ABSTRACT

Understanding the consequences of mining is most important in order to prevent its negative outcomes for the environment as natural systems are used by humans for agriculture/silviculture. The underground coal mining leads to subsidence at the surface, causing damages to structures, undulation of land surfaces, potential hydrologic impacts, impacts on streams and surface waters, as well as on forest/farmland losses. Subsidence means lateral or vertical ground movement caused by a failure of the immediate roof and subsequently failure of upper strata. It causes the ground above to sink or subside when the roof of a subsurface mine collapses.

Surface subsidence due to underground coal mining changes the surface profile. It results into development of tensile and compressive strain zones on the surface. The drainage pattern of the surface also changes. Cracks etc. are formed in tensile strain zone, whereas there is compaction in compressive strain zone. It stimulates substantial surface settlements, expands the usual geomorphological slope and creates several numbers of cracks, making significant harm to the natural condition in the mining regions. Under the complete interaction of land subsidence disruption, wind and rain influence, water loss and soil erosion can easily occur in the forestland in subsided areas, prompting the degeneration of soil quality. The irregular surface and the spreading of cracks in the subsided regions lead to increased soil evaporation zone. The evaporation strength expands and the forestland additionally loses water and nutrient retaining capacity. The drought resistance is weakened considerably, which seriously influences the growth of the plants. Furthermore, underground coal mining demolishes the structure of the water-holding layer of soil, lowering the groundwater level. Therefore, studying the impacts of subsidence induced by

coal mining on plants' health is of paramount importance and hence is critical for developing sustainable strategies to restore the health of forest land.

The goal of the present work was to study the effect of mining induced subsidence on the health of the plants. Three approaches have been adopted for this purpose (i) laboratory model for the estimation of the effects of strain on various plant growth parameters (ii) study of nutrients in soil and plant leaves from different zones (compressive strain zone, tensile strain zone and unsubsidized zone) to assess the effect of subsidence on plant health. The texture analysis of soil from three zones has also been carried out, and (iii) the estimation of change in overall health/greenness of the vegetation due to mining subsidence using NDVI (Normalized Difference Vegetation Index) based on remote sensing study.

The experimental laboratory model has been set up for the assessment of impact of subsidence on plants. The horizontal tensile strain increases with advancing face. The laboratory setup was established in such a way that these features of the field could be simulated. Two commonly available plants (i.e., chickpea and wolf's peach) were selected and grown in laboratory conditions. The reason behind selecting these plants was that the root system of these plants is sensitive, i.e., substantial morphological changes take place due to small changes in root surroundings. Four outdoor crop beds sizes of 2.5 m x 1.25 m were specially prepared in the laboratory. Two beds were kept as flat without having any subsidence (control condition). One bed was prepared for chickpea and other for wolf's peach crops for control condition. Other two beds have also been prepared in such a way that the subsidence could be progressively increased. One bed was prepared for chickpea and other for wolf's peach crops for subsidence condition. Tensile strain zone and compressive strain zone have been introduced with the help of hydraulic jacks. The magnitude of strain has also been increased periodically to simulate the increasing strain with advancing face in the field. Important health parameters of plants (biomass, vegetation water content, chlorophyll content, soil moisture, leaf area index and plant heights) have been studied periodically with increasing horizontal tensile and compressive strains, which results in progressive subsidence. The important conclusions have been drawn on impact of subsidence (compressive and tensile strain) on the health of plants. The health parameters decrease with increasing strain in tensile region. Critical value of horizontal tensile strain was observed beyond which the plant health deteriorated rapidly. It has been observed that plant health deteriorates rapidly after 10 mm/m horizontal tensile strain. It has been observed that the plant health improves with increasing horizontal compressive strain. However, it has also been observed that with further increase of horizontal compressive strain, plant health deteriorates.

The assessment of impact of subsidence on soil and vegetation has been carried out by analyzing the soil and plant samples collected from the study area through field visit. Soil samples and the leaves of dominant flora (*Shorea robusta* and *Lantana camara*) were collected from the subsidence affected zones (i.e., tensile and compressive strain zones) and a nearby subsidence unaffected zone. Soil was analysed for the three most important primary nutrients (i.e., available nitrogen, available phosphorus and available potassium). The texture analysis of soil from three zones has also been carried out. Leaves were analysed for all the essential nutrients required for the proper growth and development of the plants.

The percentage of coarse textured soil (sand) increased in the tensile strain zone while decreased in the compressive strain zone. The percentage of fine textured soil (silt+clay) decreased in the tensile strain zone and increased in the compressive strain zone.

The sand increased by 0.71% in tensile strain zone while decreased by 4.60% in compressive strain zone. Silt and clay decreased by 10.34% and 11.60%, respectively, in tensile strain zone and increased by 12.01% and 13.95%, respectively, in compressive strain zone. Fine textured soil is a good accumulator of nutrients and holds water for a longer period of time. Plant health will consequently improve in compressive strain zone, whereas it will deteriorate in tensile strain zone. The amount of nutrients has decreased in tensile strain zone and increased in compressive strain zone. Available nitrogen, available phosphorus and available potassium decreased in tensile strain zone by 3.5%, 11.26% and 3.58%, respectively, while increased in compressive strain zone by 14.98%, 21.4% and 24.15%, respectively.

The macro and micro nutrients are very important for the growth of the plants. The important macro-nutrients (N, P, K, Ca, Mg and S) and micro-nutrients (Mn, Zn, Fe and Cu) have been determined in the plant leaves of the tensile zone, compressive zone and unsubsided zone. The nutrients in plants decreased in tensile strain zone and improved in compressive strain zone. The primary and secondary nutrients, i.e., N, P, K, Ca, Mg and S decreased in tensile strain zone by 1.1%, 7.77%, 6.1%, 11.65%, 0.74% and 8.43%, respectively in *Shorea robusta* while by 0.64%, 9.97%, 1.63%, 1.64%, 1.82% and 3.49%, respectively in *Lantana camara*. The micro or trace nutrients, i.e., Mn, Zn, Fe and Cu, decreased by 1.64%, 2.56%, 5.71% and 3.95%, respectively, in *Shorea robusta* while by 1.83%, 0.51%, 3.33% and 2.49%, respectively in *Lantana camara*.

The concentrations of leaf nutrients of both the plants have increased in compressive strain zone as compared to the unsubsided zone. Primary and secondary nutrients, i.e., N, P, K, Ca, Mg and S increased in compressive strain zone by 2.2%, 11.65%, 10.33%, 5.69%, 1.11% and 10.84%, respectively in *Shorea robusta* while by

0.09%, 7.22%, 1.43%, 2.46%, 1.33% and 2.21%, respectively in *Lantana camara*. Whereas the micro or trace nutrients, i.e., Mn, Zn, Fe and Cu, increased by 1.34%, 2.56%, 3.57% and 5.26%, respectively in *Shorea robusta* while by 1.63%, 6.06%, 6.67% and 3.73%, respectively in *Lantana camara*.

There is a higher concentration of nutrients in soil in compressive strain zone and deficiency in tensile strain zone. The natural corollary is that the plant leaves in compressive strain zone will have high nutrients compared to tensile strain zone. The observations of the plant leave nutrients validate the observations of the soil nutrients.

The study in the laboratory and the field, as discussed above, suggests that plant health is damaged in the tensile zone while it improves in the compressive zone. Remote sensing study has been carried out to find out the overall effect of subsidence on plants, i.e., combined effect of both tensile and compressive strains on the greenness of the plants. LANDSAT satellite imagery has been used to know the effect of mining subsidence on plants health. This study was based on the NDVI calculation. There was a decrease in greenness in the post-subsidence stage as compared to the pre-subsidence stage, which directly shows that the subsidence has had a detrimental effect on vegetation of the study area.

The present study conclusively proves that subsidence has detrimental effect on plants' health. The tensile strain zone leads to damage in the plants. A critical value of horizontal tensile strain also has been observed (10 mm/m), beyond which the plants deteriorate rapidly. The compressive strain zone leads to a slight improvement in the plants. However, higher compressive strain will damage the plants. It has been observed that overall, the plant health deteriorated under the influence of subsidence (tensile and compressive).