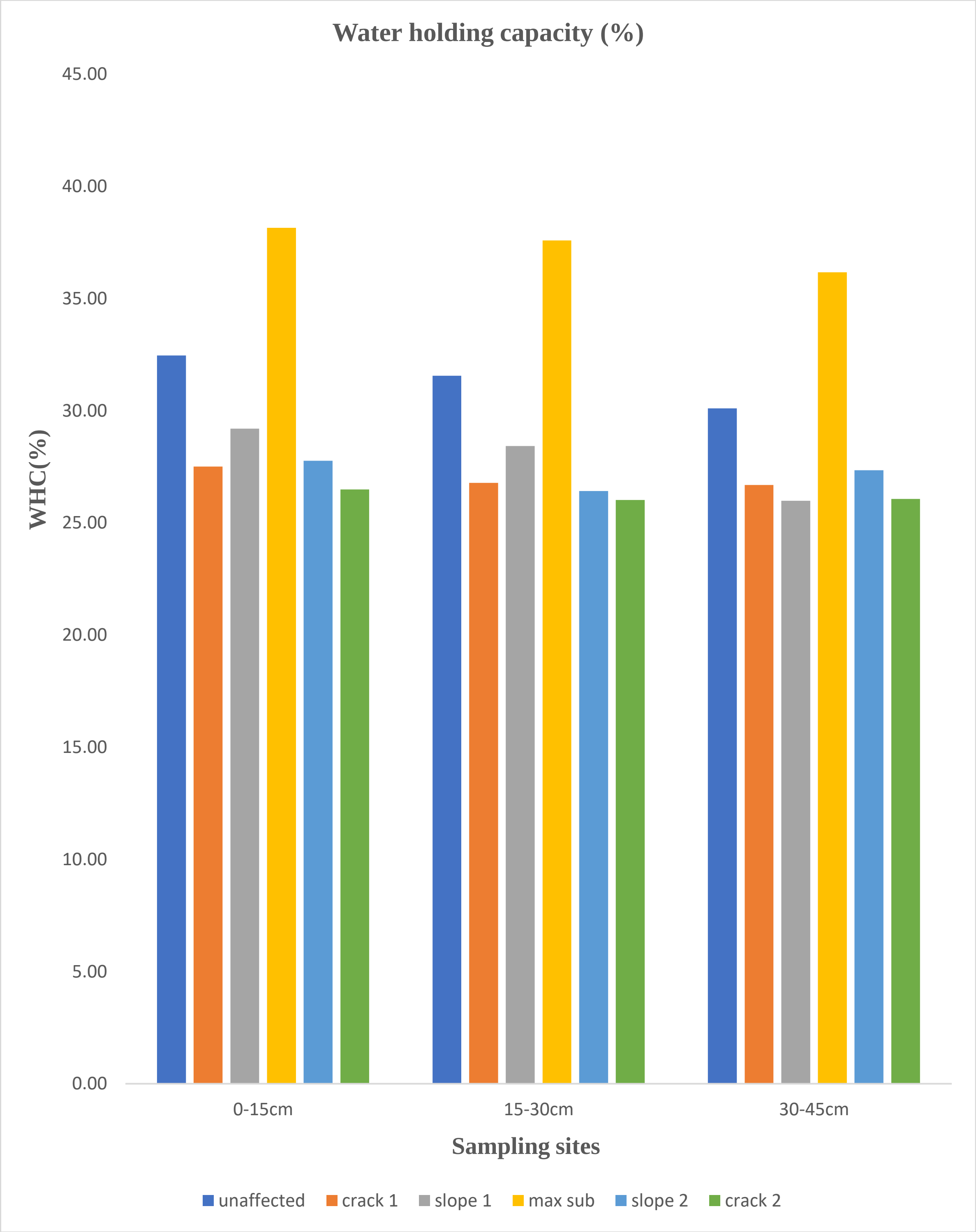


Fig 4.5: Effect of subsidence due to coal mining activities on WHC (%) of soil

Effect of subsidence was found to be significant on water holding capacity of soils in mining area.

The highest water holding capacity in maximum subsidence site could be attributed to high clay content and high organic matter content.

Tripathi *et al*. (2004) reported similar results.

4.6 Organic carbon

It is obvious from the data presented in table 4.6 and fig. 4.6 that underground coal mining activities had remarkable impact on organic carbon content in soil.

Significant difference had been found in organic carbon content of soils of all sites of mining area at the 0-15 cm depth where as insignificant difference had been noticed in organic carbon content of soils in all sites of mining area at the depth of 15-30 cm and 30-45 cm.

It is evident from the data that maximum organic carbon content was found in soils of maximum subsidence site the respective values being 0.42%, 0.32% and 0.27% at the depth of 0-15 cm, 15-30 cm and 30-45 cm. At the depth of 0-15 cm depth the organic carbon content was found to increase from crack-1 site to maximum subsidence site through slope -1 site where as same trend was not followed at the depths of 15-30 cm and 30-45 cm.

The maximum carbon content in the maximum subsidence site could be partly attributed to accumulation of surface run off organic matter, fall of leaf and other plant litter from the drying trees tilted towards maximum subsidence site.

These results are in full conformity with the findings of Tripathi *et al.* (2009).

4.7 Available nitrogen

Data pertaining to the effect of subsidence on the available nitrogen content of soil have been presented in table 4.7 and fig. 4.7.

It was observed that subsidence had highly significant impact on nitrogen availability of soils in mining area at the depths of 0-15 cm and 15-30 cm, whereas there was an insignificant variation at depth of 30-45 cm.The available nitrogen was found to

Table 4.6: Effect of subsidence due to coal mining activities on Organic carbon (%) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	0.16	0.14	0.11	0.52	**0.23**
crack 1	0.23	0.22	0.17	0.14	**0.19**
slope 1	0.17	0.30	0.19	0.13	**0.20**
max sub	0.44	0.57	0.29	0.37	**0.42**
slope 2	0.21	0.37	0.35	0.32	**0.31**
crack 2	0.34	0.31	0.25	0.31	**0.30**
SE(m±)	0.052				
CD ($P_{0.05}$)	0.156				
			15-30 cm depth		
unaffected	0.13	0.20	0.22	0.44	**0.25**
crack 1	0.28	0.27	0.13	0.13	**0.20**
slope 1	0.14	0.27	0.16	0.20	**0.19**
max sub	0.29	0.38	0.21	0.38	**0.32**
slope 2	0.24	0.36	0.25	0.32	**0.29**
crack 2	0.15	0.27	0.32	0.31	**0.26**
SE(m±)	0.04				
CD ($P_{0.05}$)	NS				
			30-45 cm depth		
unaffected	0.14	0.11	0.08	0.39	0.18
crack 1	0.25	0.08	0.16	0.52	0.25
slope 1	0.19	0.22	0.14	0.06	0.15
max sub	0.31	0.21	0.13	0.43	0.27
slope 2	0.31	0.19	0.18	0.29	0.24
crack 2	0.16	0.22	0.24	0.31	0.23
SE(m±)	0.06				
CD ($P_{0.05}$)	NS				

Table 4.7: Effect of subsidence due to coal mining activities on available N (Kg ha^{-1}) content of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
			0-15 cm depth		
unaffected	283.36	357.28	295.68	295.68	**308**
crack 1	308	320.32	292.6	283.36	**301.07**
slope 1	317.24	308	320.32	344.96	**322.63**
max sub	344.96	381.92	344.96	320.32	**348.04**
slope 2	320.32	332.64	332.64	332.64	**329.56**
crack 2	332.64	317.24	317.24	320.32	**321.86**
SE(m±)	**9.931**				
CD ($P_{0.05}$)	**29.734**				
			15-30 cm depth		
unaffected	283.36	295.68	271.04	295.68	**286.44**
crack 1	295.68	308	320.32	271.04	**298.76**
slope 1	312.32	283.36	295.68	320.32	**302.92**
max sub	332.32	369.4	344.96	357.28	**350.99**
slope 2	295.68	283.36	317.24	308	**301.07**
crack 2	282.64	332.64	308	283.36	**301.66**
SE(m±)	**8.885**				
CD ($P_{0.05}$)	**26.603**				
			30-45 cm depth		
unaffected	258.72	308	295.68	308	**292.6**
crack 1	283.36	277.2	317.24	271.04	**287.21**
slope 1	320.32	295.68	308	295.68	**304.92**
max sub	295.68	317.24	320.32	320.32	**313.39**
slope 2	271.04	283.36	289.52	246.4	**272.58**
crack 2	295.68	320.32	271.04	283.36	**292.6**
SE(m±)	**9.258**				
CD ($P_{0.05}$)	**NS**				

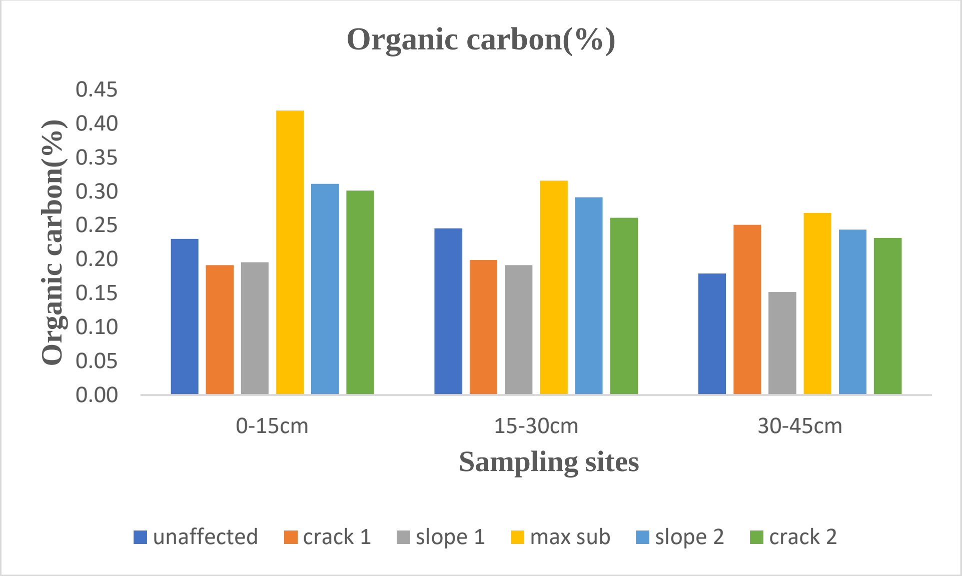


Fig 4.6: Effect of subsidence due to coal mining activities on organic carbon (%) content of soil.

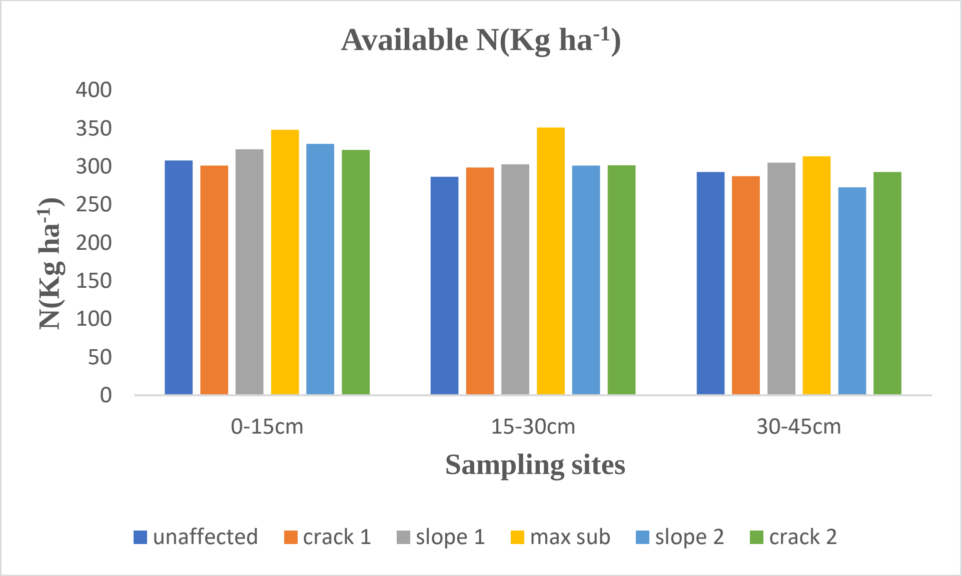


Fig 4.7: Effect of subsidence due to coal mining activities on available N (Kg ha^{-1}) content of soil.

be highest in maximum subsidence site at the depths of 0-15 cm, 15-30 cm and 30-45 cm (348.04 Kg ha^{-1}, 350.99 Kg ha^{-1} and 313.39 Kg ha^{-1}) and lowest in soils of crack-1 site at depth of 0-15 cm and 15-30 cm (301.07 Kg ha^{-1} and 298.76 Kg ha^{-1}) whereas at depth of 30-45 cm, the lowest available nitrogen (272.58 Kg ha^{-1}) was found in soils of slope-2 site.

The availability of nitrogen is related to amount of organic carbon present. Since organic carbon was higher in maximum subsidence site, so nitrogen was also higher in that site.

This result was also supported by earlier reports of Tripathi *et al.* (2009).

4.8 Available phosphorus

A perusal of the data presented in table 4.8 and fig. 4.8 indicated that there was a significant variation in available phosphorus content of soils in mining area at the depths of 0-15 cm, 15-30 cm and 30-45 cm.

It was observed from the data that the soils of maximum subsidence site had the highest available phosphorus content at the depths of 0-15 cm, 15-30 cm and 30-45 cm(30.28 Kg ha^{-1}, 29.27 Kg ha^{-1}, 29.92 Kg ha^{-1}). The available phosphorus content was found to be lowest in soils of slope-2 site at depth of 0-15 cm and 15-30 cm (17.85 Kg ha^{-1}, 18.69 Kg ha^{-1}) cm whereas at 30-45 cm depth the available phosphorus content of soils was found to be lowest in crack-1 site (18.18 Kg/ha).

The available phosphorus content of soils had increased from crack-1 site to maximum subsidence site at the depth of 15-30 cm and 30-45 whereas same trend was not followed at the depth of 0-15 cm.

The highest available phosphorus content in soils of maximum subsidence site might be attributed to presence of high organic matter in soils of that site. Organic acids present in that site solubilise phosphates and other phosphate bearing minerals and there by enhance the P availability. The increase in P availability due to the presence of high organic matter in soils might be ascribed to the replacement of phosphate ion by humate ion and formation of a coating on sesquioxide particles by humus as a protective cover and thereby reducing the phosphate fixing capacity.

Table 4.8: Effect of subsidence due to coal mining activities on available P (Kg ha^{-1}) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	16.84	19.86	22.34	24.78	**20.96**
crack 1	18.98	22.26	25.64	28.46	**23.84**
slope 1	15.86	16.86	21.98	22.86	**19.39**
max sub	24.86	29.84	31.96	34.46	**30.28**
slope 2	13.46	18.64	18.42	20.86	**17.85**
crack 2	17.42	20.84	22.24	24.86	**21.34**
SE(m±)	**1.791**				
CD ($P_{0.05}$)	**5.363**				
			15-30 cm depth		
unaffected	15.11	17.86	23.84	20.24	**19.26**
crack 1	16.62	20.42	22.32	18.42	**19.45**
slope 1	18.76	18.94	20.32	22.86	**20.22**
max sub	27.46	25.84	32.54	31.24	**29.27**
slope 2	14.42	18.84	24.64	16.84	**18.69**
crack 2	18.62	15.56	18.64	24.42	**19.31**
SE(m±)	**1.658**				
CD ($P_{0.05}$)	**4.964**				
			30-45 cm depth		
unaffected	21.24	14.15	18.32	22.42	**19.03**
crack 1	18.24	16.70	19.32	18.46	**18.18**
slope 1	16.28	21.24	22.92	24.64	**21.27**
max sub	26.06	29.84	31.24	32.42	**29.89**
slope 2	15.32	19.86	22.64	22.42	**20.06**
crack 2	23.24	17.62	24.64	20.24	**21.44**
SE(m±)	**1.538**				
CD ($P_{0.05}$)	**4.606**				

Table 4.9: Effect of subsidence due to coal mining activities on available K (Kg ha^{-1}) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	222.88	230.2	207.86	242.86	**225.95**
crack 1	202.76	216.68	224.28	252.46	**224.05**
slope 1	268.2	207.2	237.44	241.92	**238.69**
max sub	272.64	286.72	299.04	286.72	**286.28**
slope 2	240.8	215.04	212.8	263.32	**232.99**
crack 2	204.96	224.78	190.4	200.48	**205.16**
SE(m±)	**9.512**				
CD ($P_{0.05}$)	**28.481**				
			15-30 cm depth		
unaffected	224.86	194.88	212.28	214.64	**211.67**
crack 1	250.64	214.86	224.86	232.68	**230.76**
slope 1	228.46	246.86	238.56	232.78	**236.67**
max sub	288.84	256.48	253.68	285.6	**271.15**
slope 2	242.84	228.96	226.24	218.4	**229.11**
crack 2	212.56	188.16	198.74	210.86	**202.58**
SE(m±)	**6.547**				
CD ($P_{0.05}$)	**19.602**				
			30-45 cm depth		
unaffected	205.86	212.64	198.48	218.98	**208.99**
crack 1	195.92	208.84	224.86	228.86	**214.62**
slope 1	211.34	193.92	214.46	208.64	**207.09**
max sub	268.36	248.86	256.48	254.24	**256.99**
slope 2	220.46	195.46	232.64	218.98	**216.89**
crack 2	192.94	196.94	208.64	202.64	**200.29**
SE(m±)	**5.578**				
CD ($P_{0.05}$)	**16.702**				

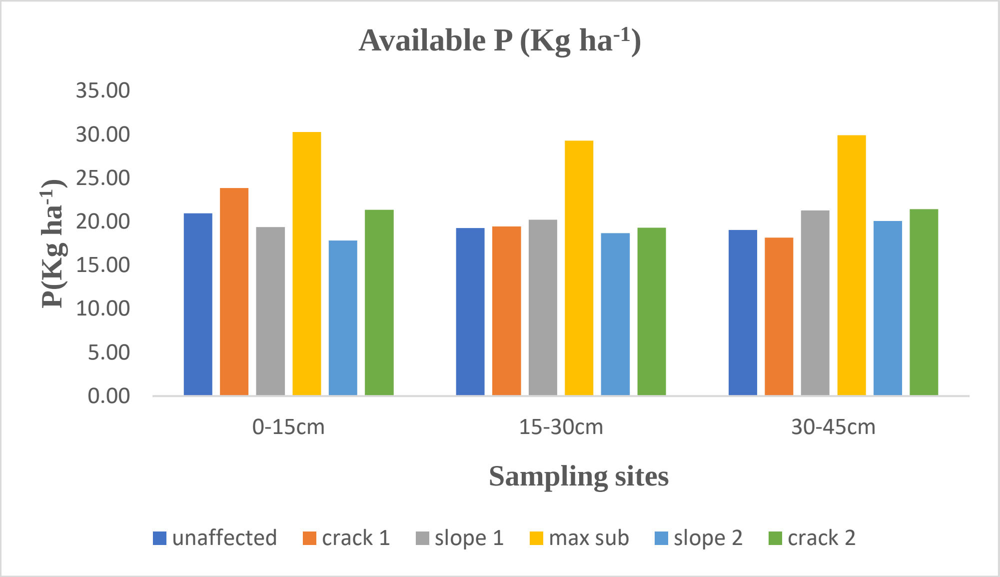


Fig 4.8: Effect of subsidence due to coal mining activities on available P (Kg ha^{-1}) content of soil.

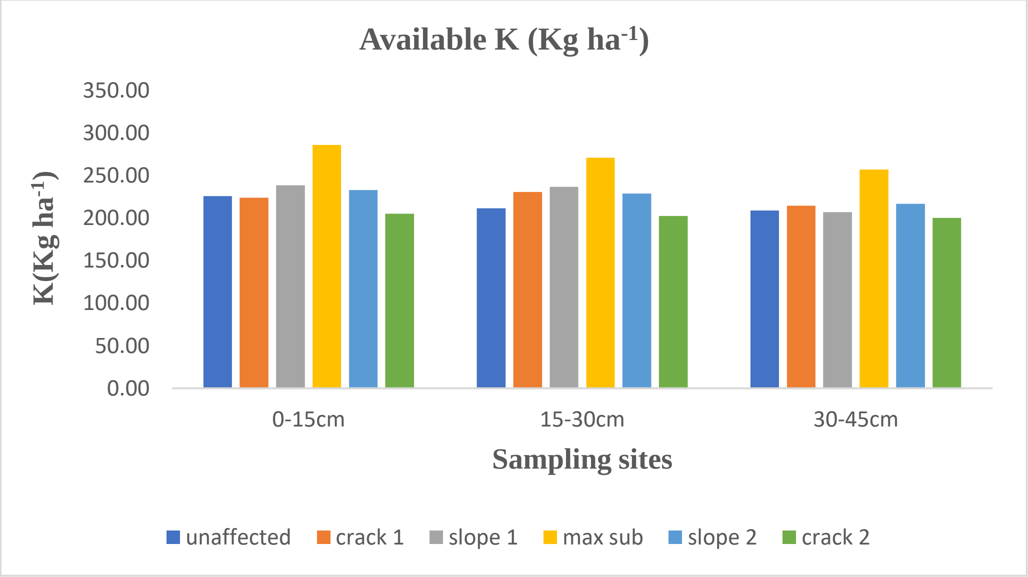


Fig 4.9 Effect of subsidence due to coal mining activities on available K (Kg ha^{-1}) content of soil.

4.9 Available potassium

A critical examination of data (table 4.9 and fig. 4.9) related to the availability of potassium in soils of mining area revealed significant effect of subsidence on the available K content.

With increase in slope, the available K content of soils increased from crack-1 site to maximum subsidence site at the depth of 0-15 cm and 15-30 cm, whereas the same pattern was not followed at depth of 30-45 cm.

Available K content was found to be highest in soils of maximum subsidence site (286.28 Kg ha^{-1}, 271.15 Kg ha^{-1} and 256.99 Kg ha^{-1}) and lowest in soils of crack-2 site (205.16 Kg ha^{-1}, 202.58 Kg ha^{-1} and 200.29 Kg ha^{-1}) at depth of 0-15 cm,15-30 cm and 30-45 cm.

The pH value of soils is known to influence the availability of K. In acid soils H^+ and hydroxyl aluminium ions compete with K^+ ion for exchange sites and are able to keep more K^+ ion in the solution phase. This could be one of the reason of higher value of K in soils of maximum subsidence site.

4.10 Exchangeable calcium

Data signifying to the effect of subsidence on the available calcium have been presented in table 4.10 and fig.4.10.

It was observed that there was an insignificant variation in exchangeable calcium of soils in mining area at the depth of 0-15 cm, 15-30 cm and30-45 cm.

The exchangeable calcium was found to be highest in maximum subsidence, the respective values being 4.5 me $100g^{-1}$, 5.10 me $100g^{-1}$ and 5.05 me $100g^{-1}$ at all the three depths i.e., 0-15 cm, 15-30 cm and 30-45 cm. The lowest value of exchangeable calcium (3.10 me $100g^{-1}$) was found in soils of crack-2 site at the depth of 0-15 cm, whereas the lowest exchangeable Ca was found in soils of slope-2 site, the respective values being 4.30 me $100g^{-1}$ and 4.40 me $100g^{-1}$ at the depth 15-30 cm and 30-45 cm.

The exchangeable calcium of soils in mining area increased from crack-1 site to maximum subsidence site at depth of 0-15 cm,15-30 cm, 30-45 cm and the availability of calcium in soils of mining area also increased from crack-2 site to maximum subsidence site at depth of 0-15 cm whereas this pattern was not followed at depth of 15-30 cm and 30-45 cm

Table 4.10: Effect of subsidence due to coal mining activities on exchangeable Ca (me 100g^{-1}) content of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
	0-15 cm depth				
unaffected	2.40	3.80	3.80	5.60	**3.90**
crack 1	2.60	4.00	3.40	4.00	**3.50**
slope 1	3.40	3.80	3.60	3.40	**3.55**
max sub	4.20	4.40	4.20	5.20	**4.50**
slope 2	3.80	2.80	4.00	4.80	**3.85**
crack 2	2.80	3.40	3.20	3.00	**3.10**
SE(m±)	**0.363**				
CD ($P_{0.05}$)	**NS**				
	15-30 cm depth				
unaffected	3.8	4.4	4.2	5.2	**4.40**
crack 1	5.2	4.6	4	4.6	**4.60**
slope 1	4.4	4	5.6	4.8	**4.70**
max sub	5.8	4.2	4.6	5.8	**5.10**
slope 2	4	3.8	4.4	5	**4.30**
crack 2	4.6	4	5.2	5	**4.70**
SE(m±)	**0.309**				
CD (5%)	**NA**				
	30-45 cm depth				
unaffected	4.6	4.4	5.2	5.2	**4.85**
crack 1	4.4	4	4.4	4.8	**4.40**
slope 1	5	3.2	6.4	4.2	**4.70**
max sub	5.6	5	3.4	6.2	**5.05**
slope 2	3.4	4	4.2	4.4	**4.00**
crack 2	3.6	4.4	5.8	4.4	**4.55**
SE(m±)	**0.437**				
CD ($P_{0.05}$)	**NS**				

Table 4.10: Effect of subsidence due to coal mining activities on exchangeable Mg (me 100g^{-1}) content of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
			0-15 cm depth		
unaffected	1.8	3.2	3	1.8	**2.5**
crack 1	2	2.2	3.4	2	**2.4**
slope 1	3	1	1.6	2.6	**2.1**
max sub	4.2	2.6	1.4	2.2	**2.6**
slope 2	2.8	2	1.8	2.6	**2.3**
crack 2	1.8	3	2.4	2.8	**2.5**
SE(m±)	**0.411**				
CD ($P_{0.05}$)	**NS**				

			15-30 cm depth		
unaffected	3.2	3.6	1	1.4	**2.3**
crack 1	2	2.4	3.6	1.4	**2.4**
slope 1	2.6	1.6	2.2	2.4	**2.2**
max sub	3.6	3.2	2	2.4	**2.8**
slope 2	2	1.6	1.6	2.6	**2.0**
crack 2	1.4	2.8	3	3	**2.6**
SE(m±)	**0.412**				
CD ($P_{0.05}$)	**NS**				
			30-45 cm depth		
unaffected	2.8	3	1.8	2.2	**2.5**
crack 1	2.2	2.4	2.8	1.8	**2.3**
slope 1	2.8	3.8	2	2.6	**2.8**
max sub	4	4	3	1.6	**3.2**
slope 2	2.4	2.4	2.6	2.6	**2.5**
crack 2	2.6	3	3.4	2.8	**3.0**
SE(m±)	**0.32**				
CD ($P_{0.05}$)	**NS**				

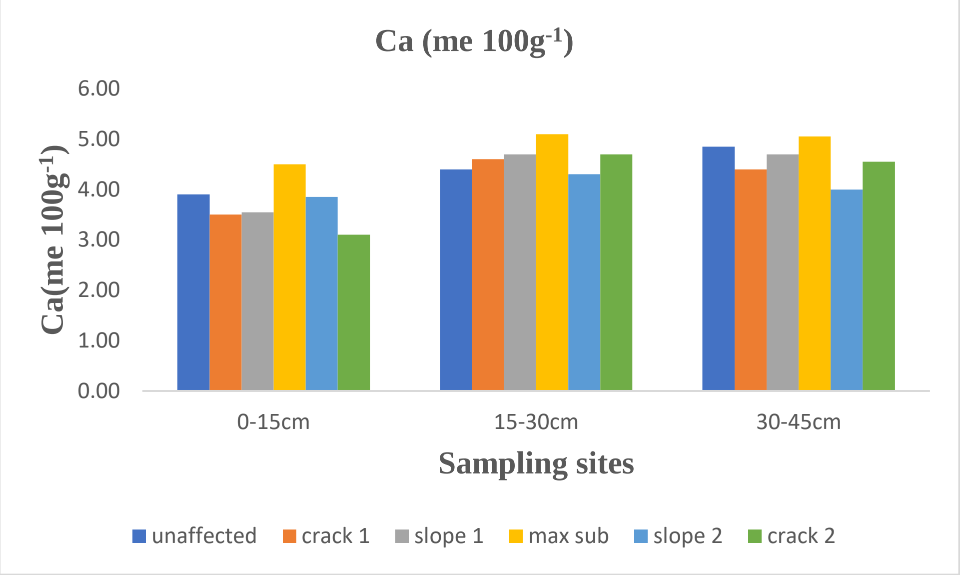


Fig 4.10Effect of subsidence due to coal mining activities on exchangeable Ca (me 100g^{-1}) content of soil.

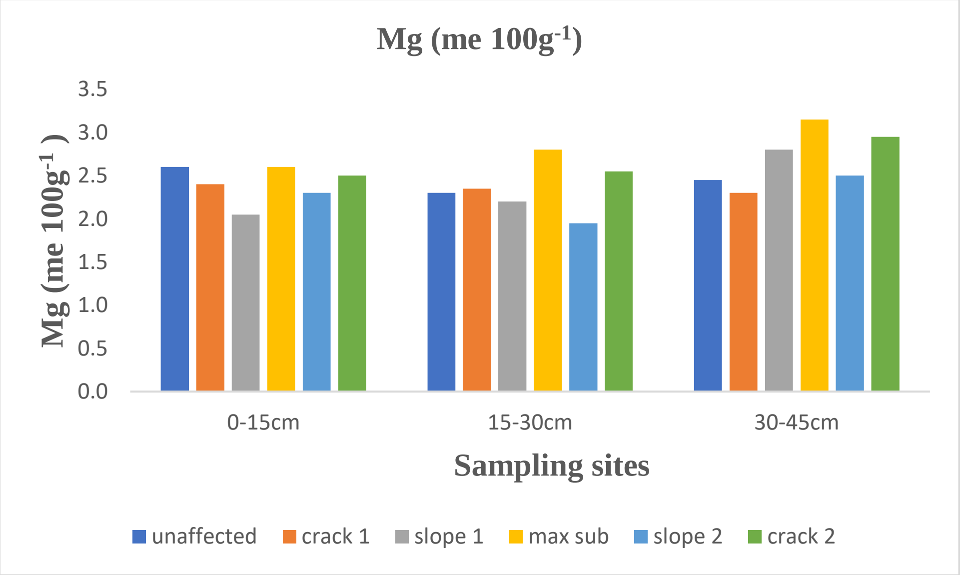


Fig 4.11 Effect of subsidence due to coal mining activities on exchangeable Mg (me100g^{-1}) content of soil

4.11 Exchangeable magnesium

It is evident from the data presented in table 4.11 and fig.4.11 that the exchangeable magnesium was found to be highest in maximum subsidence site, the respective values being 2.6 me100g^{-1}, 2.8 me 100g^{-1}and 3.2 me 100g^{-1} at the depth of 0-15 cm, 15-30 cm and 30-45cm and lowest exchangeable Mg was found in soils of slope-1site, slope-2 site and crack-1 site,

the values being 2.1 me 100g^{-1}, 2 me 100g^{-1} and 2.3 me 100g^{-1} at depth of 0-15 cm, 15-30 cm,30-45cm, respectively.

The exchangeable magnesium of soils in mining area increased from crack-1 site to maximum subsidence site at depth of 30-45, cm whereas same trend was not followed at depth of 15-30 cm and 30-45 cm. The increment of available magnesium of soils in mining area from crack-2 site to maximum subsidence site did not follow a specific pattern at depth of 0-15 cm, 15-30 cm and 30-45 cm.

However, differences in exchangeable Mg of soils were insignificant at all the depths i.e., 0-15 cm, 15-30 cm and 30-45 cm

4.12 Available sulphur

Data pertaining to available sulphur have been presented in table 4.14 and fig.4.12. The data showed that the highest availability of sulphur was observed in soils of maximum subsidence site, the values being 33.10 Kg ha^{-1}, 29.57 Kg ha^{-1} and 30.74 Kg ha^{-1} at the depth of 0-15 cm,15-30 cm and 30-45 cm, respectively. The lowest availability of sulphur was observed in soils of slope-2 site (19.89 Kg/ha), crack-1 site (19.48 Kg/ha) and crack-2 site (18.65 Kg/ha) at depth of 0-15 cm, 15-30 cm and 30-45 cm, respectively.

The availability of sulphur increased from crack-1 site to maximum subsidence site through slope-1 site at the depth of 15-30 cm. whereas the same trend was not followed in soils of mining area at depth of 0-15 cm and 30-45 cm. On the other side, the availability of sulphur was found to increase from crack-2 site to maximum subsidence site at depth of 15-30 cm and 30-45 cm. The same trend was not noticed at depth of 0-15 cm. The data showed that the effect of subsidence on available sulphur content in soils of mining areas was significant.

Table 4.12: Effect of subsidence due to coal mining activities on available S (Kg hac^{-1}) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	26.32	24.86	32.38	28.34	**27.98**
crack 1	22.24	28.68	34.86	17.20	**25.75**
slope 1	18.34	16.64	25.46	23.20	**20.91**
max sub	30.48	34.68	28.84	38.40	**33.10**
slope 2	16.28	20.62	24.46	18.20	**19.89**
crack 2	22.58	18.28	27.28	24.20	**23.09**
SE(m±)	**3.342**				
CD ($P_{0.05}$)	**7.012**				
			15-30 cm depth		
unaffected	24.28	28.24	26.46	26.68	**26.42**
crack 1	16.48	24.34	20.24	16.84	**19.48**
slope 1	28.48	18.28	22.24	18.46	**21.87**
max sub	32.78	20.24	30.24	35.00	**29.57**
slope 2	24.56	20.42	21.45	24.80	**22.81**
crack 2	20.24	22.68	18.46	20.86	**20.56**
SE(m±)	**1.927**				
CD ($P_{0.05}$)	**5.771**				
			30-45 cm depth		
unaffected	22.8	26.8	21.26	26.9	**24.44**
crack 1	18.96	21.64	19.78	21.78	**20.54**
slope 1	16.46	16.84	20.28	26.68	**20.07**
max sub	28.86	32.96	36.86	24.28	**30.74**
slope 2	17.8	14.84	22.2	22.96	**19.45**
crack 2	19.9	16.8	17.94	19.96	**18.65**
SE(m±)	**1.811**				
CD ($P_{0.05}$)	**5.423**				

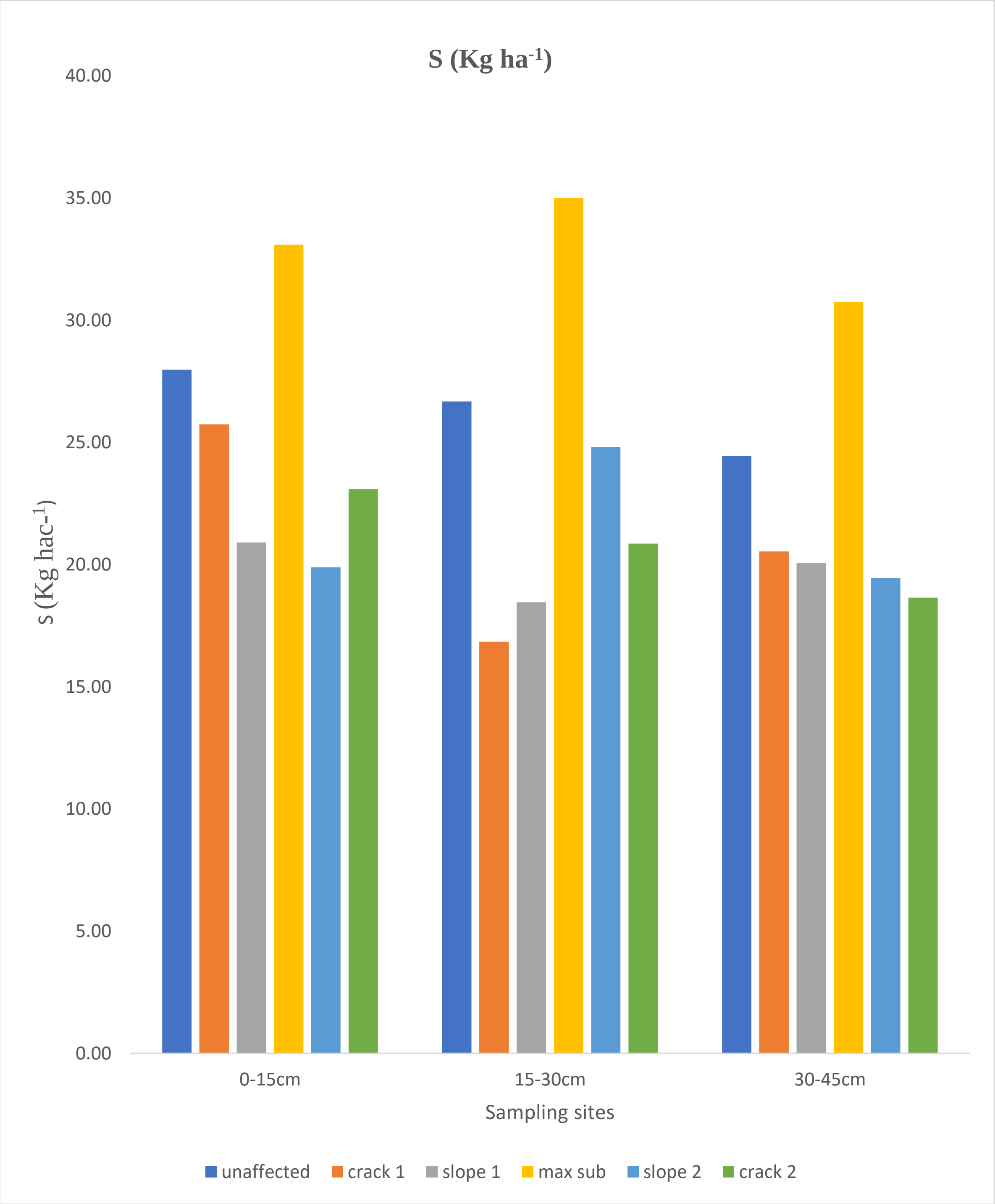


Fig 4.12: Effect of subsidence due to coal mining activities on exchangeable available S (Kg ha^{-1}) content of soil

Organic carbon is the major source of sulphur in soil. Since higher amount of organic carbon was detected in maximum subsidence site, higher value of sulphur was expected in soils of that site.

4.13 DTPA extractable Fe

A critical perusal of data presented in table 4.13 and fig.4.13 revealed that the effect of subsidence was found to be significant on the content of DTPA extractable Fe in soils of mining area at the depth of 0-15 cm and 15-30 cm, whereas there was insignificant difference in Fe content of soils in mining area at the depth of 30-45 cm.

The data also showed that the highest DTPA extractable Fe content was observed in soils of maximum subsidence site, the respective values being 54.9 ppm, 52.8 ppm and 50.5 ppm at the depth of 0-15 cm,15-30 cm and 30-45 cm. The lowest availability of iron was observed in soils of crack-2 site (38.15ppm), slope-1 site (30.1 ppm) and unaffected site (41.3ppm) at depth of 0-15 cm, 15-30 cm and 30-45 cm, respectively.

The DTPA extractable Fe content of soils showed an increase from crack-2 site to maximum subsidence site through slope-2 site at the depth of 0-15 cm, whereas the same trend was not followed in soils at the depth of 15-30 cm and 30-45 cm. There was no obvious pattern in increment of Fe content of soils in mining area from crack-I site to maximum subsidence site at the depth of 0-15 cm, 15-30 cm and 30-45 cm.

The formation of insoluble hydroxide starts as soon as the pH of the solution is raised to 6 and above. So, the solubility and bioavailability of iron increases below pH 6. As the pH of maximum subsidence site was below 6 and maximum concentration of iron was found at this site.

4.14 DTPA extractable Mn

It is clear from the data (table 4.14 and fig.4.14) that the DTPA extractable Mn content of soils increased from crack-2 site to maximum subsidence site through slope-2 site at the depth of 15-30 cm, whereas the same trend was not followed in soils of depth of 0-15 cm and 30-45 cm. The Mn content of soils also increased from crack-1 site to to.

Table 4.13: Effect of subsidence due to coal mining activities on DTPA extractable Fe (ppm) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	45	46.6	28.8	37.8	**39.55**
crack 1	35.6	38.8	46.4	40.6	**40.35**
slope 1	47.2	37.8	33	34.8	**38.2**
max sub	66	55.6	55.8	42.2	**54.9**
slope 2	40.8	34.8	42	45.8	**40.85**
crack 2	32.8	42.2	38.2	39.4	**38.15**
SE(m±)	**3.279**				
CD ($P_{0.05}$)	**9.819**				
			15-30 cm depth		
unaffected	47	48.6	37	47.2	**44.95**
crack 1	44.2	45.8	43.2	45.8	**44.75**
slope 1	33.8	26	20.6	40	**30.1**
max sub	53.8	54.2	53.4	49.8	**52.8**
slope 2	40	43.2	28.8	36.8	**37.2**
crack 2	32.4	41.6	42.2	36.8	**38.25**
SE(m±)	**2.634**				
CD ($P_{0.05}$)	**7.886**				
			30-45 cm depth		
unaffected	39	42	48.2	36	**41.3**
crack 1	43.8	44.2	42	46.8	**44.2**
slope 1	31.2	37.4	46.8	58	**43.35**
max sub	50.8	52.4	50.8	48	**50.5**
slope 2	44.8	48.2	36	42.4	**42.85**
crack 2	32.8	53	42	48.2	**44**
SE(m±)	**3.376**				
CD ($P_{0.05}$)	**NS**				

Table 4.14: Effect of subsidence due to coal mining activities on DTPA extractable Mn (ppm) content of soil.

Sampling site	R1	R2	R3	R4	Mean
			0-15 cm depth		
unaffected	54	62	58.72	46.8	**55.38**
crack 1	48	52.2	42	52	**48.55**
slope 1	58.52	48.2	42.8	48.24	**49.44**
max sub	74	82	70.8	68	**73.70**
slope 2	46.3	42.5	51.68	45.8	**46.57**
crack 2	45.08	52.94	48.8	42.04	**47.22**
SE(m±)	**2.76**				
CD ($P_{0.05}$)	**8.263**				
			15-30 cm depth		
unaffected	62.8	58	57.08	60.2	**59.52**
crack 1	69.02	59.68	54.4	62	**61.28**
slope 1	59.68	55	52.2	48.24	**53.78**
max sub	72	78	71.6	70.2	**57.20**
slope 2	44.62	49.8	48.38	52.46	**48.82**
crack 2	44.02	56.32	46.8	42.04	**47.30**
SE(m±)	**2.319**				
CD ($P_{0.05}$)	**6.943**				
			30-45 cm depth		
unaffected	46.8	54	55.04	66.42	**55.57**
crack 1	40	53.96	45.6	39.7	**44.82**
slope 1	59.8	72	66.4	46.8	**61.25**
max sub	66.5	74	72.8	64.8	**69.53**
slope 2	42.8	48.8	46.52	60.56	**49.67**
crack 2	46.8	59.56	73.04	59.78	**59.80**
SE(m±)	**4.195**				
CD ($P_{0.05}$)	**12.56**				

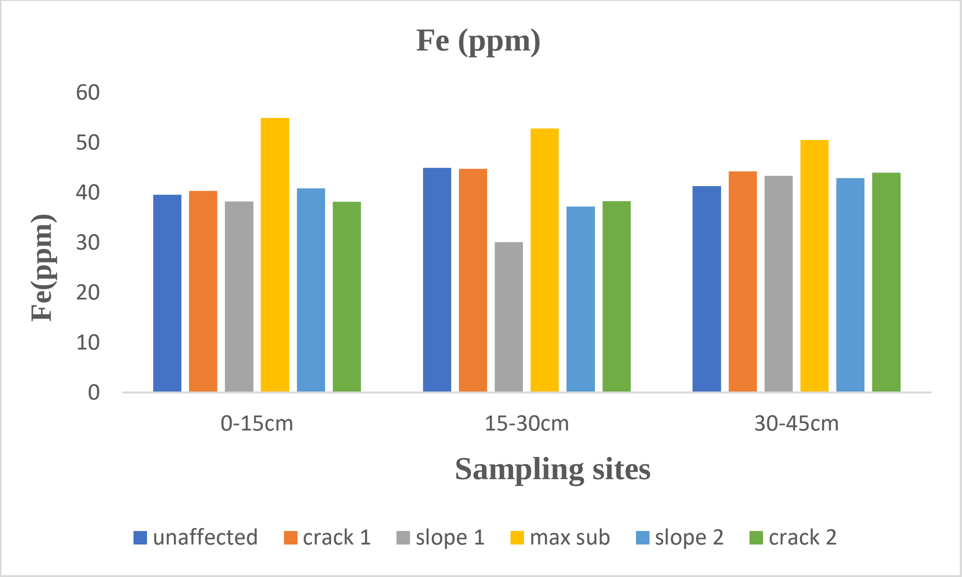


Fig 4.13: Effect of subsidence due to coal mining activities on DTPA extractable Fe (ppm) content of soil

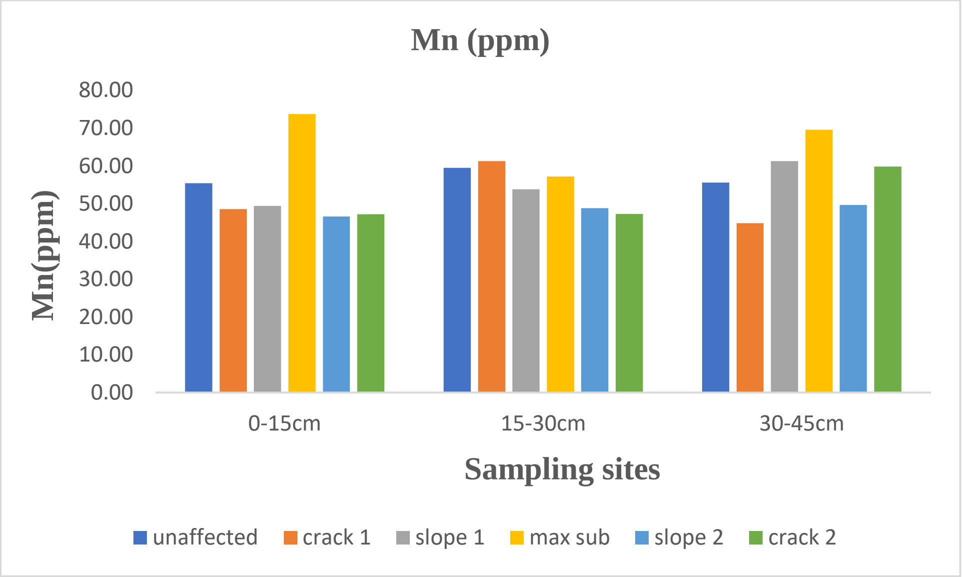


Fig 4.14: Effect of subsidence due to coal mining activities on DTPA extractable Mn (ppm) content of soil

maximum subsidence site through slope-1 site at the depth of 0-15 cm and 30-45 cm, whereas the same pattern was not followed in soils at depth of 15-30 cm The data showed that the highest DTPA extractable Mn content was observed in soils of maximum subsidence site and the respective values were 73.7 ppm, 57.20 ppm and 69.53ppm at all the depths of 0-15 cm,15-30 cm and 30-45 cm. The lowest availability of

DTPA extractable Mn i.e., 46.57 ppm was observed in soils of slope-2 site at the depth of 0-15 cm, whereas the lowest value in crack-2 site and crack-1 site were 48.82 ppm and 44.82 ppm at the depth of 15-30 cm and 30-45 cm, respectively.

Data presented in table revealed that effect of subsidence was found to be significant on the content of Mn in soils of mining area at the depths of 0-15 cm, 15-30 cm and 30-45 cm.

4.15 DTPA extractable Zn

It is evident from the data presented in table 4.15 and fig. 4.15 that the DTPA extractable Zn content of soils decreased from crack-2 site to maximum subsidence site through slope-2 site at the depths of 0-15 cm, 15-30 cm and 30-45 cm. The Zn content of soils was also decreased from crack-1 site to maximum subsidence site through slope-1 site at all the three depths i.e., 0-15 cm, 15-30 cm, 30-45 cm.

The data showed that the lowest DTPA extractable Zn content was observed in soils of maximum subsidence site, the values being 0.46ppm, 0.49ppm and 0.31 ppm at the depths of 0-15 cm,15-30 cm and 30-45 cm respectively. The highest availability of Zn i.e., 1.19 ppm was observed in soils of crack-2 site, whereas the highest DTPA extractable Zn content was found in soils of unaffected site and crack-1 site, the values being 0.75 ppm and 0.64 ppm at depth of 15-30 cm and 30-45 cm respectively.

Data presented in table revealed that the subsidence had significant effect on the content of DTPA extractable Mn in soils of mining area at depth of 0-15 cm. whereas there was insignificant difference in DTPA extractable Zn content of soils in mining area at depth of 15-30 cm and 30-45 cm.

There was observed a negative interaction between Zn and P. Since P content in maximum subsidence site was highest, availability of Zn was lowest at that site.

Table 4.15: Effect of subsidence due to coal mining activities on DTPA extractable Zn (ppm) content of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
			0-15 cm depth		
unaffected	0.4	0.6	0.4	0.6	**0.50**
crack 1	0.6	0.65	0.6	1.2	**0.76**
slope 1	0.45	0.8	1.2	0.4	**0.71**
max sub	0.2	0.45	0.35	0.85	**0.46**
slope 2	0.65	0.55	0.8	0.8	**0.70**
crack 2	1.4	1.2	0.75	1.4	**1.19**
SE(m±)	**0.133**				
CD ($P_{0.05}$)	**0.397**				
			15-30 cm depth		
unaffected	0.8	0.8	0.8	0.6	**0.75**
crack 1	0.45	0.35	0.6	1.2	**0.65**
slope 1	0.2	0.6	0.65	0.6	**0.51**
max sub	0.4	0.55	0.2	0.8	**0.49**
slope 2	0.6	0.4	0.4	0.8	**0.55**
crack 2	0.4	0.8	0.55	0.7	**0.61**
SE(m±)	**0.117**				
CD ($P_{0.05}$)	**NS**				
			30-45 cm depth		
unaffected	0.4	0.6	0.2	0.4	**0.40**
crack 1	0.55	0.65	0.6	0.75	**0.64**
slope 1	0.45	0.4	0.4	0.8	**0.51**
max sub	0.2	0.2	0.25	0.6	**0.31**
slope 2	0.65	0.6	0.45	0.45	**0.54**
crack 2	0.6	0.8	0.6	0.2	**0.55**
SE(m±)	**0.087**				
CD ($P_{0.05}$)	**NS**				

Table 4.16: Effect of subsidence due to coal mining activities on DTPA extractable Cu (ppm) content of soil.

Sampling site	**R1**	**R2**	**R3**	**R4**	**Mean**
			0-15 cm depth		
unaffected	6.8	5.6	4.8	5.2	**5.60**
crack 1	3.8	4.2	2.8	3.2	**3.50**
slope 1	2.6	3.2	3.4	5.6	**3.70**
max sub	2.4	2.1	2.4	3.4	**2.58**
slope 2	2	2.8	2.6	3.8	**2.80**
crack 2	2.1	3.6	3.2	2.4	**2.83**
SE(m±)	**0.419**				
CD ($P_{0.05}$)	**1.255**				
			15-30 cm depth		
unaffected	5.4	6.2	5.6	4.8	**5.50**
crack 1	4.2	3.2	3.8	2.8	**3.50**
slope 1	3	4.8	4	3.2	**3.75**
max sub	2.2	2.8	3.4	2.2	**2.65**
slope 2	4	3.2	3.2	2.6	**3.25**
crack 2	3.2	4	3.6	2.8	**3.40**
SE(m±)	**0.311**				
CD ($P_{0.05}$)	**0.932**				
			30-45 cm depth		
unaffected	5.2	4.6	4.2	5	**4.75**
crack 1	3.6	3.2	3.2	3.8	**3.45**
slope 1	3.8	3.6	2.6	3.2	**3.30**
max sub	2.4	2.2	2	2.6	**2.30**
slope 2	2.8	2.4	3	2.6	**2.70**
crack 2	3	2.8	2.2	3.4	**2.85**
SE(m±)	**0.199**				
CD ($P_{0.05}$)	**0.596**				

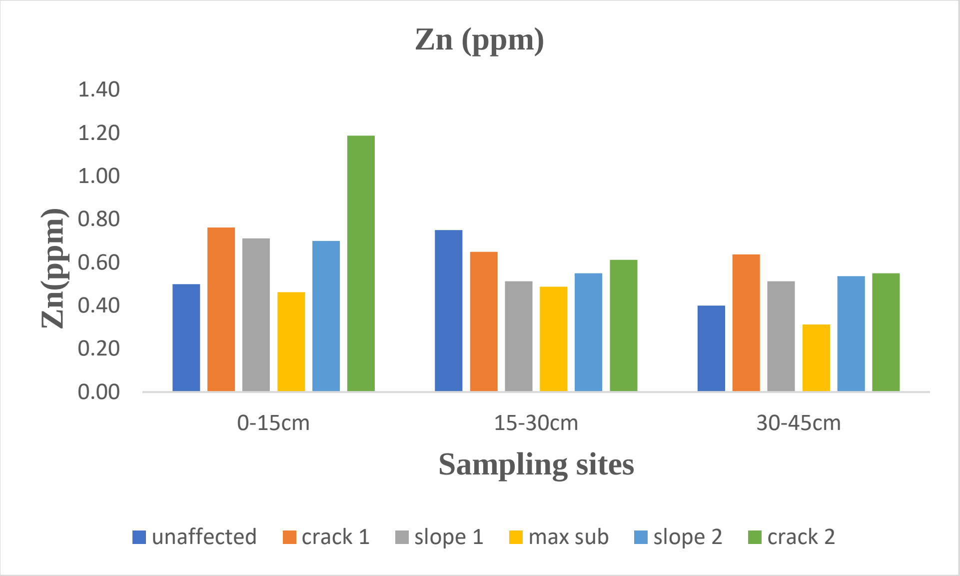


Fig 4.15: Effect of subsidence due to coal mining activities on DTPA extractable Zn (ppm) content of soil

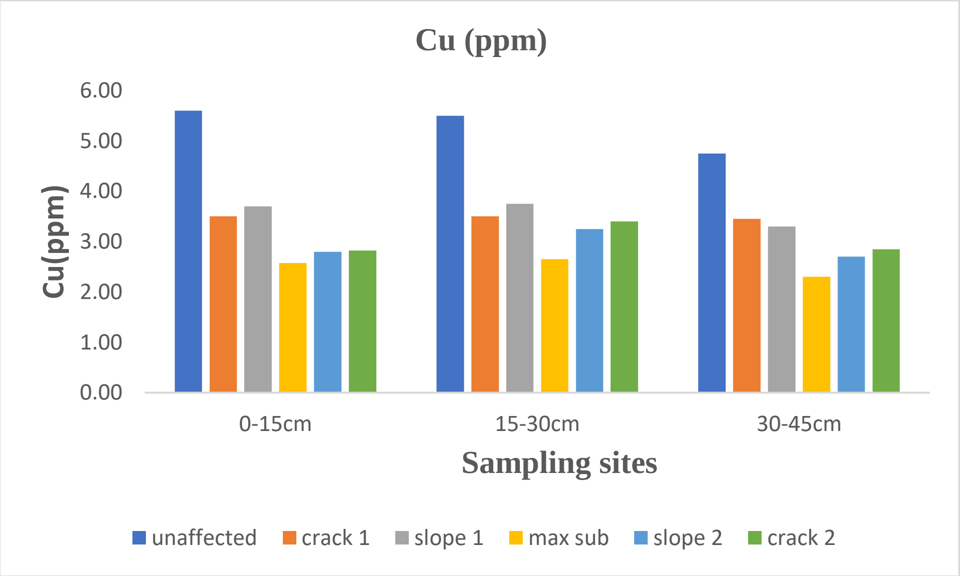


Fig 4.16: Effect of subsidence due to coal mining activities on DTPA extractable Cu (ppm) content of soil

4.16 DTPA extractable Cu

It is obvious from the data presented in table 4.16 and fig. 4.16 that underground coal mining activities had remarkable impact on DTPA extractable Cu content in soil.

Significant difference was found in DTPA extractable Cu content of soils in all sampling sites of mining area at the depths of 0-15 cm,15-30 cm, 30-45 cm.

It is clear from the data that lowest DTPA extractable Cu was found in soils of maximum subsidence site at all the three depths, viz. 0-15 cm, 15-30 cm and 30-45 cm the respective values being 2.58 ppm, 2.65 ppm and 2.30 ppm. The DTPA extractable Cu of soils decreased from crack-2 site to maximum subsidence site through slope -2 site at depths of 0-15 cm, 15-30 cm, 30-45cm. There was no specific pattern shown by DTPA extractable Cu of soils from crack-1 site to maximum subsidence site through slope-1 site in any depth i.e., 0-15 cm, 15-30 cm, 30-45 cm.

Soil organic matter contains several reactive functional groups and multivalent cations (Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}) which have the potential for forming coordinating linkages with those functional groups. Amongst the highly stable complexes, stability sequence for some selective divalent cations is as follows:

$Cu^{2+} > Ni^{2+} > Co^{2+} > Zn^{2+} > Fe^{2+} > Mn^{2+}$

Organic carbon content was found to be highest in soils of maximum subsidence site, hence might have complexed greater portion of DTPA extractable Cu resulting in lesser availability of Cu at this site.

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Chapter V

SUMMARY AND CONCLUSIONS

The present investigation entitled "Effect of subsidence on the physico-chemical properties of soil in a coal mining area of Madhya Pradesh" was carried out by collecting soil samples from Jamuna & Kotma coal mining area, with a view to observe the changes in phyico-chemical properties of soils and availability of nutrient elements due to subsidence caused by mining activities. Various samples were processed and analysed in the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi for various parameters viz. pH, EC, soil texture, water holding capacity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu.

The salient findings and relevant conclusions are given below-

Physico-chemical properties of soils

- Effect of subsidence was found to be significant on the pH of soils in mining area under study at the depths of 0-15 cm, 15-30 cm and 30-45 cm. Soils of maximum subsidence site were more acidic than the soils collected from other site at all the three depths.
- Significant variation in EC of soils was found to exist among all the sites of all sites at the depths of 0-15 cm,15-30 cm and 30-45 cm. Soils of maximum subsidence site had the highest EC value and soils of crack-2 site had the minimum EC value at all the depths.
- Sand percentage was minimum in soils of maximum subsidence site at the depths of 0-15cm and 15-30cm. The soils of maximum subsidence had the maximum clay percentage at all the three depths.
- There was a significant variation among the bulk density of soils of all sampling sites. Maximum subsidence site had the lowest bulk density and slope-1 had the highest bulk density at all the three depths.
- The water holding capacity of soils was found to increase significantly from soils of crack-2 site to maximum subsidence site through slope -2 site at all the three depths. Soils of maximum subsidence site had the maximum water holding capacity.

- Significant difference was found in organic carbon content of soils collected from all sampling sites of study area at 0-15 cm depth, where as insignificant difference was noticed in soil organic carbon content at the depths of 15-30 cm and 30-45 cm. Organic carbon content was maximum in soils of maximum subsidence site at all the three depths.
- Subsidence had highly significant impact on nitrogen availability of soils in mining area at depth of 0-15 cm and 15-30 cm, whereas there was an insignificant variation in available nitrogen of soils at depth of 30-45 cm. The available nitrogen was highest in soils of maximum subsidence site at all the three depths and was minimum in soils of crack-1 site at the depth of 0-15 cm and 15-30 cm whereas at the depth of 30-45 cm, lowest available nitrogen was recorded in soils of slope-2 site.
- There existed a significant variation in available phosphorus content of soils in mining area at the depths of 0-15 cm, 15-30 cm and 30-45 cm. The maximum subsidence site had the highest available phosphorus content at all the three depths.
- There was a significant variation in potassium content of soils sampled from all the depths. With increase in slope, the available K content of soils increased from crack-1 site to maximum subsidence site at depths of 0-15 cm and 15-30 cm, whereas the same pattern was not followed in soils of 30-45 cm depth.
- There was an insignificant variation in exchangeable calcium of soils in mining area collected from the depths of 0-15 cm, 15-30 cm and 30-45 cm. The available calcium was highest in soils of in maximum subsidence site at all the three depths. The lowest value of exchangeable calcium was found in soils of crack-2 site at depth of 0-15 cm whereas, at the depths of 15-30 cm and 30-45 cm the lowest value was found in soil of slope-2 site.
- There was an insignificant variation in exchangeable magnesium of soils in mining area at the depths of 0-15 cm, 15-30 cm and 30-45 cm. The exchangeable Mg of soils in mining area showed slightly increasing from crack-1 site to maximum subsidence site at all the depths.
- The effect of subsidence on available sulphur content in soils of mining was found to be significant. The highest availability of sulphur was observed in soils of maximum subsidence site at all the depths. The lowest availability of sulphur was observed in soils of slope-2 site, crack-1 site and crack-2 site at the depths of 0-15 cm, 15-30 cm and 30-45 cm, respectively.

- Effect of subsidence was found to be significant on the content of DTPA extractable Fe in soils of mining area at the depths of 0-15 cm and 15-30 cm, whereas there was insignificant difference in DTPA extractable Fe content of soils at depth of 30-45 cm. The highest Fe content was observed in soils of maximum subsidence site at all the three depths. The lowest availability of sulphur was observed in soils of crack-2 site, slope-1 site and unaffected site (41.3ppm) at the depths of 0-15 cm, 15-30 cm and 30-45 cm respectively
- effect of subsidence was found to be significant on the content of DTPA extractable Mn in soils of mining area at all the three depths. Highest Mn content was observed in soils of maximum subsidence site at all the three depths. The lowest availability of sulphur was observed in soils of slope-2 site, crack-2 site and crack-1 site at the depths of 0-15 cm, 15-30 cm and 30-45 cm respectively.
- effect of subsidence was found to be significant on the content of DTPA extractable Mn in soils of mining area at the depth of 0-15 cm, whereas there was insignificant difference in Zn content of soils in mining area at depth of 15-30 cm and 30-45 cm. The lowest Zn content was observed in soils of maximum subsidence site at all the three depths. The highest availability of Zn was observed in soils of crack-2 site, unaffected site and crack-1 site at the depths of 0-15 cm, 15-30 cm and 30-45 cm respectively.
- Significant difference had been found in DTPA extractable Cu content of soils in all sites of mining area at all the three depths. Lowest available copper content was found in soils of maximum subsidence site at all the three depths.

CONCLUSIONS

- The land subsidence due to coal mining activities alters significantly the soil physico-chemical properties and the content of available nutrients in soil.
- The phenomenon of subsidence resulted in enhanced clay content, soil moisture, organic carbon content and available N, P, K, Ca, Mg, S, Fe and Mn content in maximum subsidence site. Decline of Zn and Cu content took place at this site. It also caused decline in bulk density which is desirable from crop production point of view.
- On the basis of the value of physico-chemical characteristics and content of available nutrients, soils of subsidence area could be used for cultivation of agricultural crops.

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