CHAPTER-IX

SUMMARY AND CONCLUSIONS

The Pabedana coal field is located between lat. 31˚15′ – 31˚31′ and long. 56˚24′ – 56˚35′ and confined to Shemshak, Badamou, Hojedk, Formation of Pabedana region, Kerman province, SE Iran belongs to Upper Triassic to Middle Jurassic Period. Coal extracted from Pabedana mine is transported to Zarand coal washing plant which is located 65 km south of Pabedana coal mine for processing and washing. It lies between 30˚30′30″ to 30˚45′45″ latitude and 56˚15′45″ to 56˚30′30″ longitude covering an area of 235 sq. Km. The study area is located in the central part of the Central-East Iranian Microcontinent (CEIM) and south of Tabas block. Sedimentological and stratigraphical analyses indicate that the Tabas and Lut blocks were mostly covered by the sea during the Jurassic Period, whereas the Yazd Block remained emergent. The Tabas Block is characterised by gentle folded structures and deposition of ~6,000 m of undisturbed sequences of Upper Triassic to Cretaceous limestone, dolostone and shale. Pabedana area is located in Tabas Block and its supracrustal rocks are generally similar to those of other parts of Central Iran, and contain sequences of Neoproterozoic to Middle Triassic sedimentary rocks covered by extensive coal-bearing Upper Triassic to Middle Jurassic sandstone, siltstone and shale. Cretaceous conglomerates, shales and limestones uncomfortably over the older sequences.

Kerman province consists of three formations, namely, Badomu, Hojedk and Shemshak Formations. Pabedana area is made up of quartzose sandstone, siltstone, shale, coal-seam, limestone and calcareous sandstone of Upper Triassic to Lower Middle Jurassic age.

The lithostratigraphic studies reflect the tectano-sedimentary evolution of the Shemshak Foreland Basin. During the early part of Middle Jurassic, rapid subsidence in
the south resulted in the deepening and subsequent infilling of a marine basin. Shemshak Formation is composed of sandstone, siltstone, shale and limestone having thickness varying from 20 to 40 cm at places sandstones reach at thickness of 70 cm. In some places, sandstones are associated with mudstone and siltstone and they show onion skin weathering with loose lime formation.

The Shemshak sandstone member contains 50% to 75% of the quartz grains and substantial amount of lithics, chert and other fragments. Quartz grains are well sorted and polycrystalline quartz grains show strain shadows indicating the effect of deformation of source rocks. Monocrystalline quartz grains quantitatively exceed polycrystalline quartz grains. Higher content of quartz, minor amounts of feldspar and rock fragments and restricted occurrence of heavy minerals such as tourmaline and zircon suggest the partial mineralogical maturity of the sandstones. Most rock fragments are represented by carbonaceous lithics of brown colour. Some cherts are composed of authigenic silica in the form of fine grained quartz. The main types of lithics are slates and polycrystalline quartz grains which display typical metamorphic characteristics such as strong variations in crystal size and intense intercrystalline suturing among quartz crystals (Blatt et al., 1980).

Geochemical studies carried out on lower Jurassic sandstones, shales and limestone of Shemshak Formation of the Kerman province, Central Iran to infer their geochemical characteristics, source rocks, palaeoweathering and tectonic setting of this region have revealed the following:

Sandstones are quartz-rich (~ 67% quartz; ~ 75.34 wt. % SiO₂) and chemical composition indicates that these sandstones are litharenites. Detrital framework composition of the sandstones indicates an average Qt: F: L ratio of 67.25: 2.41: 30.48. Plots of Qt: F: L data on ternary diagram of Dickenson et al., (1983) suggest the derivation
of the detrital components of the sandstones from a recycled orogen. In the provenance
discrimination diagram of Roser and Korsch (1988) the sandstones plot in the quartzose
sedimentary provenance (proximal provenance). Al\textsubscript{2}O\textsubscript{3}/TiO\textsubscript{2}–based provenance
discrimination equation of Hayashi et al., (1997) and plots on Al\textsubscript{2}O\textsubscript{3} wt.% versus TiO\textsubscript{2}
wt.% diagram of McLennan et al., (1980) suggest that the bulk chemical composition of
the quartzose sedimentary provenance is similar to that of granodiorite (ultimate
provenance). Sandstones of the present study are the end product of at least two
sedimentary cycles. Detrital components of the sandstones were derived from quartzose
sedimentary provenance and the detrital material involved in the making of quartzose
sedimentary rocks, in turn were provided by a provenance having the bulk chemical
composition equivalent to that of granodiorite. CIA, PIA and CIW values indicate that the
detrital components of the sandstones witnessed moderate to intense chemical weathering
(degree of chemical weathering = 76-80%) during at least two cycles of source weathering,
fluvial transport, sedimentation and diagenesis. Detrital framework composition
SiO\textsubscript{2}/Al\textsubscript{2}O\textsubscript{3} and K\textsubscript{2}O/Na\textsubscript{2}O ratios of the sandstones indicate low to moderate maturity of
their detrital components in spite of their participation in at least two cycles of
sedimentation. This may be attributed to active uplift of the provenance, rapid erosion of
variously weathered source material, short distance fluvial transport and poor sorting. Plots
on SiO\textsubscript{2} wt.% versus (Al\textsubscript{2}O\textsubscript{3} + K\textsubscript{2}O + Na\textsubscript{2}O) wt.% diagram of Suttner and Dutta (1986)
indicate that the sandstones were deposited under humid climatic conditions. Plots on
major element-based tectonic setting discrimination diagrams of Bhatia (1983) indicate
active continental margin (ACM) setting for the quartzose sedimentary provenance.

Shales of the present study in comparison with PAAS (Post Archaean Australian
Shale) are slightly depleted in TiO\textsubscript{2}, K\textsubscript{2}O, MnO, Cr and Cu and moderately depleted in
MgO, CaO Na\textsubscript{2}O, Co and Ni contents. Depletion of Na\textsubscript{2}O and CaO in the shales relative to
PAAS suggests that either lesser amount of plagioclase detritus in the shales and/or comparatively intense chemical weathering of source rocks. ICV (Index of Chemical Compositional Variation) values indicate presence of higher quantities of clays in shales in comparison with rock forming minerals (e.g., plagioclases, K-feldspars, amphiboles and pyroxenes).

Al$_2$O$_3$/TiO$_2$–based discrimination equation (Hayahi et al., 1997) and plots of the shales on Al$_2$O$_3$ wt.% versus TiO$_2$ wt.% diagram (McLennan et al., 1989), and Cr (ppm) versus Ni (ppm) diagram (Floyd et al., 1989) indicate that felsic (granitic) rocks are the source rocks of the studied shales. Plots of the shales on ternary Al$_2$O$_3$ – (CaO+Na$_2$O+K$_2$O) – (FeO$_T$+MgO) diagram (Hayashi et al., 1997) and Fe$_2$O$_3$ – K$_2$O – Al$_2$O$_3$ diagram (Condie, 1993) also suggest felsic nature of the source rocks. Values of CIA, PIA and CIW range from 84 to 93% and indicate intense weathering of the lithocomponents of the shales during the course of source weathering, fluvial transport, sedimentation and diagenesis. Plots of the shales on the tectonic setting discriminant functions diagram (Bhatia, 1983) indicate active continental margin setting for the provenance. The inferred tectonic setting of the provenance of the sandstones and shales is totally in agreement with the tectonic activity (Cimmerian orogeny) witnessed by the central Iran during Jurassic period.

Pabedana coal is a medium ash coal, with relatively low sulfur content and belongs to subbituminous rank. Pabedana coals generally are comparable in quality with the extensively developed coal deposits in the Alborz region of Northern Iran. Atomic H/C and O/C ratios of Pabedana coal and macroscopic banded aspect of the coal indicate it as humic coal. The coal of the study area is characterized by low ash, low moisture and high volatile matter indicating short distance transportation of the parent plant debris. Sulfur content in coals is an important and characteristic feature and is genetically related to the
mode formation of the coals. The moderately low sulfur content in the Pabedana coals indicates that the coals were formed in fresh water/deltic environment.

Pabedana mines produces primary coking coal. The coal has selectively high vitrinite (59%-64%) moderate inertinite (30%-33%) and low liptinite contents (4%-9%). Petrographic investigations indicate that the Pabedana coal is dominated by terrestrially derived organic debris (vitrinite and liptinite) with low amounts of inertinite. According to the maceral composition of the studied coal samples and the evolution of the type of coal facies in the studied coal seam viz., moderate inertinite (30-33%) and low ash (9.8-12.95%) suggests a low lying marsh with relatively oxidizing open water body and higher detrital influence.

Mineralogical investigations using optical microscope and XRD indicate that the Pabedana coal samples are dominated by carbonates which are mainly represented by ankerite. Ankerite along with pyrite is commonly found as crack fillings in the coals. Illite, kaolinite, muscovite, quartz, feldspar, apatite and hematite are other minerals found to occur as minor or trace phases.

The Pabedana coals are characterized by high contents of Ca, Mg, Mn, Ba and Sr values which in turn reflect the high carbonate and phosphate contents. The high content of epigenetic ankerite mineralization is responsible for the higher Ca, Mg, Fe and Mn contents in coals. Elements Be, Co, Mn, V, Au, Cd, Ta, P, Ca, Al, Fe, Cu, Sr, Y, Rb, U, Na, Mg, K, Sn, Te, Ti, S and Cs exhibit positive correlation with ash yield thus suggesting them to be of inorganic origin. Elements Sc, Cr, Zr, Ga, Ge, La, As, W, Ce, Sb, Nb, Th, Pb, Se, Tl, Bi, Hg, Re, Li, Zn, Mo and Ba show varying negative correlation with ash yield. These elements may be present as primary biological concentrations. Pabedana coals contain low B, Mo and U and low B/Ga and $[(CaO+MgO+Fe_2O_3)/(SiO_2+Al_2O_3)]$
ratios. This data also indicate deltaic environmental depositional condition for the coal formation.

Pabedana coal mine is an underground mine operated by government and at present is administered by a private company. Exploitation of Pabedana coal mine started in 1977 and proven coal reserves are around 41 million tons. Economically extractable seams are designated d2, d4, d5 & d6 and are situated 2400-2505 meters above MSL. Long wall mining method has been adopted at Pabedana for extraction of coal. Pabedana coal mine is an underground mine having 25 stopes. In the Pabedana coal mine, the average coal production is around 174400 tons/year. d2 seam has the maximum of mining stopes and production. For extraction of coal reverse benching method is employed which are having dips more than 40 degrees, whereas longwall mining method is selected for seams with less than 40 degree dip.

In the Pabedana coal mine, where longwall mining method is practiced cutting machines such as oral and temp machines are employed. Oral machine is used for cutting the lower parts of coal seam and Temp machine contains large and strong drill bit which has the ability to rotate and move forward during cutting process of mining stope.

Working cycle of mining stope includes: (1) drilling with hand perforator, (2) detonator operation periodically, (3) explosion of wall face, (4) periodic tunnel ventilation, (5) loosing operation, (6) survey of face wall, (7) loading of load-haul-dump (LHD) loader, (8) installation of metal panels in roof and walls of tunnels, and (9) timber support with wood pillars in between panels.

Equipments used for coal mining include; jackhammer and perforator, temp (cutting coal machine), raise boring machine, jumbo drill, hydraulic Jack, LHD underground loader, wood cutting machines, locomotive charge workshop.
Coal washing processing plant is composed of four main units, including feeding unit, main building, drier building, storage building and loading building. Coal washing unit is housed in Main building where the coal is washed at five stages, viz. (i) Heavy media, (ii) Jig, (iii) Dynawhirlpool, (iv) Spiral and (v) Flotation stages. In these stages coal is washed and separated according to grain size viz., (+18mm), (+0.5-18mm), (+0.15-1mm) and (-0.5mm).

Equipments used for coal washing process include; vibration screen unit, heavy media separator unit, magnetite separator unit, jig separator unit, control jig unit, dynawhirlpool separator unit, spiral separator unit, hydrocyclone, flotation unit and chemical compositions as collector, froth flotation.

In flotation process, air is blown into slurry containing coal and water through the action of the impeller. Small amounts of reagents called frothers, typically alcohol-based compounds, are added to reduce the surface tension of the slurry. With this reduced surface tension and the mixing of the impeller, the air is sheared into small bubbles that attach to the hydrophobic coal particles. The coal-bubble aggregate then floats to the top of the cell where it is removed as froth with a skimmer. To increase the hydrophobicity of the coal, an oil collector is often added that coats the coal particles to enhance the coal-bubble attachment. The refuse minerals do not attach to the air bubbles and remain in the water and exit the cell through the tailings discharge.

Collector has been used in flotation process as a hydrophobe material. In coal flotation, pine oil and diesel oil are used as a collector and co-collector. Bituminous coals with high bituminization rank are floatable in frother whereas flotation of bituminous coals with medium bituminization rank needs non ionic oils (oil fuels) with 0.5-1.5 kg/ton value.

Frothers are utilized in flotation processes to enhance generation of fine bubbles and to stabilize the froth. In Zarand coal washing plant, pine oil (peen evil) is used as a
Coal washing is a process by which impurities such as sulfur, ash, and rock are removed from coal to upgrade its value. During cleaning process, generally 30-50% of pyritic sulfur and approximately 60% of ash-forming minerals (residue left after coal has been burned) will be removed. Zarand coal washing plant produces 4,50,000 tons/year waste materials and most of the waste materials are produced by flotation unit. Waste material produced from coal washing process is pumped to a pond situated 600 m away from the coal washing plant. Final concentrations of processed coal are transported to Efsahan iron melting plant situated 600 km by railway wagons.

Water is the most common medium for transporting crushed material in coal washing plant and hence most coal separations take place within this medium. Perhaps the greatest and the most long-standing problem in coal washery is the disposal of effluents which contains a suspension of fine solids (Bandopadhyay, 1995). The effluents from coal washing processes contain large amounts of suspended and dissolved solids, dirty materials and impurities associated with raw coal and they create serious problems of deterioration of water quality of groundwater into which they are discharged (Ghose 1999). Effluents from coal mine contain high load of TDS, calcium, carbonate and heavy metals hence contaminate the aquatic regime (Dhar et al., 1986).

In the study area, since coal being friable in nature, lot of fines are generated during the washing process which increase the turbidity, total suspended solids (TSS), total dissolved solids (TDS), oil and grease and chemical oxygen demand (COD). In the
effluents from Zarand coal washery these parameters are very high and exceed permissible discharge limit IS: 2490 (1981).

Some elements in coal namely Na, Ca, K and Mg and minor elements like Mn, F, SO₄ and Cl are found to be higher in concentration in discharged water than in raw water indicating that these elements are transferred from coal to the water.

Trace elements such as Cu, Ni, Zn, Pb, Cr, Mn and As are found to be present in the discharged water, besides Fe, which is a major element. Heavy metals like Hg, Cd and Se though found to be present in coal, are absent in the discharged water indicating that these elements are not released from coal while washing and thereby will not cause water pollution. The pH of the process water is found to be higher than the raw water which is due to intense interaction between raw coal and water during coal washery processing. However, it is found to be beyond the stipulated limit of Ministry of Environment and Forest (MOEF) schedule VI of Indian standard.

However, the fluorine in coal samples collected could not be assessed because its content is less than the detectable level. The concentrations of sulphate and chloride are much higher in the discharged water. The increase of these values in the discharged water may be due to minerals and salts present as chlorides and sulphates of the alkali and alkaline earth metals, which readily dissolve in water.

Chemical analyses data of water samples from 30 borewells in the study area (terrain adjacent to a tailings pond of a coal washery near Zarand city, SE Iran) reveals the presence of two clearly distinguishable groundwater zones having chemically differing hydrochemical facies. The Geographic Information System (GIS) has emerged as a powerful tool in analysing and quantifying multivariate aspects of groundwater occurrence. In the present study during the evaluation of groundwater quality GIS has been utilized for processing and interpretation of groundwater quality data. According to GIS techniques the
area is divided two zones (i.e., groundwater zone-A and groundwater zone-B). TDS content in the groundwater collected from 11 bore wells in the southeastern and southern parts of the study area [named as groundwater zone-A] varies from 707 mg/L to 1077 mg/L (av.= 892 mg/L). Groundwater samples from 19 bore wells in the remaining part of the study area [named as groundwater zone-B], consists of significantly higher concentrations of all major ions and its TDS content varies from 1156 mg/L to 2156 mg/L (av.= 1570 mg/L).

Among these two hydrochemical facies of groundwater, groundwater zone-A is least polluted. In the groundwater zone-A, the order of abundance of ions is Na\(^+\)\textgreater\textgreater\textgreater Ca\(^{2+}\)\textgreater\textgreater Mg\(^{2+}\)\textgreater\textgreater K\(^+\) and SO\(_4\)^{2-} \simeq HCO_3^- \textgreater Cl^- . Gibb’s ratios of the groundwater zone-A indicate evaporative concentration of solutes. Concentrations of TDS in the groundwater zone-A are mainly controlled by rock weathering with minor contributions from atmospheric, soil and anthropogenic sources. The high concentrations of (Ca\(^{2+}\) + Mg\(^{2+}\)), low values of \((Ca^{2+} + Mg^{2+})/(Na^+ + K^+)\) equivalent ratio (av.= 1.48) and significant contributions of \((Na^+ + K^+)\) to the total cation content \((Na^+ + K^+/Tz^+) = 0.40\) suggest slight dominance of the ionic contributions from carbonate dissolution over those from silicate weathering. The values of \(HCO_3^-/(HCO_3^- + SO_4^{2-})\) equivalent ratio (av.= 0.50) indicate the involvement of both carbonic and sulfuric acids during carbonate and silicate weathering which together mainly controlled the acquisition of solutes of Ca\(^{2+}\), Mg\(^{2+}\), HCO\(_3\^-\) and SO\(_4\)^{2-}. Negative values of Chloro-Alkaline Indices of the groundwater zone-A indicate ion exchange reactions between groundwater and its host environment during which Ca\(^{2+}\) and Mg\(^{2+}\) of the groundwater zone-A were exchanged with Na\(^+\) and K\(^+\) of the host rocks (Na and K-bearing clays, resulted from the weathering of detrital feldspar-bearing siliciclastic sedimentary rocks). Cl\(^-\) content of the groundwater zone-A was provided by rain water and
possibly also by dry fallout from atmosphere. NO$_3^-$ content of the groundwater zone-A was derived from anthropogenic sources.

Groundwater facies zone-B is consisting of more than the polluted variants groundwater zone-A and its additional ionic load of Ca$^{2+}$, Mg$^{2+}$, K$^+$ and SO$_4^{2-}$ was derived from down-ward percolating of effluents of the coal washery. Groundwater zone-B has also been contaminated with Na$^+$, Cl$^-$, HCO$_3^-$ and NO$_3^-$ and these pollutants were possibly derived from urban sewage, animal waste, agricultural chemicals and other anthropogenic inputs.

Groundwater zone-A and B of the study area, owing to the presence of very high concentrations of TDS, are not suitable for drinking purposes. Suitability of the groundwater for irrigation purposes has been evaluated based on its salinity (EC values), Percent Sodium (%Na), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Kelley’s Ratio, Permeability Index (PI) and Integrated effect of EC and SAR-based U.S.Salinity laboratory diagram. The groundwater zone-A and B of the study area are highly saline and are suitable only to irrigate lands growing high salt (salinity) tolerant crops. Groundwater from 15 bore wells contains low sodium content and hence will not cause sodium hazard to soil. Groundwater from 13 bore wells contains medium sodium content and these water can be used to irrigate farmlands around the downstream side of the Zarand coal washing plant.

Groundwater zone-B, in comparision with groundwater zone-A, consists of higher concentrations of As, Cd, Cu, Fe, Mn, Pb and Zn. In comparision with water from tailings pond, the groundwater zone-B consist of lower concentrations of Mn, Ni and Zn. Thus groundwater zone-B, which has more polluted variants than groundwater zone-A received the excess load of Mn, Ni and Zn from downward percolating effluents from coal washery
and the additional concentrations As, Cd, Cr, Cu and Pb were possibly derived from other anthropogenic sources (e.g., fertilizer, pesticides, urban sewage, waste dumps etc.).

Concentrations of heavy metals (viz., As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in groundwaters zone-A and B are below the permissible limits of drinking water (WHO, 1993). Hence, the concentrations of the above said heavy metals do not prohibit the utilization of the groundwater for drinking purposes. However, other physico-chemical parameters of groundwater of the study area have to be examined before recommending the usage of the water for drinking purposes.

Coal mining is one of the prime industrial sectors which are inadvertently causing environment pollution. Pabedana area with an estimated population of over 1,11,24,000 owes its urban and rural mixed status primarily the existence of very large deposits of coal. Other environmental pollution includes high suspended particulate matters in active mining areas. It also includes devegetation and presence of noxious gases like CO, H₂S in the environment. About 7 sq.Km area is subsided due to underground mining. Suspended particulate matters, SO₂ and NOₓ are found in the range of 193.4 – 1242.5 µg/m³ and 54-76 µg/m³ in mining area of the basin. CO levels are found in the range of 1950-2210 µg/m³ which is partly due to vehicular exhaust from heavy mining equipments.

In the area around coal washery plants (vegetation) are grown well in soils irrigated with coal washery water. The enhanced growth is probably due to nutrients added from washery water. Therefore, disposal of waste water to agricultural sites offers a better alternative than disposal into surface waters as it contributes to the nutrient cycling. Hence, these effluent wastewaters can be used for the restoration of degraded land, and for the growth of certain vegetation having commercial value (e.g., Pistachio).

In study area the main source of air pollution is the methane emissions during the coal production process. Methane is a powerful heat-trapping gas and is the second most
significant contributor to global warming after carbon dioxide. Coal mining world over results in the release of 2 million metric tons of methane per year which is equivalent to 51 million metric tons of carbon dioxide. Methane emissions from Pabedana coal mines makes up between 25 and 35 percent of anthropogenic methane emissions in Iran. All coals contain methane, but the amount depends on the nature of the coal. Pabedana coals have 3 to 7% methane. So it causes problem for inhalation since it is more than 5% (WHO standard). Most of the methane emitted from Pabedana mine escapes through ventilation systems put in place for safety measures or through other shafts and portals. The remainder is released during the handling and processing of the coal after it has been mined. The trains and trucks operated in Pabedana coal mine cause pollution of particulate matter. They produce two types of pollutants: one is the exhaust or fine particles (measuring 2.5 microns) and the other is dust from the road, from fugitive emissions of dirt carried by all trucks. The truck traffic from Pabedana Coal mine to Zarand coal washing plant cause air pollution to the inhabitants all along the transport route.