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*Full Length Research Paper*

# Subsidence occurring in mining regions and a case study of Zonguldak-Kozlu basin

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**Mining conducted underground causes displacements and deformations in the ground and on the surface, also called mining subsidence, depending upon mining methods and geological factors, and can eventually bring about damages and destruction on buildings and amenities on the surface. These damages and destructions can adversely affect the development of cities and city life, and can emerge as a result of on-going mining activities due to active subsidence effect, as well as post mining production with residual subsidence effects. City of Zonguldak and its town Kozlu and its near surroundings constitute the centre for hard coal basin which has been under heavy mining activities for 160 years. Hence, the mining activities comprise one of the main economical incomes and the mining subsidence affects land ownership, land use, planning, structuring, in short every aspect of life in the region. This study details the damaging vertical displacements resultant of mining subsidence in the region and the solution suggestions, in an attempt to improve these unfavorable effects, along with the results obtained from the leveling works.**

**Key words:** Deformation, displacement, mining subsidence, urbanization, Zonguldak hard coal basin.

## INTRODUCTION

For underground coal mining, it is mostly obligatory to unearth for spaces for shafts and seams to produce and carry coal. However, these spaces disrupt the natural load balance that previously exists in the ground, and generate effective stress changes around them (Hu et al., 1997). These spaces remain open as long as the strength of ground layers and the connection between them corresponds to these stresses; otherwise these spaces close down due to physical changes such as swelling, drifting and caving from the layers surrounding them (Perski and Jura, 2003). Some spaces like shafts and galleries can keep on being open for a long time because they are smaller in size and supported by various structural materials to compensate additional stresses (Kuscu, 1986).

Production spaces, however, are larger in size and thus prove neither to be practical nor economical to fortify the natural strength of ground using ground supports after a critical limit. In an underground coal mine working with the caving method, when the space opened up for production reaches a certain width, the rock layer in the ceiling of that space begins to descend by losing its strength and eventually caves in by blocks under the influence of gravity and fills up the space (Hu et al.,1997). Figure 1 depicts layer movements caused by a mine pit working with the caving method and their effects on ground surface. These movements either stop inside the ground in form of arching without reaching the surface or spread further than the production area having reflections on the surface all depending on the width and depth of production line, geological properties of the ground, structure of ground layering, speed of mining production.

All physical changes including collapsing, vertical displacement, swelling, slope change, bending and cracking are referred to as subsidence (Kratzsch, 1983; Kuscu, 1986, 1991). Figure 2a illustrates the subsidence effects resulting from operating a mining seam at a slope and its subsidence (vertical displacement), strain and horizontal displacement curves; Figure 2b, on the other

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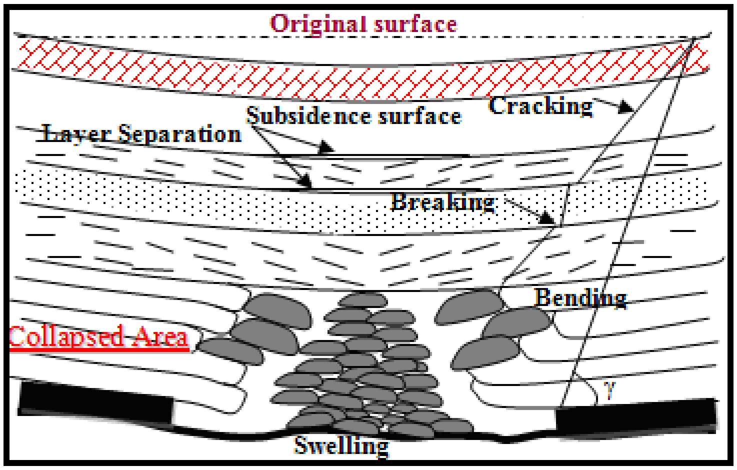



**Figure 1.** Layer movements caused by a mine pit working with the caving method and their effects on ground surface (Kuşcu, 1986).

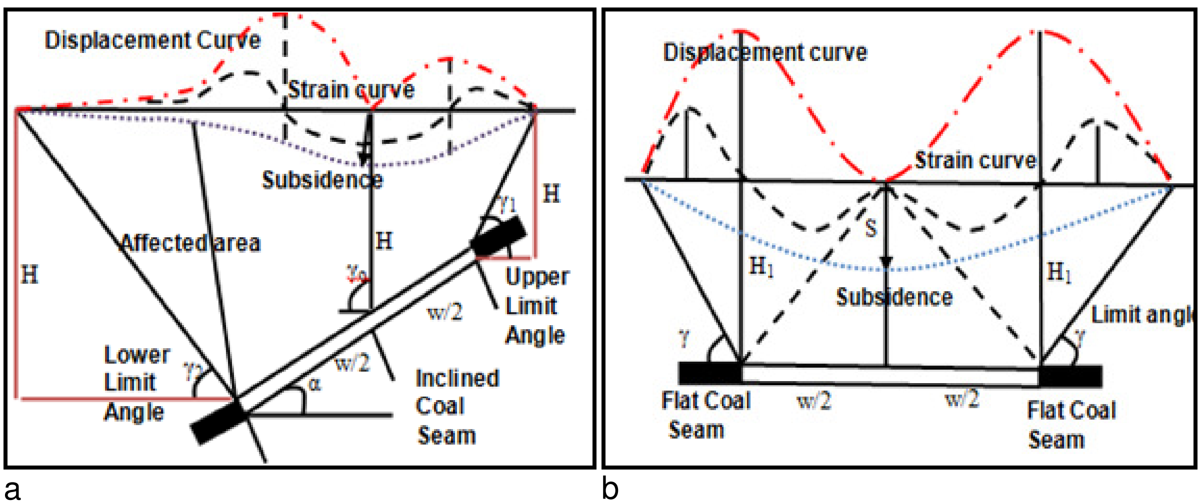



**Figure 2a.** Subsidence (vertical displacement), horizontal displacement and strain curves in an inclined coal seam (Kuscu, 1991). (b) Subsidence (vertical displacement), horizontal displacement and strain curves in a flat seam (Kuscu, 1991).

hand, shows the subsidence effects resulting from operating a horizontal mining seam and its subsidence (vertical displacement), strain and horizontal displacement curves. Subsidence resulting from mining activities induces unbalace on many structures in and on ground, and thus causes damages and loses in materials, labor and time (Erol and Kuscu, 1988). It is possible to study the prevention or reduction measures for the mining induced subsidence in two categories as the protection of existing and new structures (Malinowska and Hejmanowski, 2010). Protection of existing structures is mainly based on keeping subsidence effect under control by employing certain mining methods such as partial and harmonical production and injection of more filling into spaces as well as a few precautionary measures on or around these structures. On the other hand, the measures for new structures may include ascertaining subsidence vulnerable areas and performing new zoning plans and building regulations, and if that is not possible, constructing rigid enough buildings to withstand or to accommodate subsidence occuring underneath their foundations (Erol and Kuscu, 1988).

## SUBSIDENCE INDUCED DAMAGES IN STRUCTURES

A structure or building within the area affected by an operational mine gets under the influence of subsidence with a continuously changing–and finally diminishing–magnitude and direction. It stays undamaged resisting or

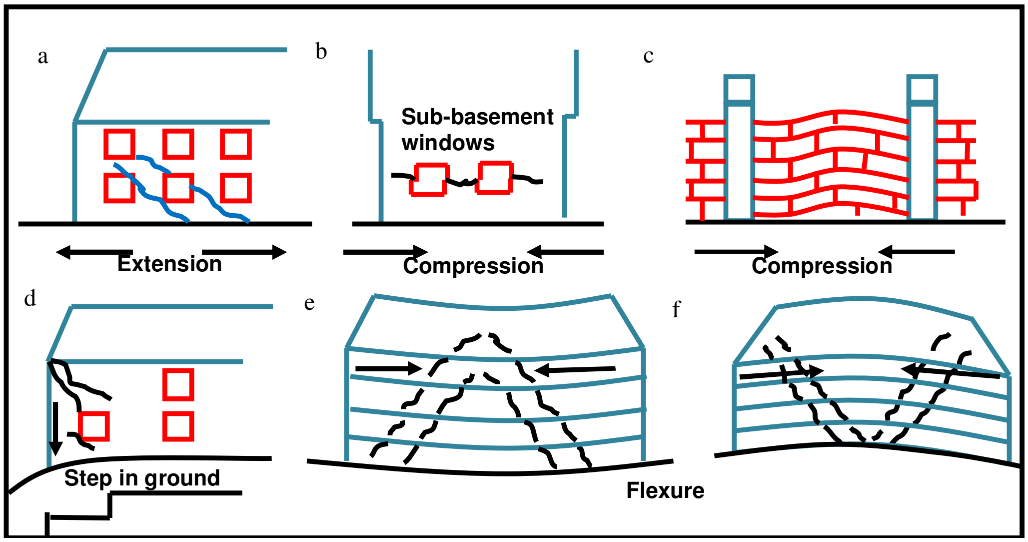



**Figure 3.** Mining induced subsidence effects on buildings and structures (Kratzsch, 1983).

accommodating the aforementioned effect or sustains slight or great damage that can result from emerging differences in slope, displacement and strain to the surface in which the building is positioned by the subsidence effect (Mancini et al., 2009; Gayarre et al., 2010). Aside from the magnitude of subsidence effects, there are peripheral and structural factors that play crucial roles in this damage such as type of ground, topographic construction position of structure in the affected area, dimensions and shapes of buildings, type of basic structural system and properties of construction materials (Kuscu and Erol, 1991). Figure 3 shows the types of damages in buildings and structures formed by mining induced subsidence effect. Today, the damages that have arisen or can possibly arise in buildings and structures are classified as light, medium and intense damages in many countries using various criteria (Kuscu and Erol, 1991)

## Protecting structures against subsidence

The factors effective on damages should be taken into account for reducing the subsidence induced damages to structures. This can be achieved by applying mining methods which can reduce subsidence effects, taking measures for existing structures, planning and establishing for subsidence-resistant new structures. It is also necessary to take some precautions to lessen losses from subsidence influence that can appear in existing buildings. These precautions are (Erol and Kuscu, 1988):

1. Selection of building site: It is necessary to settle down in areas where mining activities no longer take place or subsidence effect is ended.
2. Positioning buildings: The longitudinal axis of structure is to be positioned parallel to subsidence curves on the surface.
3. Sizing buildings: Multi-storey buildings deflect from the vertical by leaning to one side if they are constructed in an area under subsidence influence. Thus, they should have ground dimensions of a near square and in symmetrical shape, and should not have more than two storeys.
4. Partitioning buildings by joints: In case of constructing a building taller than 15 m, it should have partitioning joints.
5. Size of windows: Spaces for windows constitute the weakest areas in masonry constructions. Hence, size of windows should be kept to minimum in planning in subsidence areas.

## GEOLOGY OF ZONGULDAK HARD COAL BASIN

According to recent geologic knowledge, the rough terrain, existing at the Black Sea shore inside Eregli and Inebolu is a formation of the Mesozoic age. The strata which include coal are apparent in several areas of the surface, and the carboniferous basin is 160 km in length in this region. Zonguldak-Kozlu-Kandilli (West hard coal basin) situated to the west of the Filyos River. The first movement in the Zonguldak field was formed in the bottom of the Namurian formation. Although some movement and stresses occurred down in the Namurian, the hard coal basin in the middle of the Namurian is separate from that offshore. A mean collapse of approximately 1000 m finalized the Namurian age for the whole hard coal basin. The Westphalia age included new movement, and after the second instance, the carrying


**Figure 4a.** General bird's eye view of Zonguldak-Kozlu hard coal basin (URL1, 2010). (b) Bird's eye view of Kozlu in detail (URL1).

capacities of rivers increased causing large amounts of deposits to move to the collapsed field. The process of rapid collapse has occasional interruptions and large amounts of coalification occurred during the calm periods. Westphalia strata in this region contain thin coal veins with schist (URL2), (Karacan and Okandan, 2000)

## LOCATION OF ZONGULDAK KOZLU HARD COAL BASIN

Kozlu was established in 1941 as a town of Zonguldak city which is situated in the North of Turkey. Its municipality has 1,063 ha of central area and 1,832 ha of neighboring area. It is topographically uneven and mostly at slope and encircled by mountains, and consists of 7 districts with a population of 40,000 (Can and Kuscu, 2009). Figure 4a depicts general location Zonguldak-Kozlu while Figure 4b Kozlu in detail. Kozlu is the oldest production region in the basin and has been the stage for mining activities between the surface and –630 m depth (minus meters referring to the below ground level) for over 100 years. Its settlement areas for its habitants are also where the mining activities take place, thus experiencing mining induced subsidence problems (Kuscu, 1985; Turer et al., 2008). Figure 5 is the Ikonos satellite image of Kozlu basin, and exhibits the mining galleries between the depths of – 200 and – 630 m scattered in the basin.

This image is formed by converting the local coordinates of mining galleries into ITRF96 datum, and also depicts the production panels reaching through mining galleries. As can be seen from the figure the settlement areas are intertwined with production panels and underground mining galleries. Figure 6 illustrates the cross-section of the mining site showing the distribution of coal seams in the north-south direction in Kozlu basin prepared by Turkish Hard Coal Enterprise. It can be detected in this cross-section that, the elevation angles of the coal seams increase in south-north direction and goes deeper under the Black Sea, and that how the highly inclined production lines trigger the subsidence formation mechanism shown in Figure 2a. Figures 7a and b were obtained from Turkish Hard Coal Enterprise (THCE) and shows 3 dimensional images of coal seams in the north-south and east-west direction, respectively. These images were formed by digitizing the cross-section images taken at every 200 m intervals, one of which is given in Figure 6. As these figures clearly indicate, the coal seams in the basin exhibit a highly inclined topography and the irregular interferencing appearance.

## STRUCTURAL DAMAGES IN ZONGULDAK-KOZLU HARD COAL BASIN

Areas for mining activities in the basin are also utilized as the settlement areas, thus troubled with the subsidence issues. There are also issues in the basin rooting from the reasons such as:

1. That the aforementioned areas were distinguished as the Coal Basin by the legislation issued by Marine Ministry and effective between 1910 and 1986, which prohibited new land proprietorship acquisitions;
2. That the settled areas were registered in the name of treasury instead of private users during the first establishment cadastre works between 1950 and 1955 because of the earlier stated legislation;
3. Forestry land limitations and its problems;
4. Natural structure of the region being unsuitable for urbanization;
5. Administrative and planning mistakes.

As a result of these, the urbanization and structuring in the basin have been forced to take place in areas not in

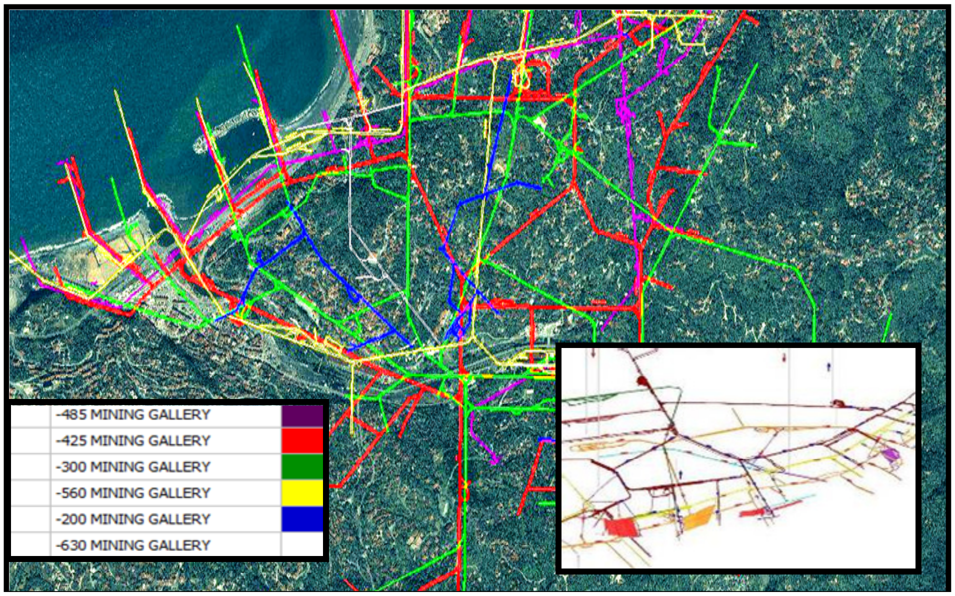



**Figure 5.** Ikonos image of Zonguldak Kozlu hard coal basin (upper) and bird's view plan of mining galleries.

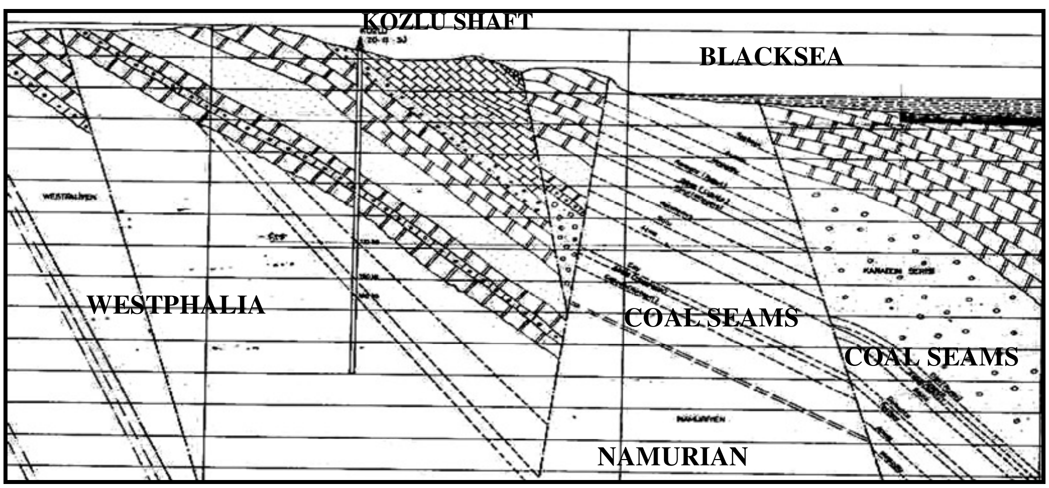



**Figure 6.** Cross-section of mining site showing the distribution of coal seams in the North-south direction (Courtesy of the Turkish Hard Coal Enterprise).

accordance with the regional zoning plans, and also moved to where the mining production galleries used to be (Can and Kuscu, 2009). Furthermore, the construction cost in the region plummeted due to the extra expenditure for the measures taken for structures to withstand the residual subsidence effects appearing especially in the old production areas. Subsidence effects have been causing much more structural damages in the region than they are supposed to. This can be attributed to the fact that, the number of illegal and shanty houses with low construction standards is on the increase, since the registered and zoned lands are scarce on the grounds that city has no effective and steady zoning plan. It is extremely difficult to make a classification in terms of subsidence magnitude and to make long term plans for production and planning owing to geological uncertainties in the basin. Thus, this results in cost rise in the construction of durable buildings. It takes many years to exploit all the coal reserve underneath and to decontaminate the region from the subsidence effect.

This is merely due to a number of coal seams overlapping each other in the hard coal basin, causing locals to live with subsidence induced damages in settlements just above the production galleries. Figures

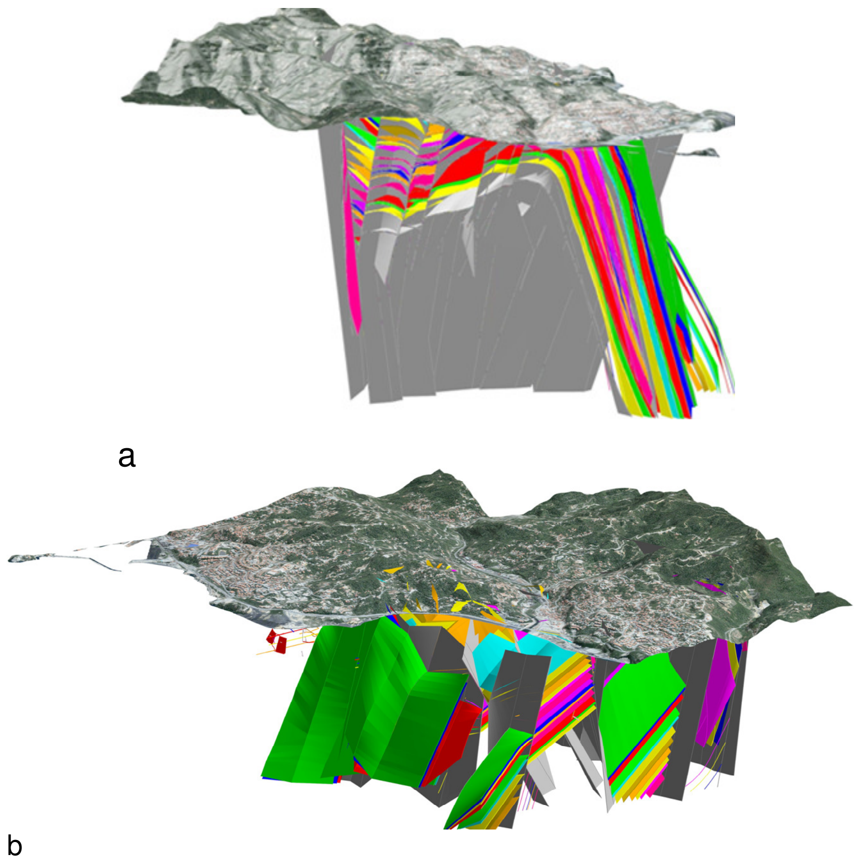



**Figure 7**(a). 3D image of the coal seams in the north-south direction (Courtesy of THCE). (b) 3D image of the coal seams in the east-west direction (Courtesy of THCE).

8a, b and c illustrate the images of damages in three buildings, denoted by 1, 2 and 3 in the maps, caused by active and residual subsidence effects in Zonguldak-Kozlu hard coal basin. For this study, the corner coordinates of the buildings were determined by Real Time Kinematic GPS avoiding any multipath creating surroundings (Mekik and Can, 2010), and placed on a map obtained from Google Earth™. Moreover Figure 5 is implanted into these figures so that one can associate the locations of buildings with the locations of mining galleries in the basin. It can be seen from the figures that, the damages on the buildings are associated with damage types a and d given in Figure 3.

## SUBSIDENCE DETERMINATION MEASUREMENTS IN ZONGULDAK-KOZLU BASIN AND DISCUSSION

A leveling network was established to conduct two periods of precise leveling measurements 10 months apart in order to determine the vertical movements resulting from the mining activities in the basin, using a digital level and bar-coded level rods. Only a few leveling points of this extensive leveling network were used for this article which concentrates on a few structural damages in the basin. The standard deviation of the whole leveling network is 2.99 mm for the 1$^{st}$ period and 2.17 mm for 2$^{nd}$ period, and global test is applied to the whole network. On the other hand, F-test was conducted for the measurements, and F-table value was 2.45 while F-test value was computed as 13.53. Therefore, one can conclude that there exist vertical displacements on the object points leveled, since the differences between the periods are found to be significant.

The results from the leveling measurements made at the selected points susceptible to mining subsidence indicate that, the elevation differences between the periods at the observation points vary from 25 to 75 mm. It is deduced that height differences in highly inclined coal seams in Zonguldak-Kozlu hard coal basin give rise to the formation of the subsidence mechanism type shown in Figure 2a. These vertical movements stemming from the productions in the steep coal seams, cause damages on buildings in a way that Figure 3 clearly indicates. Therefore, the leveling measurements conducted in this region are crucial for ascertaining the magnitude of subsidence formations and also for precautions against


a


b


c

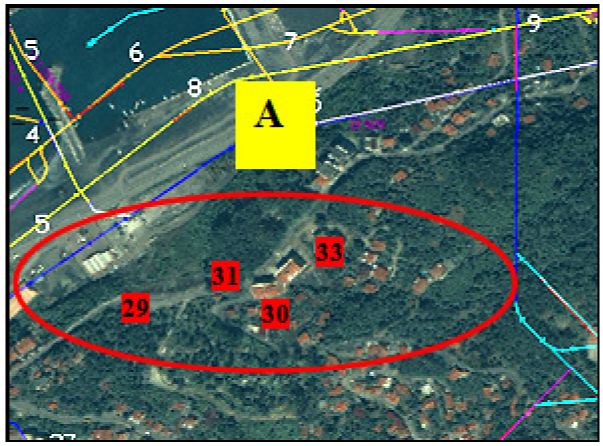
**Figure 8a**. Image and location of structural damage on building 1. (b) Image and location of structural damage on building 2. **(c)** Image and location of structural damage on building 3

potential subsidence induced damages that may occur in future. The vertical movements determined in this study are in analogy with the findings from the research carried out in the basin using InSAR technique with a correlation rate of 0.789 (Akcin et al., 2006; Kutoglu et al., 2008; Deguchi et al., 2007). This InSAR technique uses images from SAR radar satellites, in order to detect vertical ground movements (Perski and Jura, 2003; Wang et al., 2004; Ge et al., 2001; Hirose et al., 2001).

Figures 9a and 10a present the satellite images and leveling points in regions A and B, respectively, while Figures 9b and 10b depict the graphical analyses of height differences obtained from two periods of leveling measurements, respectively. As the graphs given earlier clearly indicate the coal production activities in the basin, which bring about the vertical movements and trigger the subsidence mechanism in this hard coal basin. It is found from these measurements that the coal mining induced subsidence movements influence the hard coal basin and its neighboring surroundings a great deal which is supported by the findings from the InSAR research (Akcin et al., 2006).

## CONCLUSIONS AND SUGGESTIONS

The ground movements occurring due to underground coal mining can bring out crucial issues in terms of technical, economical, legal and social standings in coal basins. The mine production in overlapping coal seam

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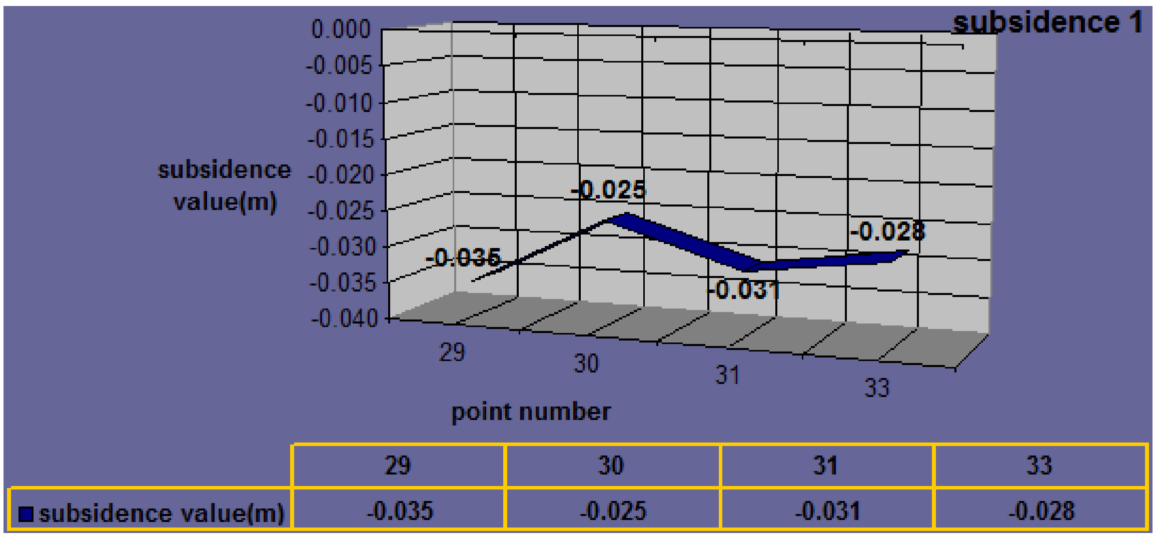
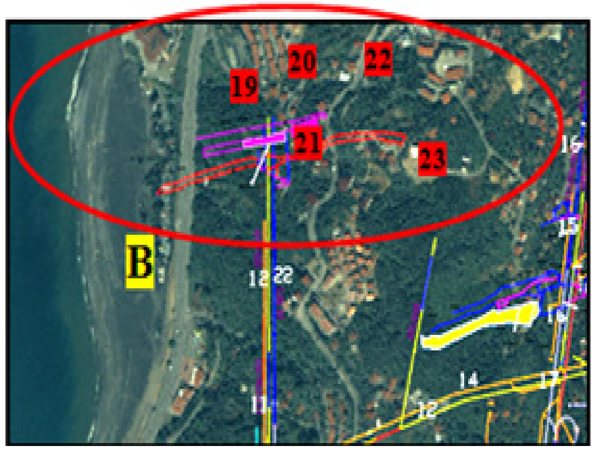



**Figure 9a**. Satellite imagery of region A containing leveling points in the hard coal basin. (b) Height differences from leveling measurements in region A.

layers is found to increase multiple subsidence effects in the basin. Any measure taken to protect existing structures and to design subsidence resistant new structures will not be economically feasible but will save lives. In view of this, it is almost obligatory to reduce the problems resulting from subsidence in the hard coal mining basin by introducing legislative and administrative arrangements. In this scope, the effective arrangements should be brought to life in the following issues:

1. Determining the settlement areas with short or long term coal production plans by assessing the economic, social and legal aspects of the issue, or opting to preserve the settlement areas by not allowing coal production;
2. Not issuing new building permits in coal production regions;
3. Allowing private land ownerships with the introduction of new zoning plans in densely populated areas by designating regions for settlement without coal reserve underneath or subsidence effects in comply with mining plans, and updating these plans annually;
4. Developing new housing estates in near surrounding, also declaring incentives for new employment investments and providing infrastructure for these estates;
5. Accounting for future coal production and urbanization plans in land selection for public amenities such as hospitals, schools, roads etc. which will encourage settlement;
6. Classifying subsidence regions using subsidence estimation methods according to magnitude of movements, and then putting proper protection measures into effect by preparing new construction specifications;
7. Monitoring important structures on the surface which may undergo subversive subsidence effect;
8. Promoting to construct small dwellings of light nature such as wood or prefabricated materials, since they are easily repaired and are not much affected by subsidence;

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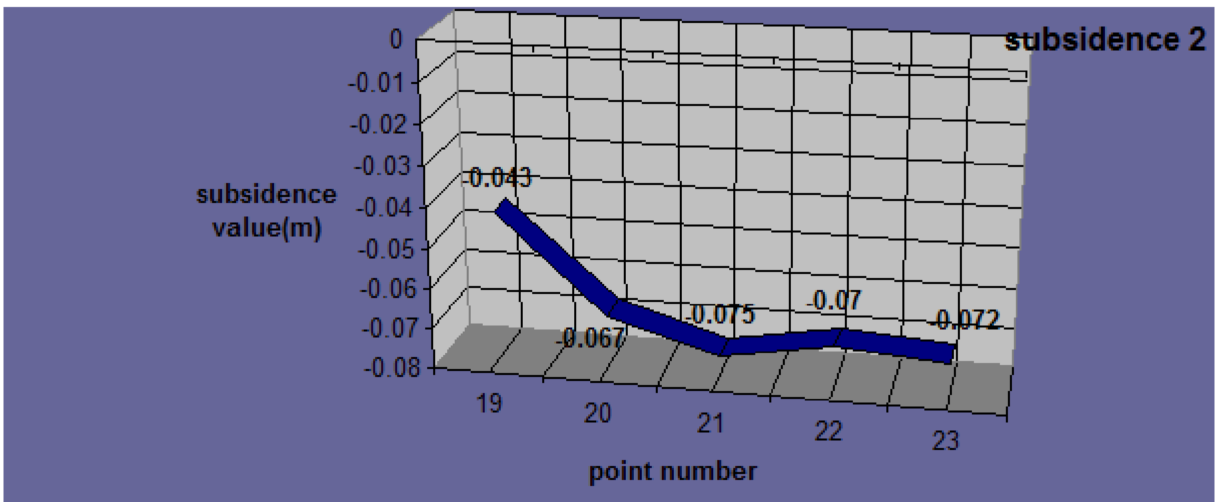


| | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|
| subsidence (m) | -0.043 | -0.067 | -0.075 | -0.07 | -0.072 |

**Figure 10a.** Satellite imagery of region B containing leveling points in the hard coal basin. (b) Height differences from leveling measurements in region B.

9. Establishing common sense and awareness among municipalities against subsidence induced damages;
10. Investigating and monitoring the subsidence phenomenon thoroughly and closely;
11. Measuring periodically for subsidence and determining the parameters of subsidence formation mechanism in the basin using geodetic positioning methods both terrestrial and space-born, and satellite-based imaging systems such as InSAR and remote sensing.

Furthermore, an authorized committee should be established to maintain coordination among interested parties, in order to investigate the issue. This committee should lead the way to prepare legislation to prevent future devastating effects of subsidence to city’s way of life.

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