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Environmental problems in a coal mining area affected by coal fires

——A case study in Ruqigou Coalfield, Ningxia, China*

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Abstract—Ruqigou Coalfield, being one of the most important coal mining areas in China, has suffered coal fire problems for more than one hundred years. Due to coal fires, about 4.513 million tons coal resources has been lost each year, and apart from a large volume of CO_2 delivered into air, environmental problems such as land degradation, land pollution and air pollution are also produced. Air pollution, as one related to coal fires, is the most dangerous problems for local people and has already led to vegetation pollution in this area. Land degradation is mainly induced with occurrence of land subsidence, fissures with due to coal mining/coal fires, and debris slide/flow. With development of opencast coal mining, a large volume of waste was produced, which is the major source of land pollution. All these environmental problems are associated with coal mining or coal fires and their comprehensive effects are deterioration of environment.

Keywords: Ruqigou Coalfield, coal mining, coal fire, environmental problems, land degradation.

1 Introduction

As one of the most important sources for power generation, coal mining industry is still increasing with population growth and economical development in China. Each year, large volumes of high quality coal are exported to various countries for power generation. However, even larger volumes of coal, estimated to be 5—10 times more than the exported volume, are annually lost due to coal fires in China. Spontaneous coal combustion has been found using remote sensing data in 104 coal fields in northern China. They are mainly distributed along latitude N35° from 74°E to 135°E in longitude. In the 11 provinces of northern China, total area affected by coal fires is about 719.51 km^2 and annual loss of coal resource is about 12.48 million tons(Kang, 1997).

Coal fires occurring in northern China not only lead to huge economical losses but also bring about many environmental problems. The most important environmental problem is enormous amount of CO_2 delivered to atmosphere. The yearly volume of CO_2 exhausted due to coal fires in China is estimated to be in order of 2%—3% of the total fossil fuel CO_2 production in the world (Rozeman, 1993). Environmental problems, such as CO_2 exhaust, land degradation, land pollution and environmental pollution(air pollution and water pollution), have been becoming more serious with development of coal mining in northern China. As one of major coal fire places in northwestern China, Ruqigou coalfield has received much attention from Chinese government. Some projects have been carried out to study characteristics and mechanisms of coal fires, as well as the environmental problems induced by coal mining and coal fires.

2 Study area

2.1 Location of the study area

The study area is located in the northern part of the Helan Mountains, 100 km from Yinchuan

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City, capital of Ningxia Huizu Autonomous Region, China(Fig. 1). It extends from 106°02′54″E to 106°11′23″E in longitude and 39°00′52″N to 39°08′10″N in latitude, covering about 2.6×10^5 km^2. Altitude varies from 1800 to 2400 m above sea level and surface has been dissected greatly. From geological view-point, the study area is an asymmetric coal-bearing syncline, and the axis of the syncline goes along NE15° in northern section and changes into NE45° in southern section. The eastern limb of the syncline is characterized by a gentle bedding plane with a dip angle of 8—12°. A steep bedding plane with a dip angle of 20—35° is normally developed in western limb.

The pronounced characteristic of lithological setting is interbedding of hard rocks(sandstone) and soft rocks(shale, mudstone, siltstone and coal layer). Soft rocks are easily weathered and eroded away due to their weakness, and hard rocks are usually left as scarps due to their high resistibility. There are totally seven coal seams developed in the study area, which outcrop at both limbs of the syncline and are covered by overburden with a changing thickness from 60 to 120 m in central part.

2.2 Climated

The study area is situated in dry continental climate zone, where maximum annual precipitation recorded is about 238 mm while maximum annual potential evaporation reaches 2720 mm. The rainfall deficit leads to water shortage both in surface and in sub-surface. Water used for local people's daily life has to be transported from outside the Helan Mountains. Temperature varies annually between − 31℃ and 35℃ and is normally below freezing point from late September to mid-April with maximum depth of frozen topsoil in 1.2 m. North-western winds prevail and strong

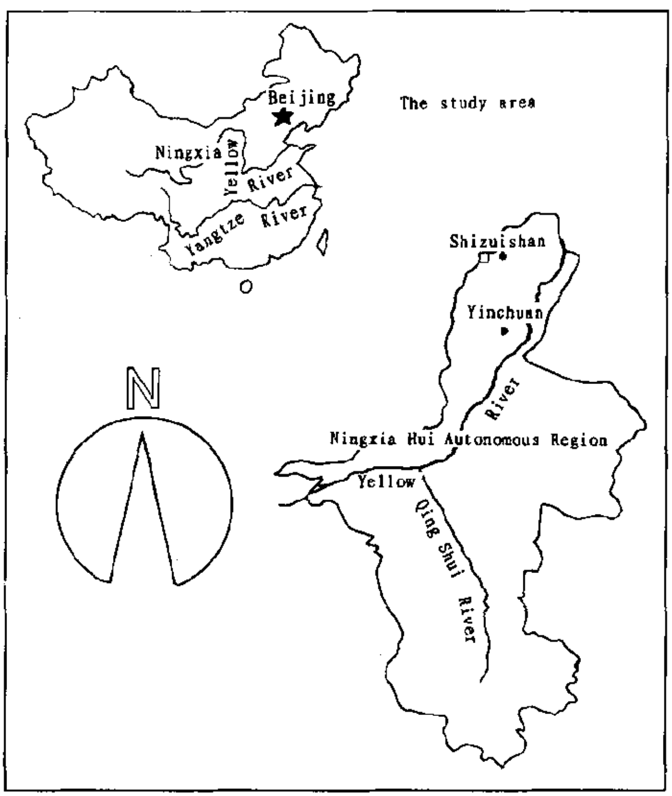

Fig. 1 Location of the study area in China

gales happen occasionally. Dry climate offers a favorable condition for coal fire formation and adverse conditions for vegetation growth.

2.3 Land cover

Owing to semi arid conditions and extensive coal mining, only small part of this area is covered by vegetation. The most common vegetation observed is sparse grasslands which are mostly distributed in flat areas and are often used for sheep grazing. Shrubs grow in some concave places on hillslopes or in valley bottom and crops cultivated by local people are restricted to lower flood plains. Some trees(poplar) are visible in residential regions.

2.4 Coal mining

Coal mining, as the most important human activity in this area, was started about one hundred years ago and was usually in the hands of private entrepreneurs at early stage. Often with limited means, mining operations were confined along outcrop regions and shallow coal seam area. Impacts of coal mining on environment in early stages were limited. Extensive official coal mining was started in the 1960's and expand fast within last decade. However, because of high accessibility of coal seams, small private pits are still playing a vital role. Apart from three state-controlled coal mining areas, there are many small private coal mines which spread over the whole study area. Due to differences in depth and situation of coal seams, some different coal extraction methods have been employed, which result in quite different environmental problems.

Opencast mining is mainly used in those places where coal seams are shallow and bedding planes are flat to gentle, by which a large amount of overburden has to be removed from above coal seam and a lot of waste will be produced. In this area, two opencast coal mining methods are used. The first one is to remove the overburden above the coal seam completely and second one is to remove the overburden partially which usually takes place under steep scarps. Apart from mine dumps, rockfalls and air pollution are also produced by these opencast coal mining methods.

Underground coal mining is widespread and is usually employed in a deep coal seam area. More than half of the study area has been affected by underground coal mining. Besides the large official coal mines, underground coal mining methods are also used in many local private coal mines. Land subsidence, as one of major environmental problems generated by underground coal mining, primarily result from the large official underground coal mining where extracted volumes of coal are much higher than in private coal mining areas.

2.5 Coal transport

Generally, there are two major means used for coal transport: railways and road. The capacity of railway transportation in this areas is limited and it is only used for large official coal mines. For most small private coal mines, the mined coal has to be transported by road which can cause air pollution produced by fly-ash and serious environmental pollution during rainy seasons.

3 Methodology and materials

3.1 Methodology

Having a full understanding of environmental problems in coal mining area, an integrated approach of field survey and aerophoto interpretation was employed. Before field survey was carried out, data collection and analysis had been taken. The major objective of this stage was to collect relevant data and to familiarize with the study area. Fortunately, quite new aerial photography (made in 1994) are available, which are helpful for making an assessment on environment problems. Based on interpretation of the aerial photographs, general characteristics of coal mining and coal fires are derived and some ecological hazards related to coal mining and coal fires are identified.

After interpretation of the aerial photographs, a field survey was carried out in August 1996, which lasted for 4 weeks. In this period, besides checking interpretation, distribution and characteristics of some environmental problems have been mapped out on a large scale topo-map(1:5000). In particular, some measurements on fissures and land subsidence are executed. Some adverse effects of these environmental problems, for example, land degradation, land pollution and coal fires are investigated and their impacts on human health and vegetation are monitored. As environmental problems associated with coal fires, air pollution and water pollution sometimes can be sensed from smell in field, however, their seriousness can only be detected through monitoring and measurement. Assessment on these two problems is mainly based on some measurements made by BRSC(Beijing Remote Sensing Cooperation, 1995).

3.2 Materials

For successfully carrying out the field work and environmental assessment, following data are used: (1) 1:5000 scale topo-map, which is used as a base map for mapping main environmental problems during field work; (2) 1:25000 scale topo-map; (3) colour infrared aerial photographs of scale 1:10000(taken in 1994), are mainly used to identify environmental problems before field work and delineation of their location.

In addition to the above data, some literatures are used to study characteristics of environmental pollution.

4 Environmental problems in the study area

Environmental problems affecting the study area are closely related to the rapid expansion of coal mining, they are: coal fires, land degradation, land pollution and environmental pollution. These problems not only bring some troubles for coal mining, but also produce some adverse effects on human life.

4.1 Coal fires

Coal fires originate at the interface of coal seams and atmosphere, both by natural and man-induced circumstances(Rozema, 1993). The dry and warm conditions of the study area provide a favorable circumstance for coal formation, and other conditions which favor coal fires are presence of faults, joints and fissures, which allow supply of oxygen to coal seams and transport of gases to surface. Various classifications are proposed for describing coal fires. In this study area, extinct, dormant and active coal fires are mainly identified based on the state of coal fires. Usually cracks are observed on surface and H_2S, CO, SO_2 heat fluxes and smoke are visible/felt in crack areas.

4.1.1 Characteristics and formation of coal fires

Except for some natural factors, human factors initiating coal fires are mostly associated with small private coal pits. Once coal fire occurs, it spreads faster along strike than along dip direction due to air diminishing with depth increase. Underground coal fires can result in cracks on surface which in turn help the coal fire to advance further. Also, it has been found that coal fires extend faster in bare bedrock areas than in those areas covered by loose materials, which is probably ascribed to that loose materials make cracks filled and isolate the coal fire from air.

Coal fires occurring in this area are mainly distributed at the edge of the syncline which are probably related to depth of the coal seam. Up to now, more than 20 spots have been found with fire and from initiation date of the coal fires, it was found that coal fires expand rapidly since extensive coal mining in the 1960s(Table 1). This is because of the disruption of original situation with coal mining, which makes more coal exposed to air. Among the coal fires identified, most of them are still burning or in a dormant state except for a few extinct places. Total area affected by the coal fires reaches 2.32 km^2, and around 4.513 million tons coal resource is lost each year.

Table 1 Coal fires initiated within different periods(based on BRSC, 1995)

Period	Before 1900	1900—1960	1960—1970	1970—1980	1980—1990	1990—1995
Number of coal fires initiated	6	2	3	2	4	5
Coal fire areas identified, 10^6 m^2	–	–	1.661	–	2.21	2.32
Loss of coal resource estimated, 10^6 tons	–	–	2.146	–	–	4.513

4.1.2 Potential impact of coal fires

The direct result of coal fires could be formation of burnt rocks which will lead to vegetation withering and landscape degradation. With burning of underground coal seams, coal voids may be formed which will result in surface subsidence. The subsidence induced by coal fires is commonly restricted to large coal fire areas, however sometimes, rather large subsidence can be observed at coal mined areas due to burning of the left coal pillars. This could be a combined effect of coal fires and coal mining. As one consequence of coal fires, fissures are widespread in this area, and often follow pre-existing discontinuities. Occurrence of cracks may to a great extent promote coal fires to extend outwards.

Coal fires can also be a triggering factor for rockfall which usually takes place under scarps. Under influence of coal fires, rockmass become more disintegrated which is prone to fall down in scarp areas.

Due to coal fires, a large volume of harmful gases, such as H_2S, SO_2 and CO is delivered into air, which causes air pollution in this area. Additionally, water pollution can be induced with land deterioration(mass movement) and air pollution (acid rain etc.).

4.2 Land degradation

Land degradation in the study area mainly results from following geological hazards:

Subsidence and fissures: Subsidence is a vertical movement of earth surface due to underground extraction (Singh, 1991). Most subsidence areas in this area are related to underground coal mining and their characteristics are largely dependent on overburden thickness, overburden strength, overburden structure, the size of coal mined area and the volume of coal mined(Mozumdar, 1991; Prasad, 1991). Except for underground coal mining, underground coal fires can also result in surface subsidence. Based on field survey, about twelve areas, around 2.12 km^2 have been obviously affected by subsidence and more areas are affected by fissures.

Fissure, as the most pronounced phenomenon in coal mining area, can be a result of both underground coal mining and underground coal fires. Extendence and width of fissures in this area varied. Length of fissure changes from several meters to more 200 m due to underground coal mining and width of the fissures are normally ranging from several centimeters to less than ten meters. The fissures associated with coal mining have a large size compared with the fissures induced by underground coal fires.

Due to subsidence and fissure, earth surface is greatly disrupted and soil texture is changed, which result in reduction of water-capacity of soil. With occurrence of subsidence and fissure, land desertification or degradation appear and poor land cover is obsered in many subsidence areas.

Rockfall: In term of geological hazards, a fall is a free movement of materials away from steep slopes such as cliffs. Based on the materials detached, falls are divided further into rockfalls, debris falls and soil falls. A steep slope in topography and a well-developed joint system constitute major determinants for rockfall. Rockfall is highly liable under action of gravity under such geological background of the study area.

For the above mentioned reasons, rockfalls occur widely in the study area. It can be a consequence of one of following processes: weathering, coal mining, coal fires and some human activities. Rockfalls resulting from coal mining are easy to be identified based on morphological features and land cover. They are produced either by opencast coal mining under scarp or underground coal mining due to subsidence. In coal fire area, underground coal burning make joints open and rockmass disintegrated, which makes the rockmass prone to fall down along joint planes. These rockfalls are mainly observed at some large coal fire areas.

Whether they are induced by weathering, by coal mining, or by coal fires, rockfalls often directly destroy original land-cover. Due to limited rainfall in this area, vegetation is more difficult to recover after being destroyed, thus a low coverage of vegetation is commonly observed in rockfall-prone area. Like land subsidence and fissure, rockfalls contribute to land degradation.

Debris slide and debris flow: Debris slides are failures of unconsolidated material that break up into smaller and smaller parts as slide advances downslope(Varnes, 1984). The materials involved are mostly colluvium and weathered portions of densely fractured rock masses. In this area, debris slides are observed in many places, one of which is large waste piles which is susceptible due to steep slope and low shear strong of loose materials. Road cutting and land subsidence can undermine slope, which makes loose materials on slope surface subject to debris slide.

Occurrence of slides has given rise to land degradation by destroying original land cover. Debris slides occurred at dump area are prone to initiate debris flow during rainstorm seasons, which is highly dangerous for local people due to its high velocity and unpredictability. Such ones, which occurred in this area in 1992, had claimed 10 lives and resulted in a lot of damage on buildings(BRSC, 1995).

4.3 Land pollution

With expansion of opencast coal mining, a large volume of waste has been produced and many areas are occupied as mine dump which form land pollution. Mine dumps could be the most unrecognized but still the most dangerous of the environmental problems in the study area, and their formation is ascribed to removal of overburden from above coal seams by opencast mining. The complete opencast coal mining has produced much more waste, compared with the partial coal mining method under scarp. Based on field survey, around 5.2×10^4 km^2, 17.04% of total study area has been affected by mine dumps.

Those mine dumps are mainly composed of loose materials from opencast mining. They are usually tipped locally on sites close to mines or lower places forming some conical waste piles that consist of a flat top and a very steep side-slope. The side-slope, controlled by loose materials, can reach 70 degrees in slope steepness that is vulnerable to debris slides/flow.

Since most mining wastes are piled at lower places, such as valley bottom, alluvial terraces and flood plains, the study area is at a high risk of debris flows during rainstorm seasons. Many areas have been affected by mine dumps, however, no any reclamation measures are adopted to this area up to now. With development of coal mining, a large amount of dumps could be further produced.

Thus many lands have to be occupied for accommodating mining waste. Due to special nature of the waste, the mine dump area is hard to be planted before some technical treatments are made. The direct consequence of tipping mine waste is land deterioration and dispoil, and reclamation of the dispelled land are becoming urgent problems for local people.

Widespread mine dumps are also a potential source of air pollution and water pollution. During rainy season, it is common to find coal dust polluted water both in river channels and on ground, which are mostly related to mine dumps.

4.4 Environmental pollution

4.4.1 Air pollution

In this area, air pollution concerns two aspects: increase of floating dust and increase of harmful gases. Floating dust is mainly caused by blasting, waste tipping and road transport of coal. Gases emitted from coal fires, such as H_2S, SO_2 and CO, are the principal culprit for increase of harmful gases in air. A monitoring of principal gases has been carried out in the study area in 1994 (Fig. 2), which reveals that coal fire released much more harmful gases, and poses strong influence on air quality, and gas H_2S emitting from coal fires, is the conspicuous one which exceeds normal range. This is dependent on chemical composition of coal.

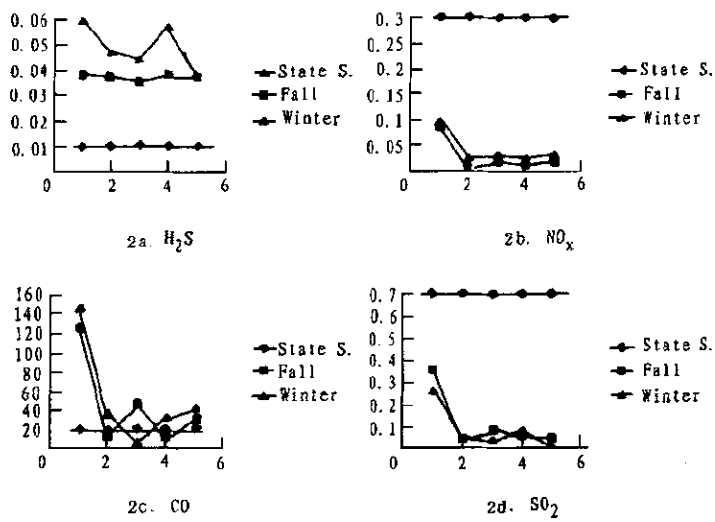

Fig. 2 Air pollution in the study area

The number of 1 5 in X axis from left to right represents respectively different investigation sites: 1. Sample in coal fire area I; 2. sample close to cracks in coal fire area II; 3. sample 20 m far from crack in coal area II; 4. sample 50m far from crack in coal fire area II; 5. sample in residential area. The state S means the normal range for each pollutant based on state standard

4.4.2 Water pollution

Water pollution will be induced when volume of pollutants in water is larger than self-purification capacity of the water body in a given region. Since self-purification capacity depends on volume of water body and water circulation rate, the rainfall deficit in this area makes water bodies more vulnerable to be polluted.

Waste water is mainly from two sources: daily life and underground coal mines. In the waste water discharged from coal mines, biological oxygen dissolution, chemical oxygen dissolution and suspended solid particles are main items which surmount the upper limit and other monitoring items are within normal range. Some measurements made in this area have shown that in the water for daily life, content of nitrogen at ammonia specification, total number of bacteria, content of copper ion and chemical oxygen dissolution exceed the upper limit regarding to state standard; in the drinking water, only content of nitrogen at ammonia specification exceeds the upper limit.

Apart from the above factors, surface run-off going by dump areas during rainy seasons is another important source of water pollution. With increase of coal mining and improvement of daily life, more and more waste water will be discharged, which will produce a strong impact on water resource.

4.4.3 Potential impact

Air pollution is the most serious problems for local people. Unlike other environmental problems which can be avoided through studying their formation and characteristics, the polluted air has to be inhaled everyday by local people. Air pollution can lead to lowering of ability on epidemic prevention and increase of catching diseases on respiratory tracts, tuberculosis (TB) and black lung. Some examinations carried out on local people have already shown that the rate of catching above-mentioned diseases is obviously higher than people living in uncontaminated areas (BRSC, 1995). Because of its invisibility and latent effect, it has not been realized as a real problem by local people.

Water pollution can also create some problems for human life. Though most water used for daily life and drinking is from outside this area, crops cultivated in alluvial terrace are usually irrigated using surface or underground water which has been polluted by coal mine waste water, which will lead to crops and vegetables polluted. It is harmful for local people if the polluted crops or vegetables are consumed.

4.4.4 Vegetation

Due to environmental pollution, plants growing in this area have been seriously influenced. Some measurements performed on chemical composition in grass and poplar tree have shown that some elements in plants have already exceeded the normal range(Fig. 3).

Based on monitoring results, it is concluded that coal fires have much more effect on the content of Cu, F and Zn and little effect on Cd, S and Pb in plants. However, for Cd, S, Pb, although the monitoring results are within the normal range, some differences still remained between coal fire sample areas and residential sample area. The content of Cd, S and Pb in vegetation near coal fire areas is usually higher than that in the residential sample areas.

5 Discussion

Based on the above analyses, it was found that environmental problems occurred in the study area are mostly induced by coal mining, as well as by coal fires. Meanwhile, occurrence of environmental problems can bring about some adverse effects on coal mining and coal fires. Their comprehensive effects are environmental deterioration. In northern China, about 719.51 km^2 area are currently executed and about 104 coal mines are affected by coal fires. The environmental problems related to these areas will become more serious with development of coal mining. To study the formation and potential impacts of these problems will be important for environmental protection and conservation in coal mining area of northern China, which could also make a contribution to global change and environmental conservation.

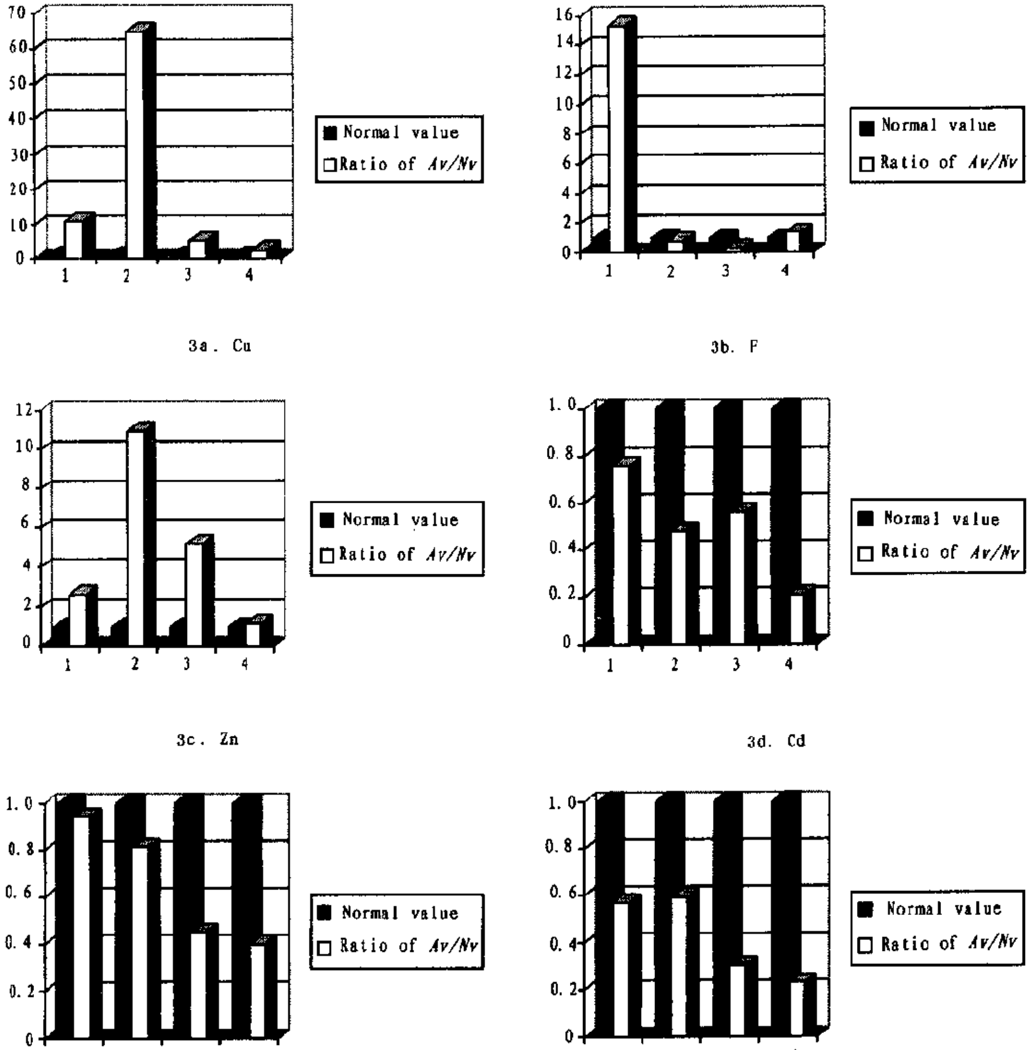

Fig. 3 Monitoring results on element in plants(BRSC, 1995)

The numbers of the X-axis are: 1. grass sample far from coal fire area I; 2. grass sample close to coal fire area I; 3. poplar (tree) sample in residential area I; 4. poplar sample in residential area II. Y-axis with dark box represents the normal range of the element value in plants, which has been changed into relative value "1" and Y column with white colour represents relative value measured in different plants in sample areas(Av/Nv), here, Av is the actual monitoring value; Nv is the theoretical normal values of elements in plants.

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