CHAPTER 6 COMPREHENSIVE ANALYSIS OF CONTAMINATION IN THE PILOT PROJECT AREA

CHAPTER 6 COMPREHENSIVE ANALYSIS OF CONTAMINATION IN THE PILOT PROJECT AREA

6.1 Soil Contaminated Zones in the Pilot Project Area

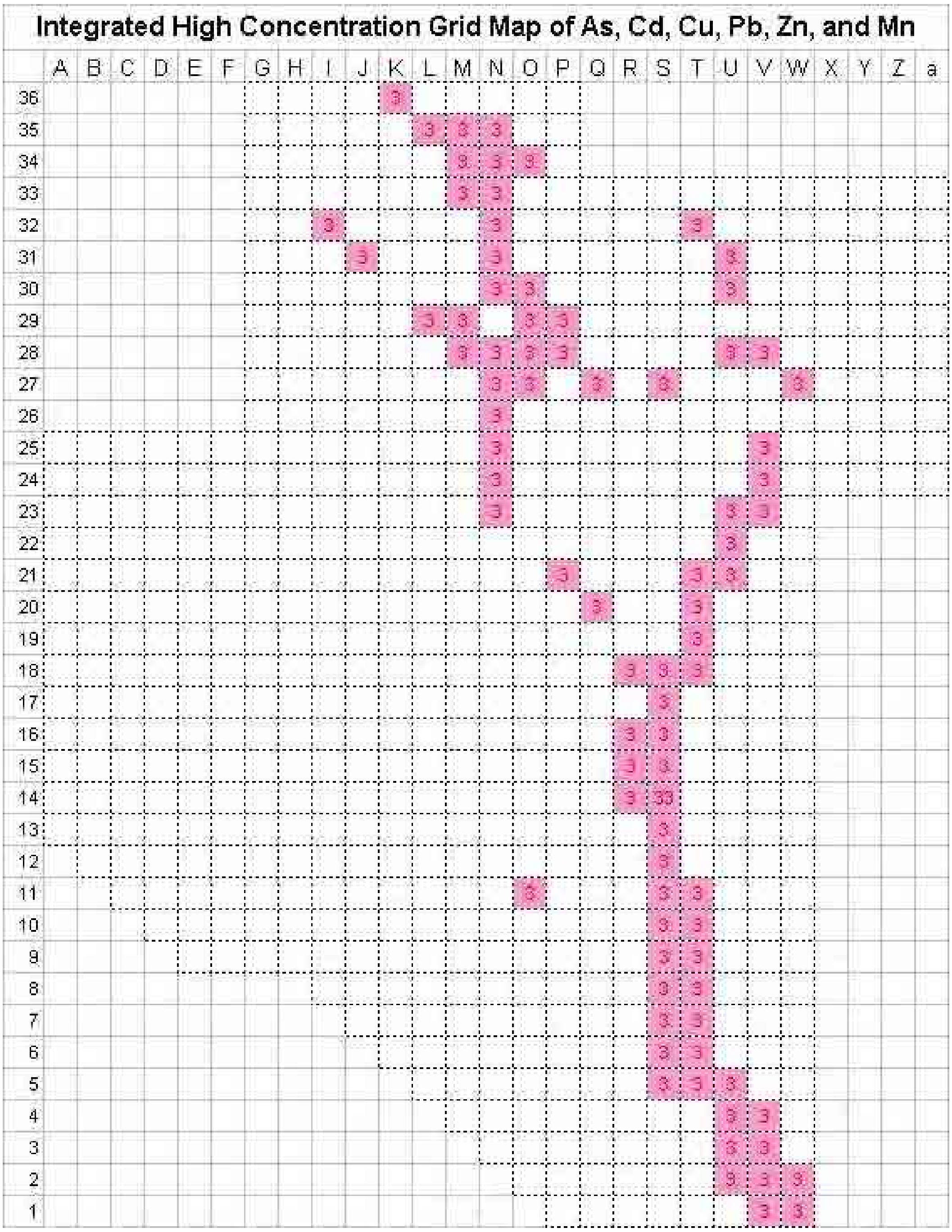
The high concentrations of heavy metals in the Pilot Project (P/P) area can be classified mainly into two groups, namely As-Cd-Cu-Pb-Zn-Mn and Co-Cr-Ni. The As-Cd-Cu-Pb-Zn-Mn Group clearly shows relations to the soil contaminations derived from the spill incident of the tailings dams in 1976, the mining activities of the Zletovo Mine site and Pb-Zn mineralisation locally found in the north eastern part of the area. Therefore, high concentrations of the As-Cd-Cu-Pb-Zn-Mn Group can be attributed to soil contamination by human causes except the high concentrations area in the north eastern part of the area, where high concentration of these heavy metals were caused by Zn-Pb mineralisation. On the other hand, as discussed in Chapter 5, the Co-Cr-Ni Group, especially located in the south western part of the area, is considered to be originated from the sedimentary rocks of the Tertiary formation. Therefore, high concentrations of the Co-Cr-Ni Group were naturally caused and are excluded from further consideration in the study.

The integrated high concentration grid map of heavy metals of As-Cd-Cu-Pb-Zn-Mn (400m grids) is shown in Figure 6.1. Most of the high concentration grids are distributed along the Kiselica, Koritnica and Zletovska Rivers as shown in Figure 6.2 plotted in the topographical map.

The Kiselica River flows to the west side of the Old Tailings Dam and along the New Tailings Dam. The high concentration grids are particularly distributed around the Old Tailings Dam (TD-I) and processing plant, western and southern parts of the tailing dams (TD-II, III, IV and V), around the battery factory, and lower and lowermost (after bridge of the main road) stream of the Kiselica River. The soil contamination extending to the western part of the tailings dams seems to be affected by dust of the tailings materials migrated from tailings dams by wind.

The Koritnica River is flowing from the Zletovo Mine site. Fragments and gravels of ore and mineralised rocks containing much Pb and Zn ore minerals are found in the bottom sediments along the river. Although some of the contaminated fragments and gravels might be derived from natural causes, most of them are likely to have occurred by mining activities. The contaminated sediments are also flowing from the Koritnica River into the Zletovska River.

The soil contamination zone along the Zletovska River after the junction of the Kiselica River becomes much wider and longer, because contaminated sediments derived from the Koritnica and Kiselica Rivers are mixed together, especially along the small stream like irrigation canal in parallel with the Zletovska River as shown in Figure 6.2.



400m grid soil survey area and grids

3 High heavy metal concentration grid with more than one heavy metal among six (As-Cd-Cu-Pb-Zn-Mn) exceeding the threshold value of the 400m grid soil survey

Figure 6.1 Integrated High Concentration Grid Map of Heavy Metals
(Soil contamination by As-Cd-Cu-Pb-Zn-Mn)

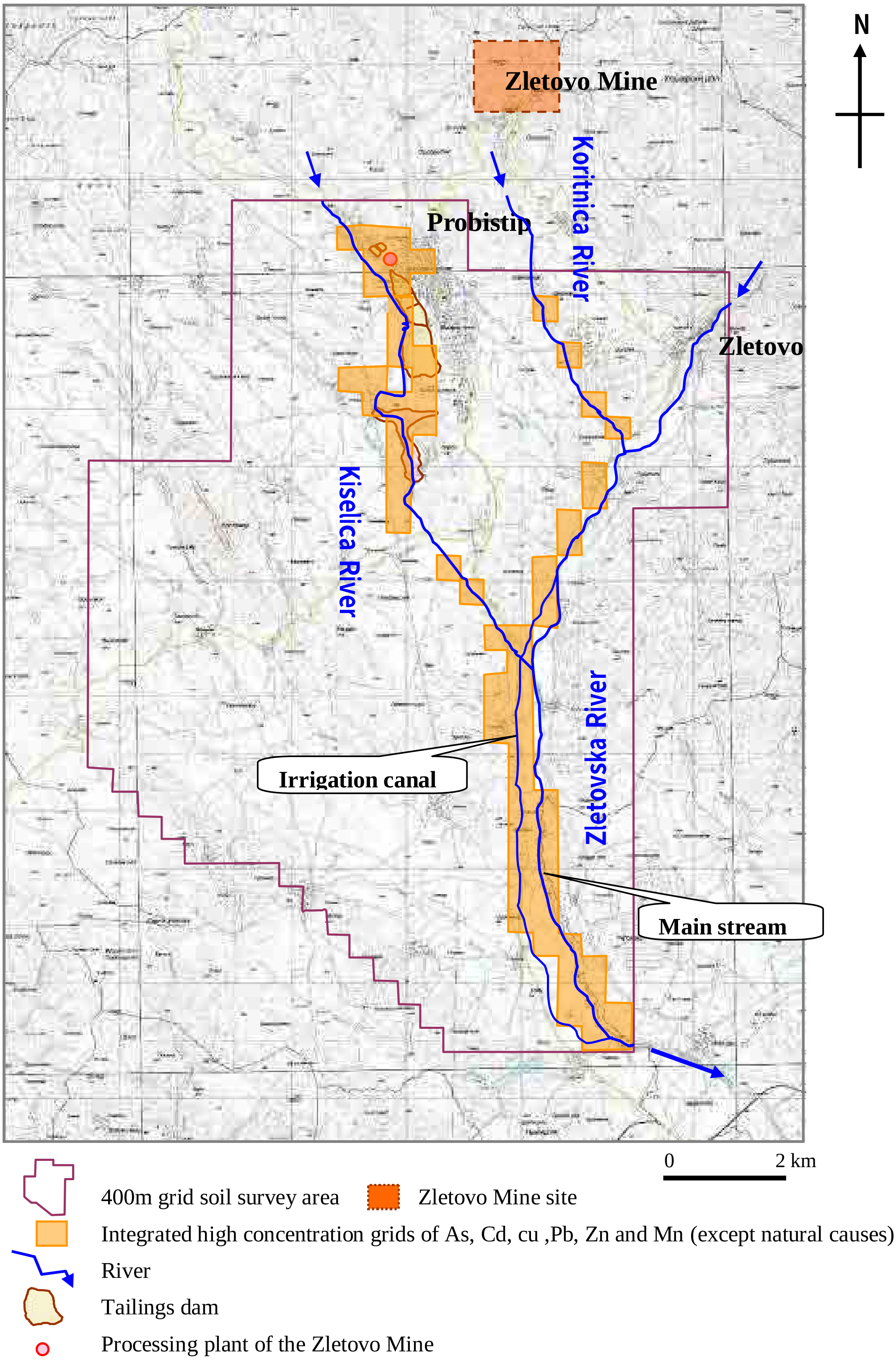


Figure 6.2 Distribution of Heavy Metals on the Surface Soil in the P/P Area
(Concentration of 400m surface soil)

6.2 Contamination of Surface Water and River Bottom Sediments in the Pilot Project Area

The surface water of the Kiselica River is characterized by high concentrations of Zn and Mn. In particular, the uppermost stream (SW-06) of the river (Figure 6.3) is marked by high Pb and Zn concentrations and middle stream (SW-05) of the Kiselica River shows also the highest concentrations of Zn and Mn, and it appears to be affected by the tailings dams.

The surface water of the uppermost stream (SW-03) of the Zletovska River is clean, all measured concentrations of heavy metals being less than the standards for water quality. However, after the junction with the Kiselica River, the concentrations of Mn increase and exceed the standard for water quality, because contaminated water of the Kiselica River flows into the Zletovska River and contaminated water is likely to be eluted from river bottom sediments around the junction of the Kiselica River (Figure 6.3).

On the other hand, the river bottom sediments of all locations in the area contain much Pb, Zn, and As, and, in particular, the samples of the lower stream of the Kiselica River show very high contents of Pb and Zn. According to the results of field investigation and drilling survey, tailings materials and/or weathered (oxidised) tailings are widely found in the lower stream of the Kiselica River and western side of the middle stream of the Zletovska River. Therefore, much old tailings, including also recent tailings, are still remaining around the junction of the two rivers (Figure 6.3) and they became the secondary contamination sources of soil and water.

6.3 Groundwater Contamination in the Pilot Project Area

6.3.1 Monitoring Well and Surface Water

Most of groundwater along the Kiselica and Zletovska Rivers is contaminated by Zn, Mn and Pb, and the groundwater of MBH03 (Zletovska River) well contains Cd and Cu exceeding the Water Quality Standard (0.01mg/L). In particular, groundwater contamination at the middle stream of the Zletovska River has a close relation with the remaining old tailings on the river bottom. Therefore, the high concentrations of heavy metals including Zn, Mn, Pb, Cu and Cd are possibly attributed to elution from the remaining old tailings materials and they are contaminating the groundwater as well as surface water.

In addition, the groundwater of MBH07 well, located at the upper stream of the Kiselica River and west of the New Tailings Dam, contains high concentrations of Mn and Zn. It is possible that new tailings still continue to flow out from the Old Tailings Dams through the new canal, and contaminated groundwater is also flowing into the downstream (Figure 6.4).

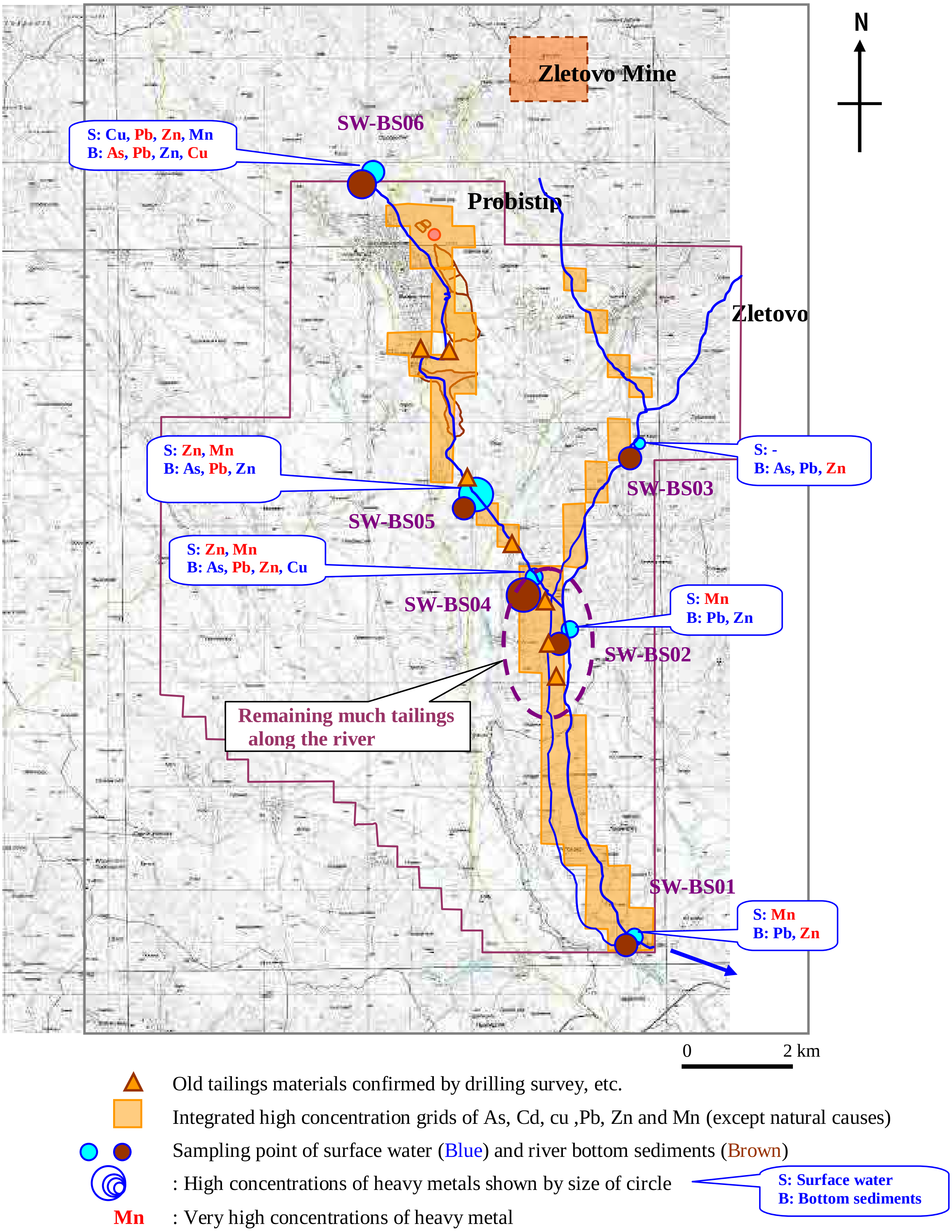


Figure 6.3 Distribution of Tailings and Heavy Metals on the Surface in the P/P Area
(Concentration of 400m surface soil, surface water and river bottom sediments)

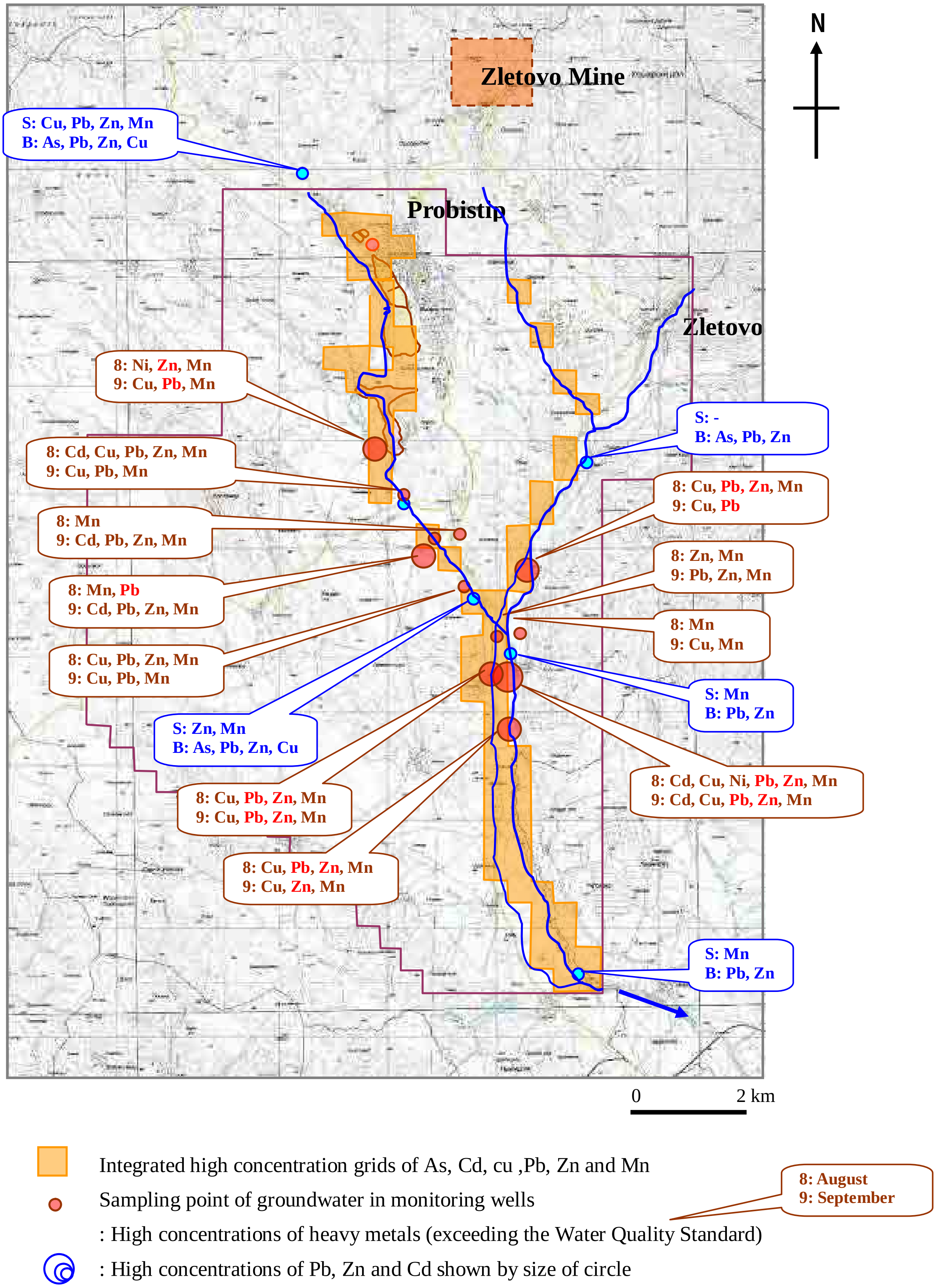


Figure 6.4 Distribution of Heavy Metals in the Groundwater in the P/P Area

(Concentration of 400m surface soil, surface water and River bottom sediments)

The Tailings Dam is one of the sources of contamination. For understanding the effect of dissolving components from the Tailings Dam to surface water and groundwater (monitoring well), the results of the elution analysis of the tailings samples and heavy metal concentrations of groundwater and surface water were considered.

Based on the results of elution analysis of the tailings, four components of Cd, Pb, Zn and Mn were selected for the further consideration, since they are the heavy metals characterizing the tailings materials with high concentrations. Because these four heavy metals show good correlations as shown in Table 6.1, the ratios of Pb/Zn, Zn/Mn and Cd/Mn are used for consideration. Table 6.2 shows Pb/Zn, Zn/Mn and Cd/Mn ratios of the tailings, surface water and groundwater.

Table 6.1 Correlation Coefficients of Elution Values of the Tailings

Correlation Coefficient	Cd	Pb	Zn	Mn
Cd	1			
Pb	0.740	1		
Zn	0.977	0.808	1	
Mn	0.956	0.599	0.914	1

Table 6.2 Pb/Zn, Zn/Mn and Cd/Zn Ratios of the Tailings, Surface Water and Groundwater

Sample No.	Location	Pb/Zn	Zn/Mn	Cd/Zn*100
Old Tailings Core Samples	Upper part of Kiselica R.	0.038	0.17	0.79
New Tailings Core Samples	Middle part of Kiselica R.	0.11	0.04	1.64
SW01	Lower part of Zletovska R.	0.07	0.15	0
SW02	Middle part of Zletovska R.	0.13	0.18	0
SW03	Upper part of Zletovska R.	2.00	0.07	0
SW04	Lower part of Kiselica R.	0.00	0.13	0
SW05	Middle part of Kiselica R.	0.02	0.06	0
SW06	Upper part of Kiselica R.	0.02	0.48	0
MBH01	Upper part of Zletovska R.	0.44	0.20	0.04
MBH02	Upper part of Zletovska R.	1.00	0.11	0.04
MBH03	Middle part of Zletovska R.	0.03	0.26	1.84
MBH04	Middle part of Zletovska R.	0.13	0.02	0.01
MBH05	Middle part of Zletovska R.	0.73	0.84	0.01
MBH06	Lower part of Zletovska R.	0.18	0.88	0.02
MBH07	Upper part of Kiselica R.	0.22	0.02	0.01
MBH08	Upper part of Kiselica R.	0.58	0.11	0.04
MBH09	Middle part of Kiselica R.	1.19	0.02	0.02
MBH10	Middle part of Kiselica R.	0.80	0.05	0.01
MBH11	Middle part of Kiselica R.	0.16	0.21	0.01
MBH12	Lower part of Kiselica R.	1.24	0.21	0.01

* Average values were used for the tailings

The following are the chemical characteristics of elution values of the tailings, surface water and groundwater.

(1) Tailings

The tailings of the Old Tailings Dam show lower Pb/Zn and Cd/Zn and higher Zn/Mn compared with those of the New Tailings Dam. Consequently, the elution values of the Old Tailings Dam show relatively lower Pb and Cd, and higher Zn compared with those of the New Tailings.

(2) Surface Water

The surface water of the Zletovska River shows relatively higher Pb/Zn and Zn/Mn, and Cd values are lower than the detection limit. The enrichment of Zn at the SW02, located near the mouth of the Kiselica River, can be attributed to the dissolution of Mn from the secondary deposits of the tailings occurring at that location. The surface water of the Kiselica River shows relatively low Pb/Zn. Zn/Mn is relatively high in the upper stream area and becomes lower in the lower stream area. The tendency of the higher Zn and lower Pb in the upper stream area can be explained by dissolution of heavy metals from the Tailings Dams.

(3) Groundwater

The groundwater along the Zletovska River shows higher Pb/Zn in the upper stream area. The groundwater seems to be diluted in the lower stream area. It seems to be enriched in the middle stream area because of dissolution of heavy metals from the secondary deposits of the Tailings. The increase of Zn/Mn toward lower stream with abrupt increase in the middle stream area is attributed to the enrichment of heavy metals by the secondary deposits of tailings. The Cd/Zn is very low along the Zletovska River with an exception of a very high (1.84) point in the middle stream area. This is also explained by dissolution of heavy metals from the secondary deposits of the tailings. The groundwater along the Kiselica River shows lower Pb/Zn and Zn/Mn in the upper stream area. The gradual increase of these towards down stream is explained by the addition of heavy metals from secondary deposits of the tailings occurring along the river side. The Cd/Zn is very low in the groundwater along the Kiselica River., but it tends to become slightly higher in the middle stream area.

6.3.2 Well and Spring Water

The analytical results of well/spring and river water in the P/P area show the high concentrations of As, Co, Ni, Pb, Zn Mn. The water quality of well/spring water is high in As, Co, Ni and Pb concentrations, being higher than the Standard of Drinking Water in most of the wells and springs. It is a serious health problem that more than half of the wells/springs in the P/P area are still used as a source of drinking water by the local residents in spite of the fact that the most of them are not appropriate for drinking.

Among the heavy metals showing high concentrations (As, Co, Ni, Pb, Zn and Mn), the influences of the mining activities, including the past and the present, elevating concentrations of heavy metals, are clearly observed for Co, Mn and Zn. The concentration of these heavy metals are clearly high for the water samples collected along the Kiselica and Koritnica Rivers where mine workings and tailings dams of past and present are located.

Most of the well/spring samplers show As and Ni concentrations exceeding the Standard of Drinking Water, and all of river water samples have Ni concentration greater than the Water Quality Standard. Further, all water samples including well/spring and river water show similar values of As and Ni. These suggest that the high concentrations of As and Ni in water of the P/P area were caused by natural features of the area, probably geological in nature. Similar to As and Ni, most of the water samples show high Pb concentration exceeding the Standard of Drinking Water and the Water Quality Standard, and concentrations of Pb tend to be higher in the Kiselica and Koritnica River areas. In addition to the natural causes, Pb concentrations seem to have been elevated by the mining activities of the area.

6.4 Soil and Groundwater Contamination Mechanism in the Pilot Project Area

6.4.1 Sources of Soil Contamination

Sources of soil contamination by heavy metals in the area are apparently derived from mining activities and related mining facilities, etc., and natural causes including mineralization zones, geological units, etc. The high concentrations of heavy metals caused by the nature such as geological features are excluded from the definition of the soil contamination for this study. Therefore, the high concentrations of heavy metals including Ni, Co, Cr zones in the south western and north western parts of the area, Zn and Mn zones in the north eastern part of the area were excluded for further consideration.

Sources of the soil contamination in the area consist of old and new waste dump areas of mine sites, processing plant, tailings dams, battery factory, old wastes dump, etc. as shown in Figure 6.5 and Table 6.3.

(1) Old Wastes

Old waste dumps including mining activities from the Roman age are found in the northern part of the area. There are some old caves with wastes around the present mining sites in the northern part of the area. However, the volume of wastes, etc. is unknown. In general, acidic water containing high concentrations of heavy metals seeps from the old wastes. The surface water of SW-06 (Figure 6.5), located in upper stream of the Kiselica River, contains high concentrations of Cu, Pb, Zn and Mn. This water seems to be affected by seeped water from old wastes.

(2) New Wastes

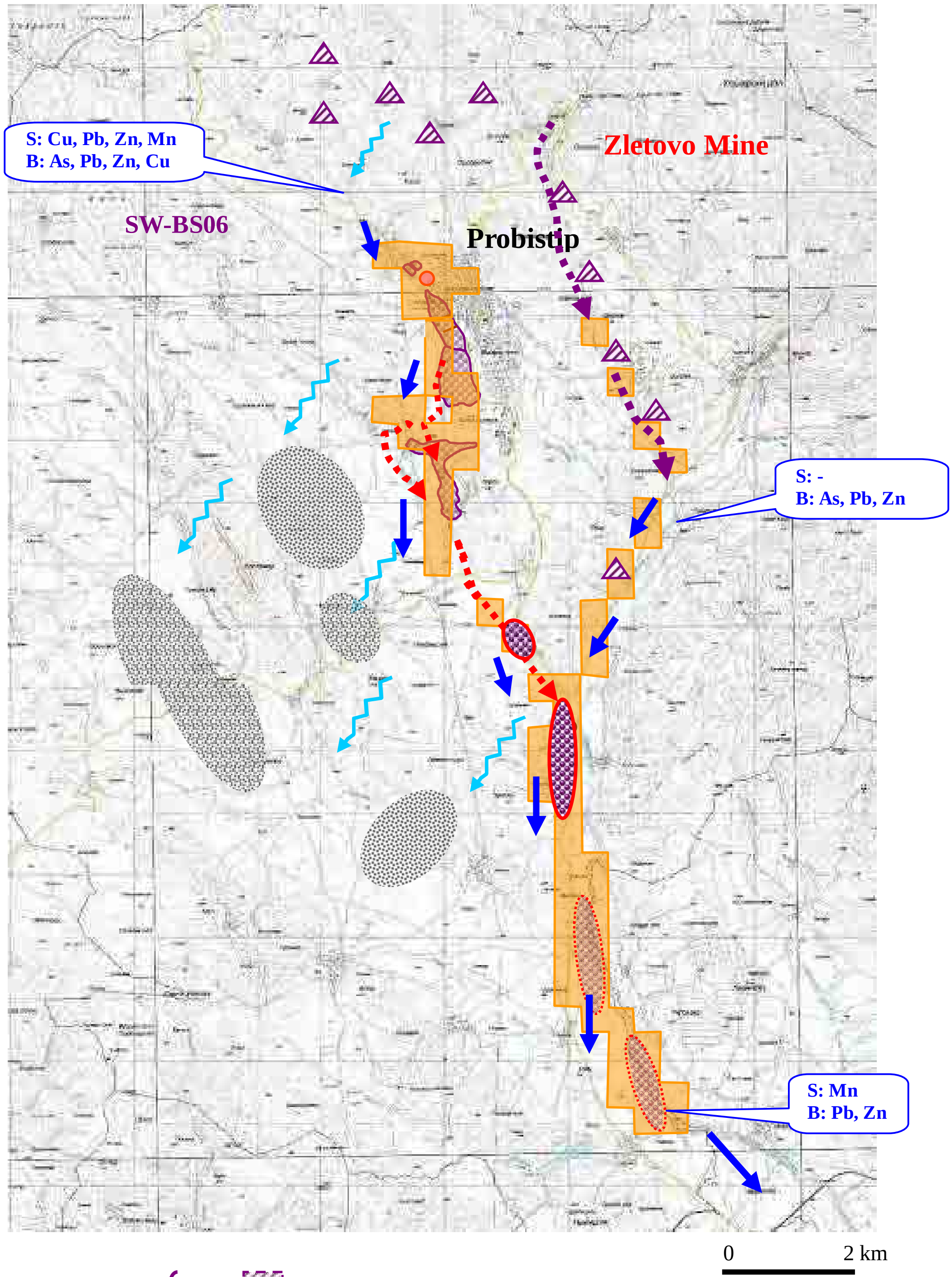
New wastes by recent mining activities are being dumped around the adits of the mine and disposed into the Koritnica River. Numerous fragments and gravels of low grade ore and waste are found along the river, and most of fragments and gravels are coated by black manganese oxide.

(3) Adits

Acidic water (pH 2 to 4) has been discharged mainly from adits of the mine and generally contains high concentrations of heavy metals, including Pb, Zn, Cd, Cu, Mn, etc. Most of discharged water drains into the Koritnica River as shown in Figure 6.2.

(4) Mineral Processing Plant

The processing plant for crude ore is located in the northern part of Probistip residential area and beside Tailings dam TD-I. There is a transportation route of crude ore, ore dressing equipments, stockyards of crude ore and concentrates, transportation equipments of tailings to dumping sites, etc. in the plant site. Implement of actions to improve environmental management by the mining company is needed.



Contamination sources of soil and groundwater: Mine area; Old wastes of ore (inferred); Tailings dams; Secondary contamination source zone

Advection and diffusion: Wastes of ore disposed to the river; Tailings spilled along the rivers; Diffusion by flying dust; Tailings dust from TD, etc.; Advection and diffusion by groundwater

Figure 6.5 Soil and Groundwater Contamination Mechanism in the P/P Area

Table 6.3 Contamination Sources in the P/P Area

<table>
<tr><th>Sources of Soil Contamination</th><th colspan="2">Location</th><th>Condition</th><th>Influence to Soil and Water Contamination</th></tr>
<tr><td rowspan="11">1. Primary Sources</td><td colspan="2">Old mine sites</td><td>- Old ore wastes: From the Roman age, small scale</td><td>Acid water to river, caves, dust, etc.</td></tr>
<tr><td colspan="2">Mine site (Zletovo Mine)</td><td>- Using at present, Pb-Zn sulphide ore, underground mining</td><td>Acid water, caves, dust, etc.</td></tr>
<tr><td rowspan="5">Old tailings dams</td><td>TD-I</td><td>- Soccer pitches, covered by soil and grass
- Located in residential area</td><td>Acid water with heavy metals, collapse in small scale, dust, etc.
(dust: air pollution)</td></tr>
<tr><td>TD-II</td><td>- Sub-station, etc., covered by soil
- Located in residential area</td><td>Seeped acid water with heavy metals, erosion, collapse of tailings, dust, etc.
(dust: air pollution)</td></tr>
<tr><td>TD-III</td><td>- Covered by soil and re-forestation
- Located along Kiselica River</td><td>Seeped acid water with heavy metals, erosion, collapse of tailings, dust, etc.
(dust: air pollution)</td></tr>
<tr><td>TD-IV</td><td>- Bare-ground
- Located along Kiselica River</td><td>Seeped acid water with heavy metals, erosion of dikes, collapse and spill out of tailings, dust, etc.
(dust: air pollution)</td></tr>
<tr><td>TD-V</td><td>- Bare-ground
- Located along Kiselica River</td><td>Seeped acid water with heavy metals, erosion of dikes, collapse and spill out of tailings, dust, etc.
(dust: air pollution)</td></tr>
<tr><td colspan="2">New Tailings Dam</td><td>- In use at present
- Located along old Kiselica River</td><td>Drainage of acid water with heavy metals, collapse, spill out of tailings, dust, etc.
(dust: air pollution)</td></tr>
<tr><td colspan="2">Processing Plant</td><td>- In use at present
- Located in residential area</td><td>Acid water to river, caves, dust, industrial waste, etc.</td></tr>
<tr><td colspan="2">New wastes of ore</td><td>- Dumping and disposed into River</td><td>Acid water to river, caves, dust, etc.</td></tr>
<tr><td colspan="2">Battery Plant</td><td>- Disposal of wastes</td><td>Soil and water contamination</td></tr>
<tr><td rowspan="5">2. Secondary Sources</td><td colspan="2">Lower stream of Kiselica River</td><td>- River bottom sediments</td><td>Seeped water with heavy metals from tailings, dust, etc.</td></tr>
<tr><td colspan="2">Around junction of Kiselica and Zletovska Rivers</td><td>- Sediments</td><td>Seeped water with heavy metals from tailings, dust, etc.</td></tr>
<tr><td colspan="2">Along the Koritnica River</td><td>- River bottom sediments</td><td>Seeped water with heavy metals from ore wastes, dust, etc.</td></tr>
<tr><td colspan="2">Middle stream of Zletovska River after junction with Kiselica River</td><td>- Sediments</td><td>Seeped water with heavy metals from tailings, dust, etc.</td></tr>
<tr><td colspan="2">Lower stream of Zletovska River</td><td>- River bottom sediments</td><td>Seeped water with heavy metals from ore wastes, dust, etc.</td></tr>
</table>

(5) Tailings Dams

Tailings dams consist of six separate dams, namely TD-I, TD-II, TD-III, TD-IV, TD-V (Old Tailings Dams) and New Tailings Dam as shown in Figure 6.2. These dams are intensive contamination sources of soil, water (and groundwater) and air.

(6) Battery Factory

A part of the Battery factory still continues to be operated at present. As demonstrated by the results of the soil survey, high concentrations of heavy metals were confirmed in and around the plant. Planning and implementation of improved environmental management are necessary at the plant.

6.4.2 Secondary Contamination Sources

(1) Spill Incidents of Tailings and Secondary Contamination Sources of Tailings

The main collapse of tailings occurred in 1976 and much tailings material was spilled to downstream along the valley of Kiselica and Zletovska Rivers.

There are varying reports regarding the depth of the tailings residues that covered parts of the valley in the days after the collapse, and this would of course depend on the width of the valley. In Tripitanci (located in the valley 8km south of Probistip), the tailings reached in the valley of 2 to 3m deep. Further south in Pisica (14km south of Probistip), the depth of tailings was 15cm.

At the bridge over the Kiselica River (in between Buciste and Neokazi), the tailings blocked the channel under the bridge and built up against the bridge, so that the tailings were even pushed across the road. The tailings visibly remained around the bridge for 3 to 4 years.

Consequently, in several locations, including areas between the Old and New Tailings Dams, middle stream of the Kiselica River, lowermost stream of the Kiselica River, middle stream of the Zletovska River, and downstream of the Zletovska River, oxidised tailings are confirmed still to remain along the rivers by geological and drilling surveys. These remaining tailings are thought to be secondary contamination sources, because very high concentrations of heavy metals of soil are widely found in those areas.

(2) Secondary Contamination Sources of Sediments along the Koritnica River

Numerous fragments and gravels containing much Pb (galena), Zn (sphalerite) and Cu (calcopyrite, etc.) ore with coating by manganese oxide are found in alluvial sediments along the Koritnica River.

These sediments are originated from the Zletovo Mine area, partly natural and mostly ore wastes from the mine site.

These sediments are considered to be high potential sources of high concentration of heavy metals in soil. Therefore, it is necessary to enforce strict environmental management.

6.4.3 Soil and Water Contamination in the Area

The advection/diffusion mechanism of soil and groundwater in the P/P area is summarised below.

(1) Stage-1

The primary soil contamination in the area mainly originates from the old and present mine sites (ore waste dump areas), Old and New Tailings Dams and processing plant as shown in Figure 6.5. Most of the contamination sites are located in the northern to central parts of the P/P area, and the components of soil contamination consist of Cd, Cu, Pb, Zn, Mn and As. Although the primary soil contamination occurred in and around the original sites, the contamination of heavy metals were gradually extended to a much wider area by surface water, groundwater and air dust as shown in Figures 6.6 and 6.7.

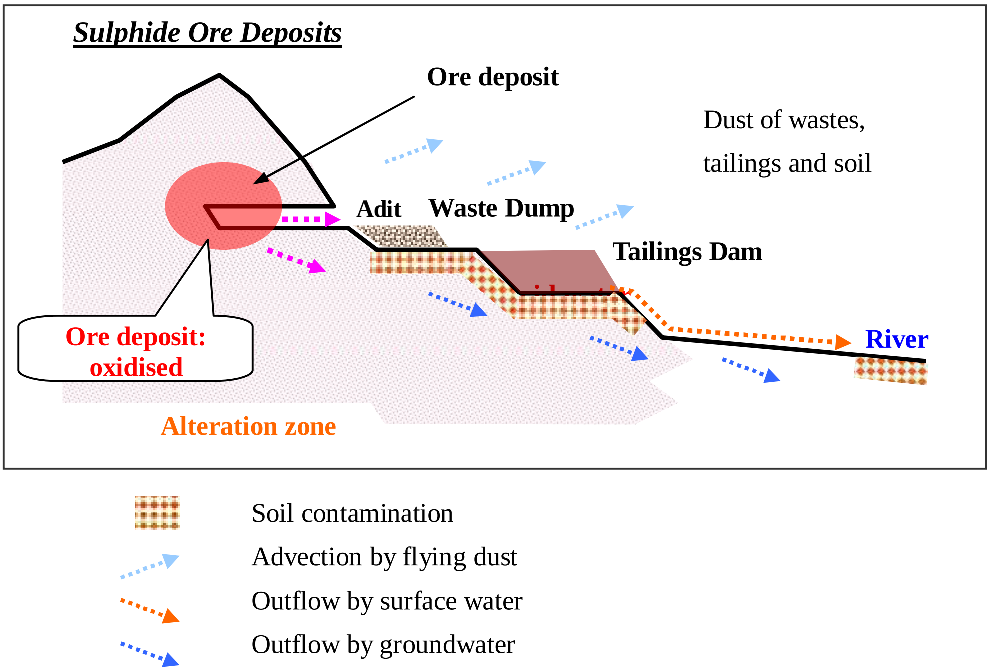


Figure 6.6 Soil Contamination Mechanism in the P/P Area

(2) Stage-2

The main collapse of the tailings dam occurred in 1976 and much tailings material was spilled and widespread to downstream along the valley of the Kiselica and the Zletovska Rivers. After 30 years, in several locations, including the areas between Old and New Tailings Dams, middle stream of the Kiselica River, lowermost stream of the Kiselica River, middle stream of the Zletovska River, and downstream of the Zletovska River, much tailings are still remained along the rivers. These remained tailings are secondary contamination sources as shown in Figure 6.5.

In addition, numerous fragments and gravels containing much ores were brought about from the mine site and became high potential sources of high concentrations of heavy metals in soil as shown in Figure 6.5.

Although the secondary sediments of tailings were emplaced in the middle stream of the rivers, the sediments will migrate slowly to the downstream depending on the strength of the river flow (especially flooding).

(3) Stage-3

After the soil contamination by spill incident of the Old Tailings Dam, contamination by tailings was widely extended to the downstream in the area, and the primary and secondary soil contamination gradually migrated to the downstream and diffused to the surroundings of the rivers.

Much tailings dusts flew from the Old and New Tailings Dams have been diffused around the tailings dams, and a part of tailings dusts is likely to have reached to the south-western and southern agricultural lands in the area by southwestwards wind (Figures 6.6 and 6.7). As a result of migration of tailings dusts, the soil and groundwater contamination have occurred after emplacement of the dust in the sites, and it was followed by crop contamination at the sites.

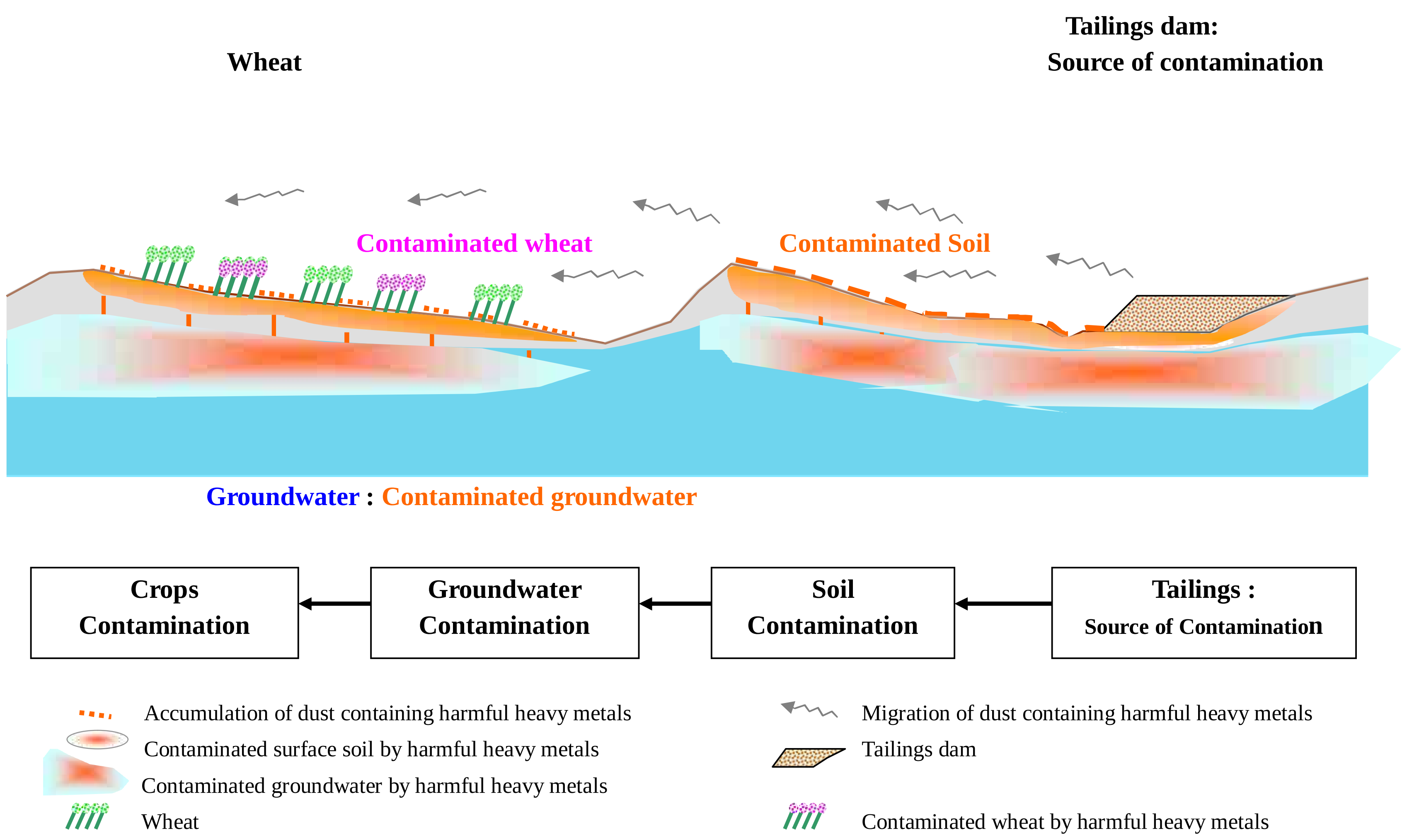


Figure 6.7 Schematic of Soil Contamination Mechanism among Soil, Groundwater and Crops in the P/P Area

CHAPTER 7 RISK ASSESSMENT AND COUNTER-MEASURES OF SOIL AND GROUNDWATER CONTAMINATION IN THE PILOT PROJECT AREA

CHAPTER 7 RISK ASSESSMENT AND COUNTER-MEASURES OF SOIL AND GROUNDWATER CONTAMINATION IN THE PILOT PROJECT AREA

7.1 Risk Assessment in the Pilot Project Area

7.1.1 General

Risk assessment is useful to clarify the soil contamination and to examine the counter-measures for soil contamination. The risk assessment methods are practically applied in the soil contamination site in the EU countries, such as Holland, Germany, UK and USA.

The risk assessment of the P/P includes two aspects: one is the exposure risk to human health by contaminated surface soil and groundwater, and the other is agricultural risk to human health by crops containing harmful heavy metals.

In this report, the initial risk assessment was examined for the P/P area to plan the mitigation measures of soil contamination based on the risk characterisation in the area.

7.1.2 Exposure Risk Assessment of Contaminated Soil and Groundwater in the Pilot Project

(1) Methods and Conditions of Exposure Risk Calculation

a. Methods and Conditions

Exposure risk to human health by contaminated surface soil and groundwater was calculated by software of "GERAS 1.2 Heavy metals Version 1.2, 2006" (Copyright: AIST, Japan). The calculation conditions of the exposure assessment are shown as below.

1) Exposure pathway: Soil intake, inhalation of soil (dust), agricultural products (crops and stems), drinking of groundwater.
2) Concentration of heavy metals : Content value of 400m grid soil results.
3) Risk characterisation: TDI (Tolerable Daily Intake) of WHO.
4) Risk calculation of heavy metals is shown below.
    - Setting of calculation condition of exposure amount of heavy metals
        - Unit area for calculation: Area of 400m grid
        - Analytical data: Content values of 400m grid survey results
        - Objective components: 6 components of As, Cd, Hg, Ni, Pb and Zn defined as TDI

- Conditions for exposure amount
  - Exposure pathway: Ingestion and skin-contact
  - Exposure period : Long-term exposure
  - Common scenario of ingestion of contaminated soil
- Calculation of exposure amount of heavy metals
  - Using GERAS 1.2 Heavy metals Version 1.2, 2006 for exposure amount of heavy metals
  - Obtaining exposure amount of heavy metals
- Calculation of risk amount of heavy metals
  - Formula of risk calculation of each heavy metal: Using TDI of WHO as shown below

Risk amount of heavy metal = Exposure amount x Harmful Effect

Harmful Effect = 1 / TDI

- Obtaining risk amount of each heavy metal: As the risk amount obtained was harmfulness calculated only by TDI, each risk of heavy metal based on the TDI can be added each other. It is same procedure as TEQ (Toxic Equivalent) risk calculation of dioxins. Particularly, for soil contamination by multi metals in the P/P area, total risk amount is considered to be useful as a indicator for analysis.
- Total risk amount of individual heavy metals is considered as the risk amount for each of 400m grid area.

$$\text{Total risk amount} = \Sigma (M_{1\sim6})$$

- Although total risks of individual heavy metals is considered for the risk assessment, the risk amount and distribution map of exposure risk for soil and groundwater by each heavy metal are given in Data6 and Data7.

5) End-point for target value (counter-measures): 10% of TDI

b. Data of the Pilot Project

The 400m soil survey covers nearly a whole area of P/P area, therefore, the Action Plan should be developed by the risk assessment using results of 400m grid soil survey to understand the general features of the whole area of the P/P.

The numbers of soil samples for content and elution analyses of 400m grid soil survey are 679 and 68, respectively.

c. Case Study

1) The total exposure amount was calculated by added together each exposure amount of heavy metals which are specified by pathway of soil - human health. Objective components include As, Cd, Hg, Ni, Pb and Zn.
2) The risk of heavy metals was calculated based on the land-use as a ratio of exposure frequency shown in Table 7.1.

Table 7.1 Exposure Frequency by Land-use for the Risk Assessment

Residential Area	Agricultural area	Orchard	Tailings dam	Forest, bush & pasture
Exposure frequency: 365days, 24 hrs/day	Exposure frequency: 365days, 8 hrs/day	Exposure frequency: 365days, 12 hrs/day	Exposure frequency: 365days, 12 hrs/day	Exposure frequency: 365days, 12 hrs/day

3) The total risk was calculated by adding together each risk of heavy metals which are specified by TDI, including As, Cd, Hg, Ni, Pb and Zn.

(2) Characterisation of the Contamination Components

a. Components of soil contamination

The contamination components consist of As, Cd, Hg, Ni, Pb and Zn of the heavy metals. These components are designated as harmful components by the process of setting up the reference values for soil in the P/P. However, Ni in soil of the P/P area is considered to be mostly originated from natural causes, therefore it should be excluded from the risk analysis.

b. Pathway of soil - human health

The pathway of soil - human health generally consists of intake of soil, inhalation of soil, drinking of groundwater, eating of agricultural products, etc. This study is concerned with intake of soil, inhalation of soil and drinking groundwater. Although eating of agricultural products is very important factor for the risk assessment, information concerning soil features of the whole area of the P/P is necessary for this study and it is presently not available.

c. Time of exposure

The time of exposure is shown in Table 7.2.

Table 7.2 Time of Exposure

Items	Day of the week	Home	Outside	Background
Adult	Week day	24	0	0
	Holiday	20	4	0
Infant	Week day	22	2	0
	Holiday	19	5	0

d. Year of inhabitation

The year of inhabitation is shown in Table 7.3.

Table 7.3 Year of Inhabitation

Items	Day of the week	Year of inhabitation	Unit
Contaminated land	Adult	64	year
	Infant	6	year
Non-contaminated land	-	-	year
Total		70	year

e. Body weight

Table 7.4 Body Weight

Items	Weight (kg)
Adult	50
infant	15
Average	47

f. Intake of soil

Table 7.5 Intake of Soil

Items	Average weight (mg/day)
Adult	100.00
infant	200.00

g. Intake of Groundwater

Table 7.6 Intake of Groundwater

Items	Intake (L/day)
Adult	2
infant	1

h. Breathing volume

Table 7.7 Breathing Volume

Items	Breathing volume (m^3/day)
Adult	15
infant	6.1

i. Mechanical condition of Soil

The mechanical condition of soil is shown in Table 7.8.

Table 7.8 Mechanical Condition of Soil

Items	Value
Volume ratio of gas in the soil	0.25
Volume ratio of pore water	0.55
Volume ratio of soil solid	0.2
pH of soil	7
Temperature of soil (K)	283
Weight ratio of organic carbon in soil	0.15
Weight ratio of clay in soil	0.38
Specific gravity of soil (g/cm^3)	1.2

(After Kawabe et al. 2003)

(3) Exposure Risk Calculation of Soil and (drinking) Groundwater

The exposure risk analysis was calculated by the following order:

1) Selection of heavy metals for the risk assessment,
2) Exposure amount of heavy metals in soil,
3) Exposure amount of heavy metals in drinking groundwater,
4) Total exposure amount of heavy metals in soil and drinking groundwater,
5) Exposure risk of heavy metals in soil characterised by land-use (on-site risk assessment),
6) Exposure risk of heavy metals in soil characterised by land-use (on-site risk assessment),
7) Exposure risk of heavy metals in drinking groundwater (On-site risk assessment),
8) Total exposure risk of heavy metals in soil (characterised by land-use) and drinking groundwater (on-site risk assessment).

a. Selection of Heavy Metals for the Risk Assessment

The risk calculation of the heavy metals requires a harmful effect value for each heavy metal. The harmful effect value for each heavy metal is generally characterised by TDI of WHO. Among the heavy metals, TDI of As, Cd, Cu, Hg, Ni, Pb and Zn (seven components) were set up by WHO, and these seven components were selected as harmful components for the risk assessment.

On the other hand, Co and Cr are excluded from the risk calculation, because TDI of these heavy metals are not available. Further, the mean value of Cr of P/P area is far less than the average soil of Bowen (1979), hence the risk is thought to be relatively low. Compared to Co value of average soil of Bowen, 8mg/kg, Co values of P/P area are not so high with the maximum value of 36mg/kg, hence the risk of Co does not seem to be significantly high.

Mn was not considered as a harmful metal in this study, because Mn is not specified as a harmful component for soil contamination in many countries. Further, the Mn used for TDI is dissolved manganese (Mn), which is a different Mn type from one included in soil.

b. Exposure Amount of Heavy Metals in Soil

The exposure amount of heavy metals in soil as on-site risk assessment is calculated by "GERAS 1.2" (Kawabe, et al., 2003). The distribution of exposure amount of heavy metals in soil based on total risk amount is shown in Figure 7.1 and the distribution maps of exposure amount on each heavy metal are given in Data7.

The calculation of exposure amount of heavy metal in soil shows that 400m grids of Level 4, which have exposure amount of 10 to 100 times more than the exposure amount calculated from the Reference Value, occur only in the limited areas, such as north of the processing plant, Tailings Dam No.1, the Old Tailings Dam, near the New Tailings Dam, the middle stream area of the Kiselica River, middle to lower stream area of the Zletovska River.

The 400m grids of Level 3, with exposure amount of less than 10 times more than the exposure amount calculated from the Reference Value, occur in areas north of the processing plant, near the Old and New Tailings Dams, north eastern part of the P/P area, the residential area of the southern part of the Probistip and the widespread area along the Zletovska River. Particularly, part of the residential area of the Probistip is occupied by Level 3 grid. All the areas other than mentioned above are covered by Level 2 grid with exposure amount of less than the one calculated from the Reference Value.

c. Exposure Amount of Heavy Metals in Drinking Groundwater

Most of the well and spring waters located in the P/P area are used for daily life as drinking water, domestic animals and irrigation. Particularly, well water of the villages, including Kukovo, Pestrisino, Troolo, Zarapinci located in the southwestern part of the area, Petrsino, Neokazi located in the central part of the area, and Gujnovci and Pisica located in the southern part of the area, is used for drinking water.

According to the groundwater survey results of the P/P area, most of well water in the area is contaminated by heavy metals. Therefore, it is necessary to examine drinking groundwater by the risk assessment.

The exposure amount of heavy metals in soil and drinking groundwater as on-site risk assessment was calculated by "GERAS 1.2" (Kawabe, et al., 2003). The distribution of exposure amount of heavy metals in groundwater based on total risk amount is shown in Figure 7.2 and the distribution maps of exposure amount on each heavy metal are given in Data7.

The exposure of heavy metal in groundwater actually occurs by drinking it, hence the exposure area of heavy metal in drinking groundwater is limited in the south western, southern and central parts of the area as shown in Figure 7.2.

d. Total Exposure Amount of Heavy Metals in Soil and Drinking Groundwater

Total exposure amount of heavy metals in soil and drinking groundwater is shown in Figure 7.3. The grids of Level 3 are widely distributed in the southwestern and southern parts of the area.

e. Exposure Risk of Heavy Metals in Soil (On-site Risk Assessment)

The exposure risk of heavy metals in soil as on-site risk assessment is calculated by the following formula.

<u>Risk of Heavy Metals</u> = (Exposure Amount) x (Harmful Effect)

<u>Harmful Effect</u> = 1 / TDI

The distribution of the exposure risk of heavy metals is shown in Figure 7.4. The end-point of the exposure risk of soil and drinking groundwater is 10% of Tolerable Daily Intake (TDI). The exposure risk levels are classified into six levels as shown in Table 7.9.

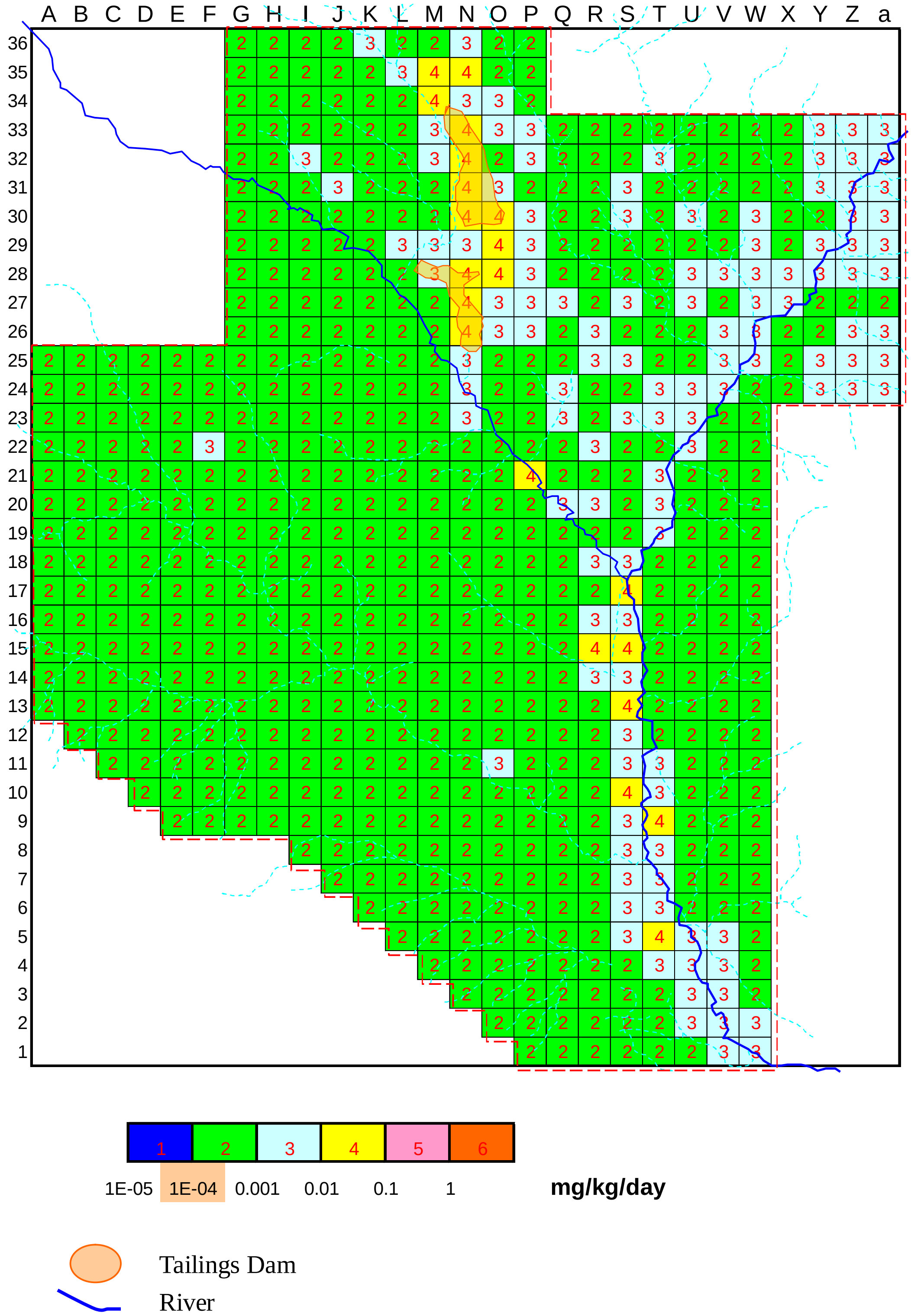


Figure 7.1 Exposure Amount of Heavy Metals in Soil by the On-site Risk Assessment (As, Cd, Hg, Ni, Pb, and Zn)

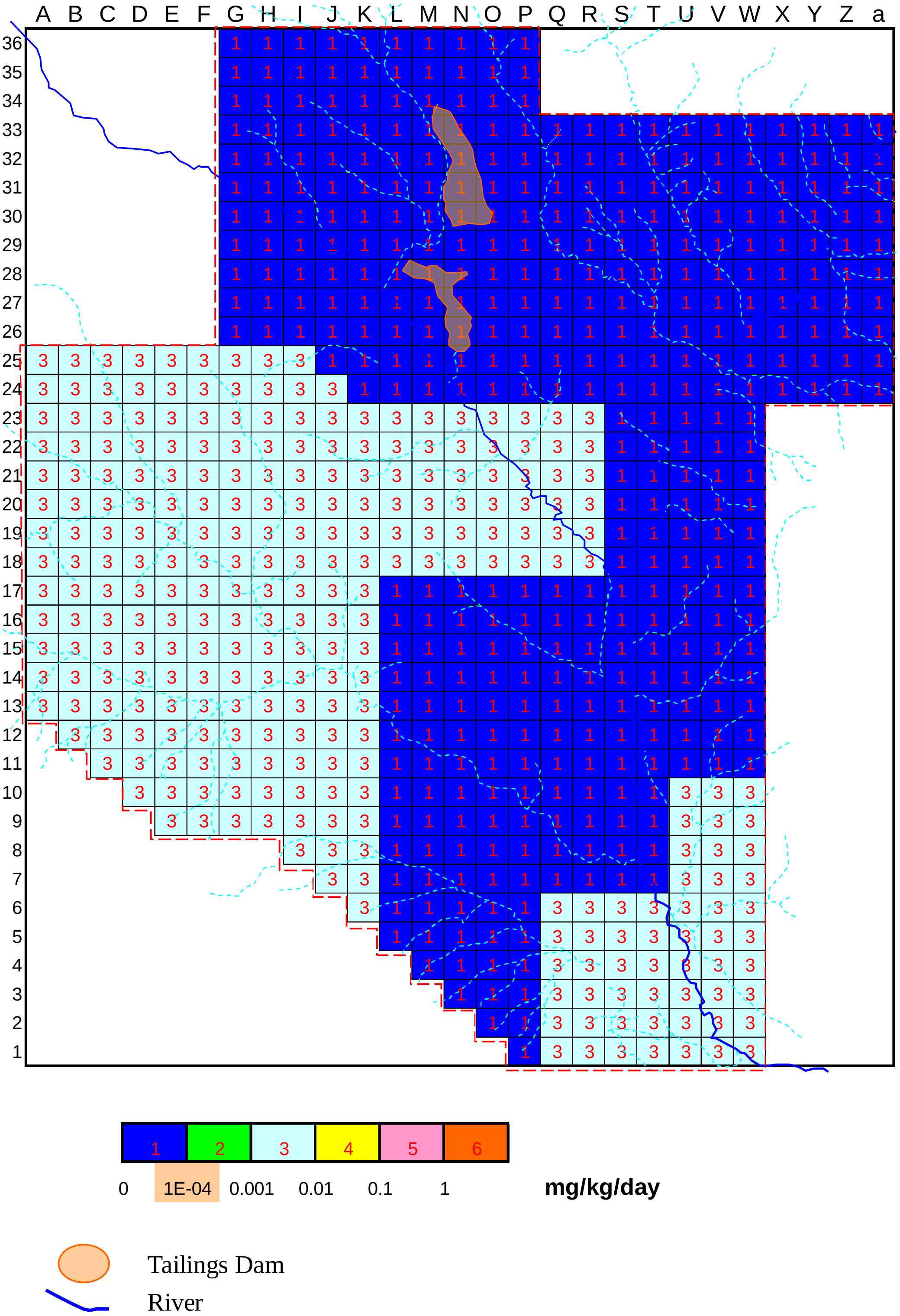


Figure 7.2 Exposure Amount of Heavy Metals in (drinking) Groundwater by the On-site Risk Assessment (As, Cd, Hg, Ni, Pb, and Zn)

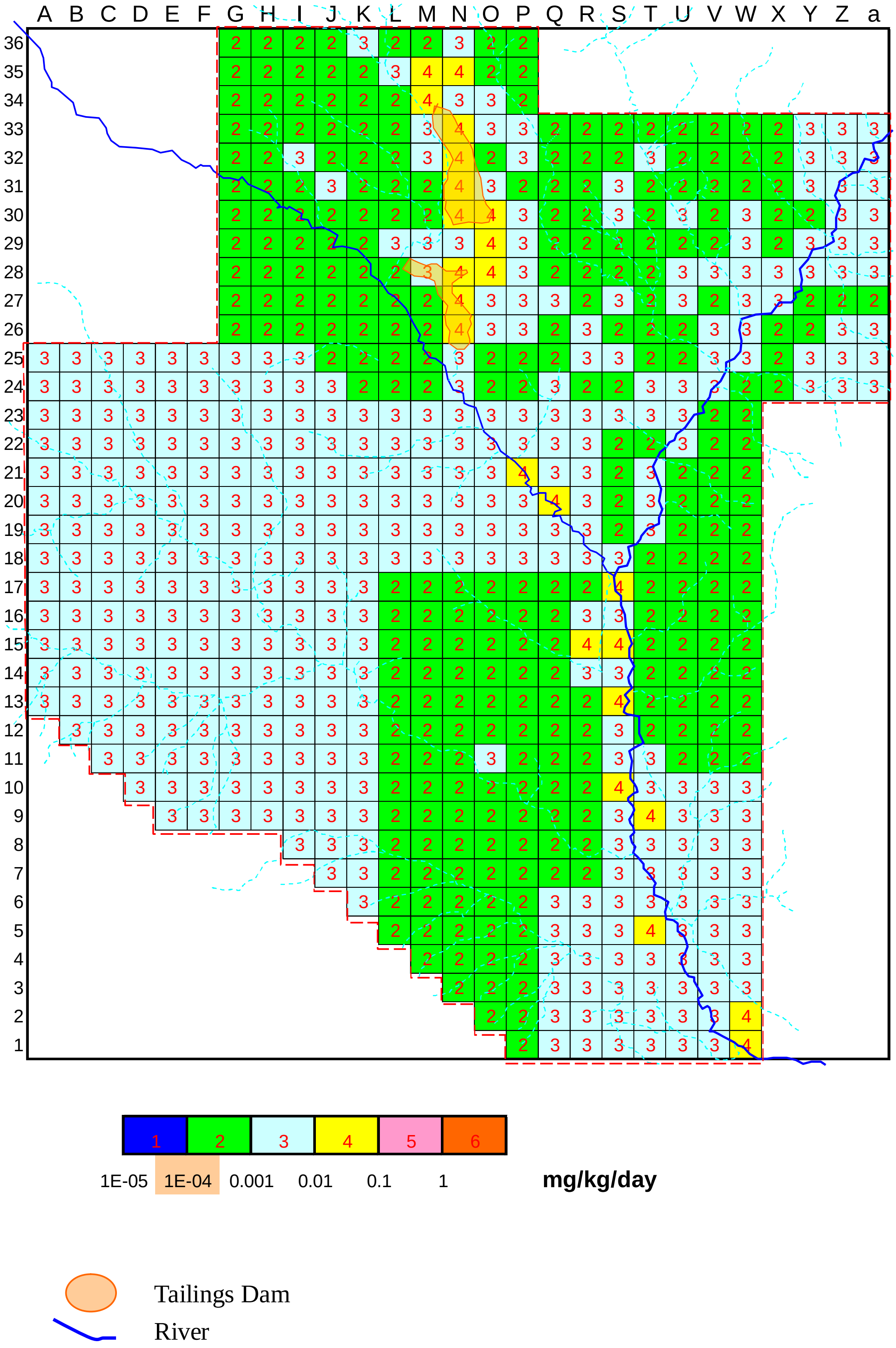


Figure 7.3 Total Exposure Amount of Heavy Metals in Soil and (drinking) Groundwater by the On-site Risk Assessment (As, Cd, Hg, Ni, Pb, and Zn)

Table 7.9 Exposure Risk Level of Soil and Drinking Groundwater in the P/P Area

Exposure Risk Level	Exposure Risk Amount (mg/kg/day)	Remarks
1	~ 0.004	Less than 10% of TDI (End-point)
2	0.004 ~ 0.04	10% of TDI to TDI
3	0.04 ~ 0.4	TDI to 10 times of TDI
4	0.4 ~ 4	10 times of TDI to 100 times of TDI
5	4 ~ 40	100 times of TDI to 1,000 times of TDI
6	40 ~	1,000 times of TDI to 10,000 times of TDI

As shown above, exposure risk of heavy metal is calculated from the harmful effect as a function of TDI and exposure amount of heavy metals obtained considering land use. The results of the calculation show that 400m grids of Level 5, which has risk of 1,000 to 10,000 times more than the risk calculated from 10% of TDI Value as an end-point, occur in the limited areas of near the Processing Plant, the Tailings Dam No.1. The 400m grids of Level 4, which have the risk of 100 to 1,000 times more than the risk calculated from TDI Value, occur in the P/P area near the Processing Plant, the Old and New Tailings Dam, north eastern part of the P/P area, southern part of the residential area of Probistip and along the Kiselica and Zletovska Rivers. All the areas other than mentioned above are covered by Level 2 to 3 grids with the risk of less than 10 times more than the risk calculated from the Reference Value.

f. Exposure Risk of Heavy Metals in Soil Characterised by Land-use (On-site Risk Assessment)

The exposure risk mainly depends on the land-use of the site. The exposure frequency to the human body by land-use for the risk assessment is shown in Table 7.1.

The exposure risk characterised by land-use of heavy metals in soil as on-site risk assessment is calculated by the following formula.

<u>Exposure Risk by Land-use</u> = <u>Risk of Heavy Metals</u> x (<u>Exposure Frequency</u> / 24 hrs)

Exposure frequency (Table 7.1)	: Residential Area	: 24 hrs/day
	: Agricultural area	: 8 hrs/day
	: Orchard	: 12 hrs/day
	: Tailings dam	: 12 hrs/day
	: Forest, bush & pasture	: 12 hrs/day

The distribution of the exposure risk of heavy metals in soil characterized by land-use based on the total risk amount is shown in Figure 7.5 and the distribution maps of exposure risk on each heavy

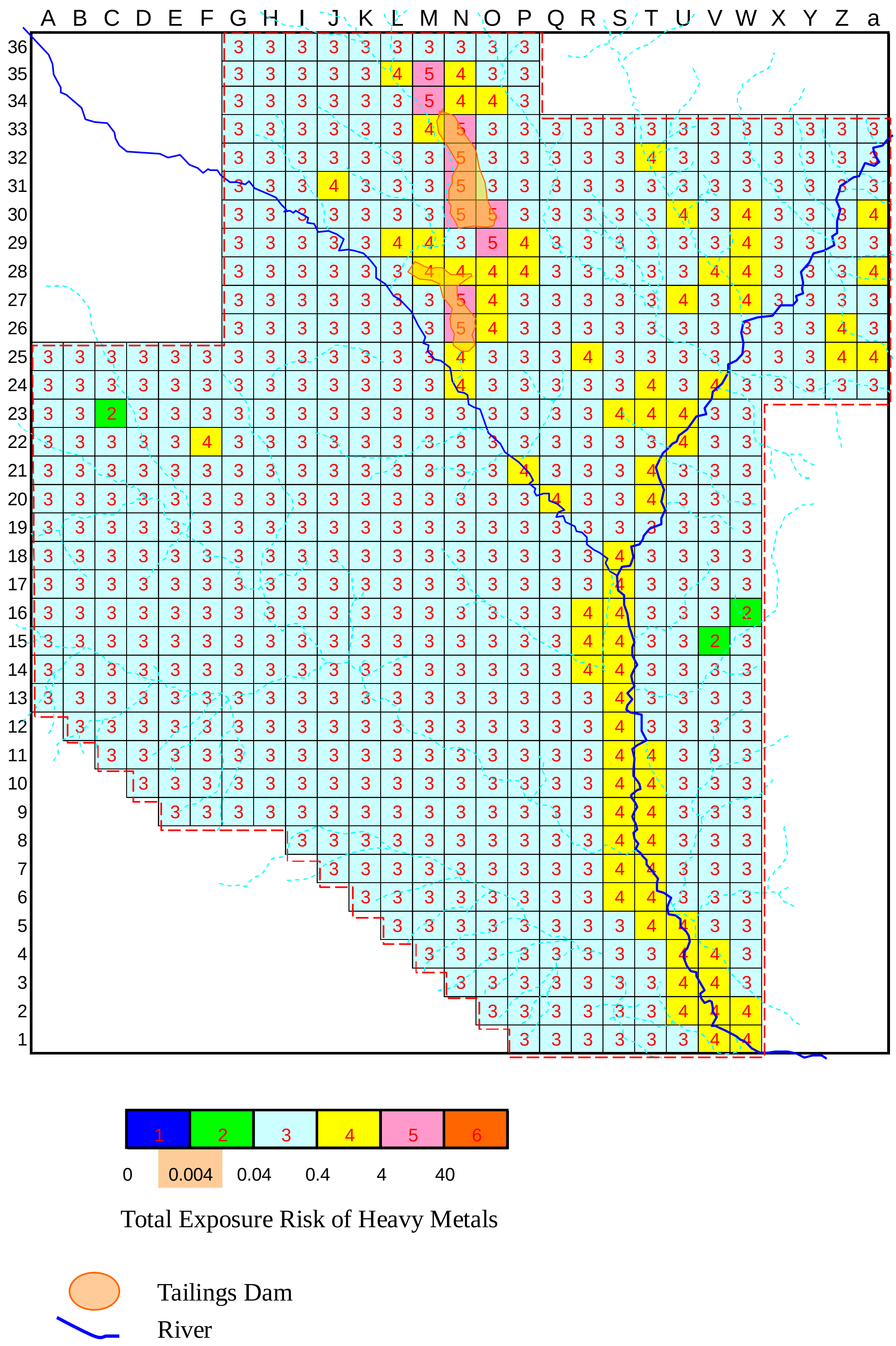


Figure 7.4 Exposure Risk of Heavy Metals in Soil

metal are given in Data 7.

The exposure risk levels in the northern and eastern parts of the area range from 3 to 5, mostly similar to those of the exposure risk of heavy metals in soil (Figure 7.4). However, the exposure risk levels of agricultural land located in the western and south western parts of the area reduce from Level 3 to Level 2.

g. Exposure Risk of Heavy Metals in Drinking Groundwater (On-site Risk Assessment)

The exposure risk of heavy metals in drinking groundwater as on-site risk assessment is calculated by the following formula.

Risk of Heavy Metals = (Exposure Amount) x (Harmful Effect)

Harmful Effect = 1 / TDI

The distribution of the exposure risk by heavy metals in drinking groundwater based on the total risk amount is shown in Figure 7.6 and the distribution maps of exposure risk on each heavy metal are given in Data7.

The distribution of exposure risk by heavy metals in drinking groundwater is similar to the distribution of exposure amount. The exposure risk levels range from 3 to 4. The grids of Levels 3 and 4 occur in the western and eastern parts of the P/P area where the groundwater is used for drinking. The risk level of grids in the southwestern part of the area decreases to Level 3, because the concentrations of As content in groundwater are slightly lower than those of surrounding grids.

The exposure risk level by contaminated (drinking) groundwater, which is between level 3 and level 4, shows same level as the zones of high exposure risk by contaminated soil along the Kiselica and Zletovska Rivers, because directly drinking contaminated groundwater affects the exposure risk more than that of contaminated soil.

If groundwater is contaminated but not used for drinking, the exposure risk is extremely low, giving exposure risk level 1.

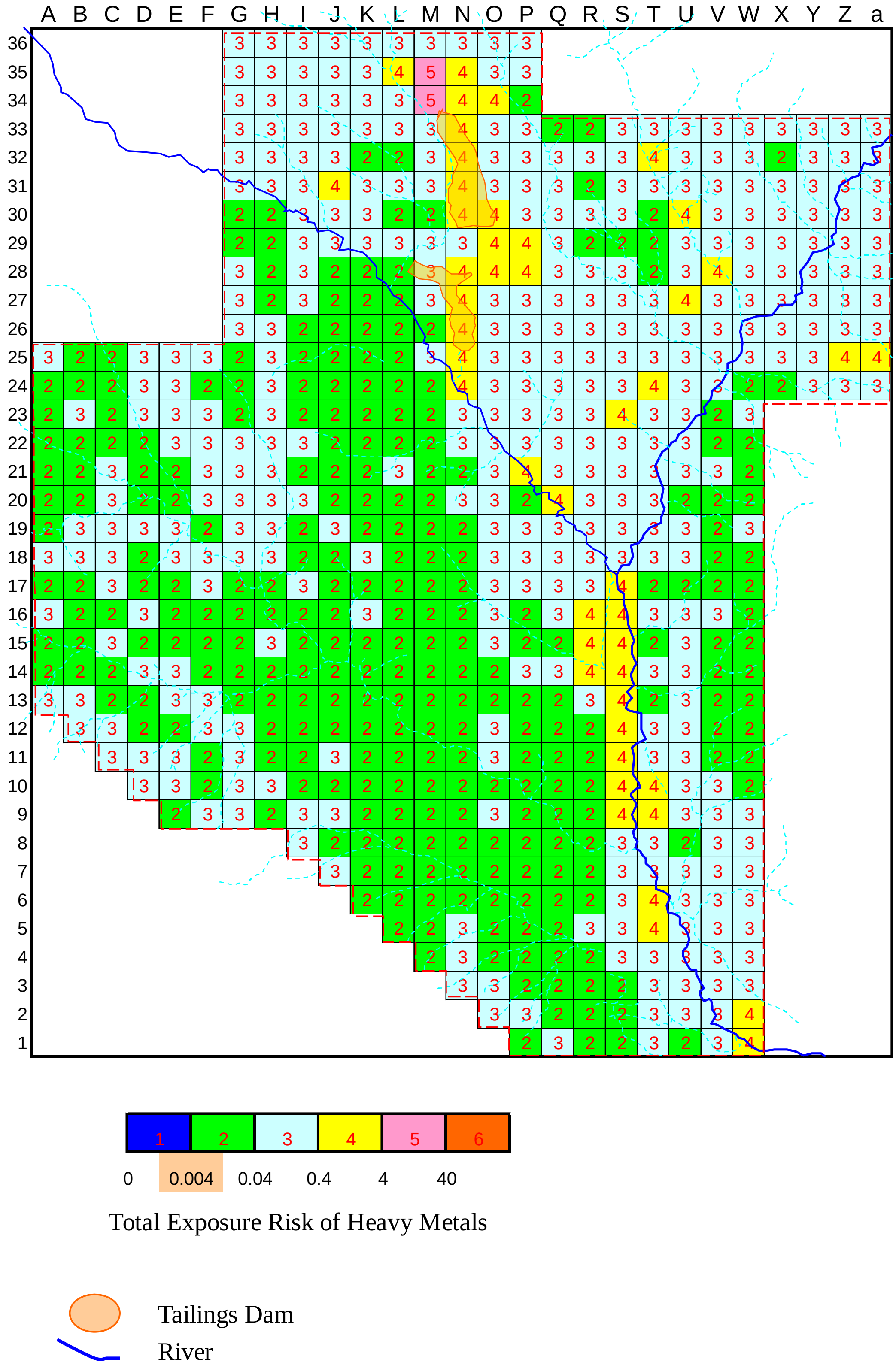


Figure 7.5 Exposure Risk of Heavy Metals in Soil Characterised by Land-Use

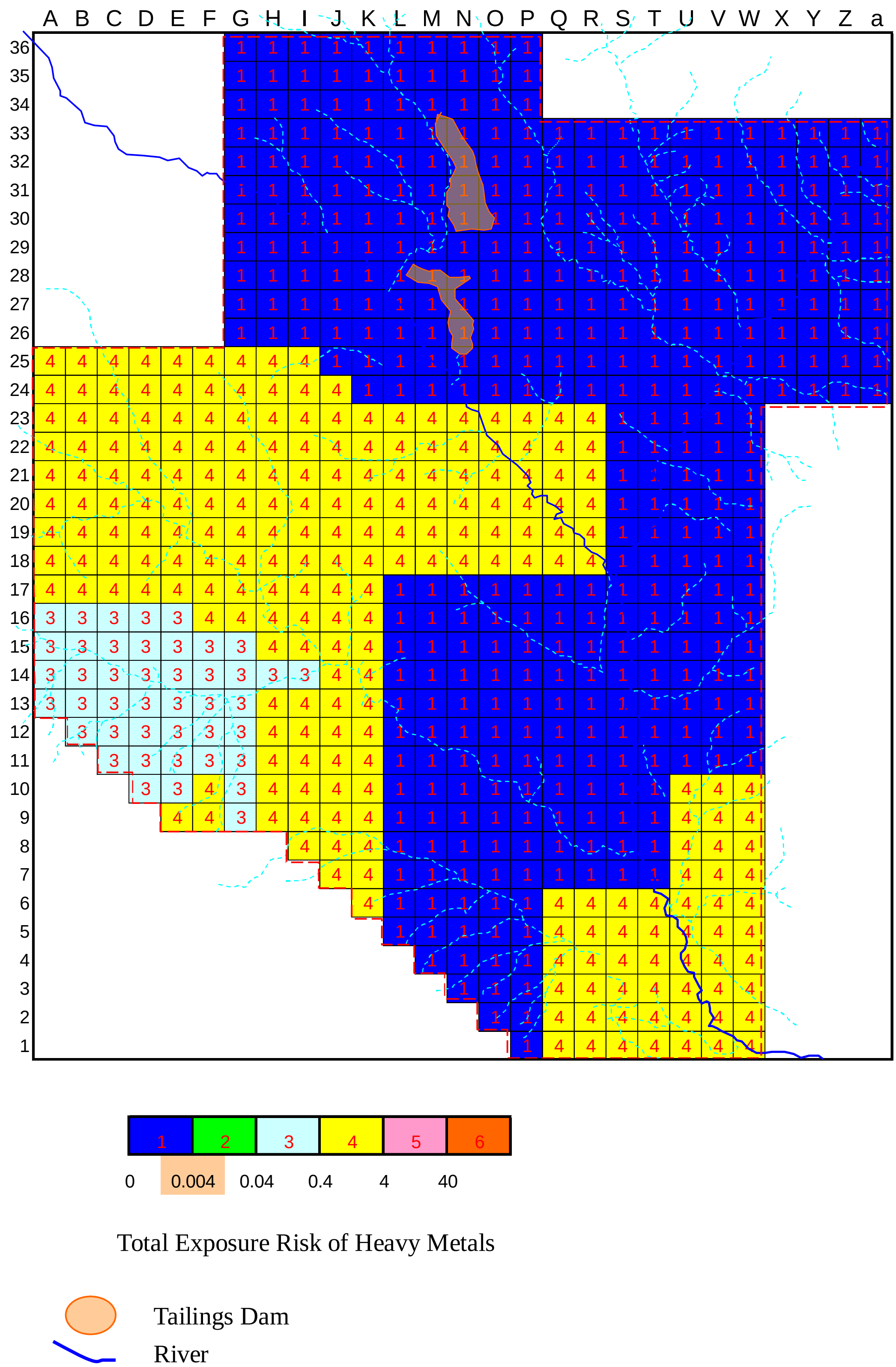


Figure 7.6 Exposure Risk of Heavy Metals in Groundwater

h. Total Exposure Risk of Heavy Metals in Soil Characterised by Land-use and Drinking Groundwater (On-site Risk Assessment)

The present total exposure risk of heavy metals in soil and drinking groundwater as on-site risk assessment is calculated by the following formula.

<u>Risk of Heavy Metals</u> = Exposure risk of soil by Land-use + Exposure risk of drinking groundwater

The distribution of the exposure risk by heavy metals in soil and drinking groundwater based on the total risk amount is shown in Figure 7.7, and the distribution maps of exposure risk on each heavy metal are given in Data7.

The results of the calculation show that 400m grids of Level 5, which have risk of 1,000 to 10,000 times more than the risk calculated from 10% of TDI Value as an end-point, occur in the limited areas of near the Processing Plant, the Tailings Dam No.1. The 400m grids of Level 4, which have the risk of 100 to 1,000 times more than the risk calculated from TDI Value, widely occur in the P/P area near the Processing Plant, the Old and New Tailings Dam, north eastern part of the P/P area, river plains along the Kiselica and Zletovska Rivers, and western, central and southern parts of the area.

The 400m grids of Level 3, which have the risk of 10 to 100 times more than the risk calculated from TDI Value, are found in the northern half and southwestern parts of the area. The 400m grids of Level 2 are locally found in the central, eastern and southern part of the area.

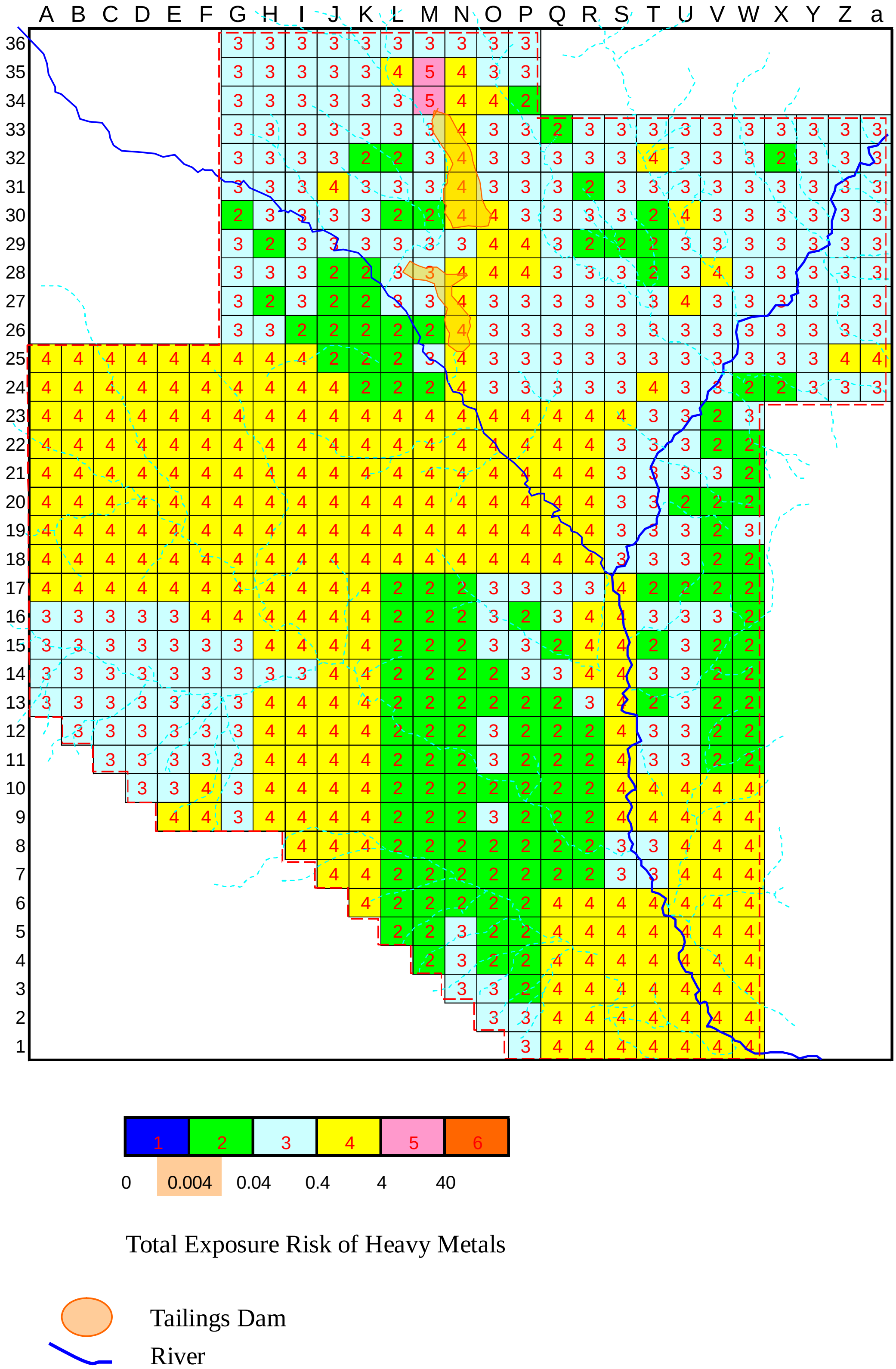


Figure 7.7 Total Exposure Risk of Heavy Metals in Soil and Groundwater

(4) Assessment of Total Exposure Risk of Soil and Drinking Groundwater

The total exposure risk levels of soil and drinking groundwater in the P/P area consist of four exposure risk levels, ranging from Level 5 to Level 2. The features of each exposure risk level are shown in Table 7.10.

Table 7.10 Total Exposure Risk Levels of Soil and Drinking Groundwater in the P/P Area

Exposure Risk Level	Exposure Risk Amount (mg/kg/day)	Number of Grid		Location	Source of Contamination	Remarks
		No.	%			
5	4 ~ 40	2	0.3	North	- Tailings dams - Mineral processing plant	- Grid M35, M34: Inside of urban area of Probistip
4	0.4 ~ 4	274	40.4	1. North	- Tailings dams - Mineral processing plant - Battery plant	- Grid L35, N35, N34,O34: Inside of urban area of Probistip - Grid O29, O28, P29, P28: Industrial area
				2.Northeast	- Ore waste from mine along the rivers - Natural causes	- Pasture and forest
				3. Centre	- Secondary tailings along the river - Drinking groundwater (wells)	- Agricultural land and Pasture - No water supply
				4. West	- Drinking groundwater (wells)	- Agricultural land and Pasture - No water supply
				5. West	- Drinking groundwater (wells) - Natural causes	- Agricultural land and Pasture - No water supply
				6. Southeast	- Secondary tailings along the river - Drinking groundwater (wells)	- Agricultural land and Pasture - No water supply
3	0.04 ~ 0.4	274	40.4	1. Northwest	- Natural causes	- Agricultural land and Pasture - No water supply
				2. Northeast	- Ore waste from mine along the rivers - Natural causes	- Pasture and forest - Probistip residential area
				3. Southwest	- Drinking groundwater (wells) - Natural causes	- Agricultural land and Pasture - No water supply
				4. South	- Secondary tailings along the river	- Agricultural land and Pasture
2	0.004 *1~ 0.04	129	18.9	1. North		- Agricultural land - Water supply
				2. South		- Agricultural land and Pasture - Water supply (locally)

*1: End-point: 10% of TDI (Tolerable Daily Intake: 0.004mg/kg/day)

High exposure risks of harmful heavy metals are caused by tailings of the tailings dam, tailings of secondary deposition, contaminated (drinking) groundwater and natural source such as mineralisation.

The exposure risk of contaminated soil is marked by extending along the rivers. The exposure risk of contaminated groundwater is characterised by high risk and is widely diffused in the area. In addition, harmful heavy metals such as As, Co and Ni derived from natural causes also affect an increase of exposure risk in the area.

Total exposure risk levels in the P/P area can be evaluated based on the amount of risk, natural environmental situation and condition of habitation of the sites as shown in Table 7.11.

Table 7.11 Evaluation of Total Exposure Risk Levels

Exposure Risk Level	Condition of Risk	Evaluation (Living condition)	Counter-measures
5	Very High	- Not appropriate to use for residential, cultivation, industrial and commercial areas	- Need urgent counter-measures for reducing very high risk - Need to announce hazardous nature to the residents in and around the sites
4	High	- Not appropriate to use for residential, cultivation, industrial and commercial areas - Not drinking contaminated groundwater	- Need prompt counter-measures for mitigation against high risk - Need to announce hazardous nature to the residents in and around the sites - Need to announce not drinking contaminated well water - Need to take an official procedure to check the water quality of drinking water
3	Moderate	- Not appropriate to use for residential and cultivation areas, and careful consideration is necessary for land use - Not drinking contaminated groundwater	- Need to implement counter-measures for mitigation against moderate risk - Need to announce hazardous nature to the residents in and around the sites - Need to announce not drinking contaminated well water - Need to take an official procedure to check the water quality of drinking water
2	Low	- Appropriate for any purposes of use	

The grids of total exposure risk levels 5 and 4 in the P/P area are not appropriate areas for use for residential, cultivation, industrial and commercial activities. Particularly, as the grids M35, M34 L35, N35, N34 and O34 are located inside of the urban area of Probistip, it is necessary to take counter-measures for reducing risk by harmful heavy metals as soon as possible.

Although the grids O29, O28, P29 and P28 are designated as the total exposure risk Level 4, the soil contamination is probably derived from the battery factory, and these grids are located near the residential area of Probistip. Hence, it is necessary to take counter-measures for reducing risk by harmful heavy metals.

Water from most of the wells/springs of villages in the P/P area has high concentrations of heavy metals, exceeding the Standard of Drinking Water. It is a serious health problem that the water is used for drinking by local residents in half of villages of the P/P area. It is necessary to conduct chemical analysis of the well/springs water at the accredited laboratory (MoH) to confirm the situation of water quality. If the water is confirmed to be contaminated, the counter-measure should be taken immediately to prevent the local residents to use water for drinking and other sources of water supply must be prepared.

7.1.3 Agricultural Risk Assessment of Crops in the Pilot Project

In this study, "agriculture risk" was defined as "the risks of agricultural products by heavy metals" The agricultural risk includes the risks of human health and economical values of crops by the crops contaminated with heavy metals. The agricultural risk used in the report means "the risks of crops (wheat, rice and corn) by heavy metals".

The agricultural risk of crops generally arise through various pathways from the materials with harmful heavy metals, such as soil, surface water, groundwater, air, dust, fertilizer, agricultural chemicals, etc. to crops. The agricultural risk of crops was assessed by the relationships between contaminated soil and crops using the results of content and elution analyses of soil and content analysis of crops (wheat, corn and rice) in Phases 2 and 3 of the P/P.

(1) Analytical Results of Crops and Soil in Phase 2

For assessing the results of the crops analysis, Cd (0.2mg/kg) and Pb (0.2mg/kg) values of the Maximum levels of heavy metals in foodstuffs of Macedonia were taken.

None of wheat, corn and rice samples exceeds the Standard Value of Cd, however, 30 samples (36%) of wheat, 8 samples of corn and 3 samples of rice exceed the Standard Values of Pb.

The wheat samples exceeding the Standard Values of Pb are mainly distributed in the areas of west of Kiselica River and west of Belosica river, to the southwest of the tailings dams (Appendix 13). Since concentrations of Pb in content and elution analysis are not particularly high in that area, an effect of heavy metal enriched dust may be attributed to high concentrations of Pb in wheat in the area. Since most of the corn and rice samples were collected in the area along the Kiselica and Zletovska Rivers, and high concentration of Pb in corn and rice samples were caused by soil and water with high concentration of heavy metals.

(2) Additional Crops Survey

In Phase 3 (2007), chemical analysis of 32 wheat samples and soil samples was conducted to examine yearly variation of Pb in wheat and relations of Pb concentrations between wheat and soil (Figures 5.36, 5.37 and 5.38).

Pb concentrations of wheat are high, ranging from <0.05 to 0.36mg/kg at an average of 0.12mg/kg, which are lower than the results of the Phase 2 survey with average value of 0.27mg/kg. The samples with Pb concentration exceeding the standard values are seven (22%), which is less than Phase 2 survey when 36% of the samples exceeded the Regulated Value.

The results of 32 wheat and soil samples do not show any clear chemical relation of Pb between wheat and soil samples. The consistently lower concentrations of Pb in 2007 wheat samples than those of 2006 samples probably suggest a yearly variation of Pb concentrations in wheat.

It seems that yearly variations of Pb concentration in wheat caused by weather conditions and etc. exist, suggesting that long term continuous monitoring is necessary to understand the Pb concentration of wheat in the area. Pb concentration of soil, including content and elution, does not play a key role to determine Pb concentration of wheat. A combination of factors such as soil, groundwater, dust, etc. must be considered for understanding the mechanism of Pb concentration of wheat. Based on the results of 2006 and 2007, the samples with high concentration of Pb seem to be distributed in the similar area.. These areas are not recommended for cultivation of wheat as long as this environmental situation continues.

(3) Agricultural Risk Assessment of Crops

The agricultural risk of crops was assessed using the standard value of heavy metals in crops of Macedonia. The agricultural risk of crops, using the Standard Value of Pb content in wheat (0.2mg/kg), is shown together with the exposure risk of Pb in soil in Figure 7.8.

The relationship between Exposure Risk Level of Pb in soil and wheat exceeding the Pb Standard Value, as shown in Table 7.12, is recognized to be not clear, because the rate of the occurrences of contaminated wheat is 25% of total wheat samples collected in the Exposure Risk Level 4 grids, being lower than 39% in the Exposure Risk Level 3 grids. The wheat samples exceeding the Standard Value of Pb content is widely scattered in the area as shown in Figure 7.8. Thus, ,the agricultural risk in the area is relatively high. However, the agricultural risk cannot be clearly divided into agricultural high risk and low risk zones in the area due to the limitation of present survey. As the difference between results of crop analysis in 2006 and 2007 demonstrates annual variation of Pb concentration probably caused by climate conditions and etc., it is necessary to continuously monitor the quality of crops for clarifying the agricultural risk in the area.

Due to the relatively high agricultural risk in the area, the P/P area is thought to be not appropriate agricultural land for wheat. Therefore, it is necessary to examine the mitigation of agricultural risk, including changing of crops, etc. and mitigation counter-measures, including covering of tailings dams, etc. as well as conducting the monitoring of crop analysis for confirming the agricultural risk during the implementation of the counter-measures in the area are necessary. Examples of possible appropriate crops other than wheat are;

- Oil beat (for production of bio-diesel fuel)
- Plants with different purpose and ability to extract heavy metals
- Orchard

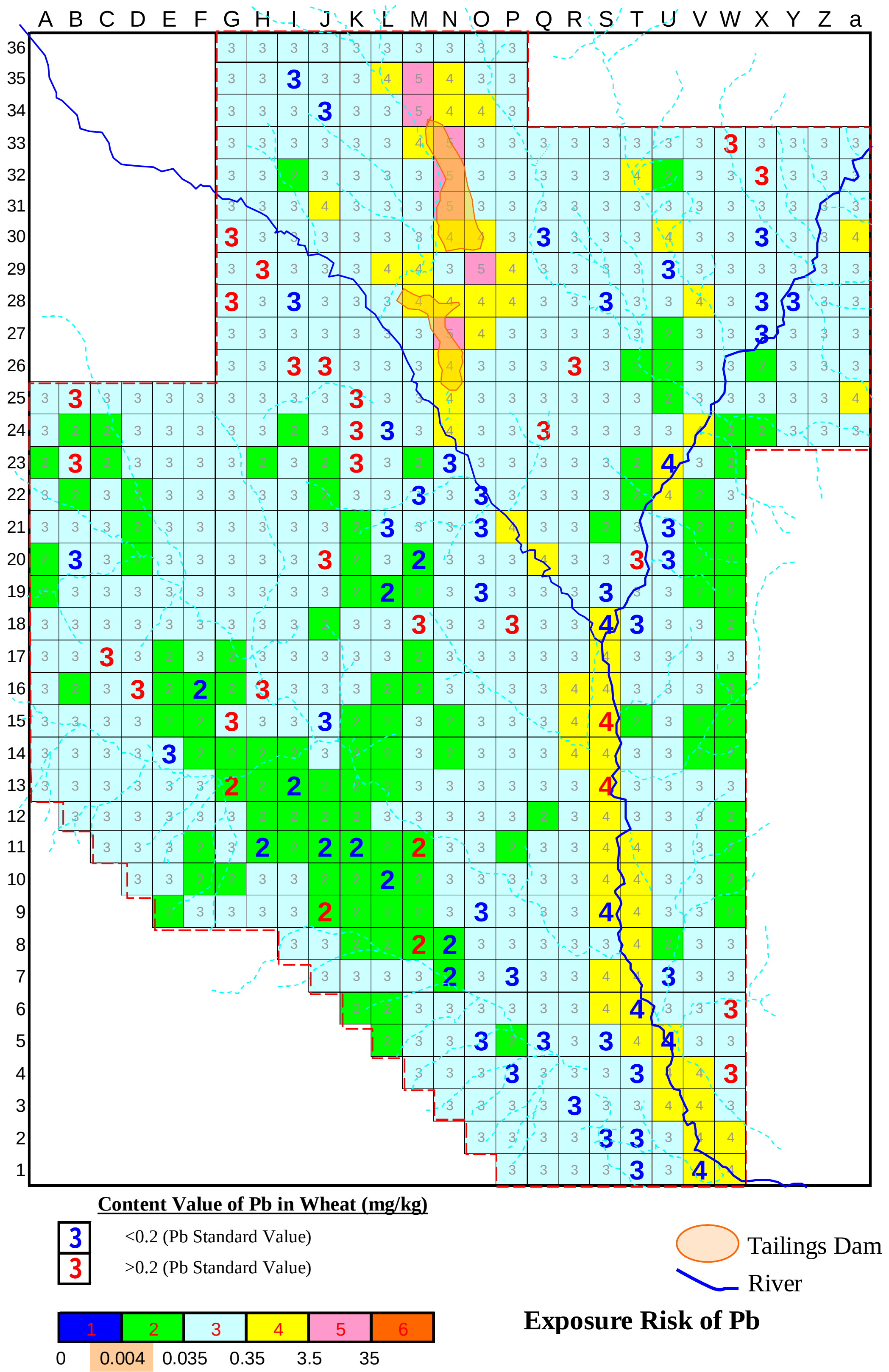


Figure 7.8 Relationship between Exposure Risk of Pb Content Value in Soil and Agricultural Risk of Pb Content Value in Wheat Samples Collected in 2006

Table 7.12 Occurrence of Wheat Exceeding the Pb Standard Value Related to Exposure Risk of Pb Content Value in Soil Based on the Results of 2006

Exposure Risk Level	Number of Grid exceeding Standard Value of Pb Content in Wheat			Rate of Contaminated Wheat (%)	Remarks
	Total	>0.2mg/kg	=<0.2mg/kg		
4	8	2	2	25	- Contaminated wheat is located along the Zletovska River.
3	62	24	38	39	- Contaminated wheat is mainly located in the western half of the area.
2	14	4	10	29	- Contaminated wheat is mainly located in the western half of the area. - Contaminated wheat highly occurs in the area of Level 2.
Total	84	30	54	36	

7.2 Counter-measures for Soil and Groundwater Contamination in the P/P Area

7.2.1 General

In this study, the risk characterisation, exposure risk assessment, agricultural risk assessment of crops, soil and groundwater contamination mechanism, social priority and cost and benefits are particularly taken into account for considering the mitigation against the soil and groundwater contamination in the area.

7.2.2 Potential of the Mine Pollution

Mine pollution mainly depends on the mining methods, type of ore minerals, etc. The Zletovo Mine in the P/P area is operated by underground mining and the main ore minerals are Pb and Zn sulphides.

The main potential origins of mine pollution generally consist of several facilities or areas, including mine sites and facilities, waste dump areas, processing plants (except smelting plant), tailings dams, and existing spilled tailings and other potential in the downstream of the rivers. The main potential influences to the environment derived from the mine facilities in the Zletovo Mine area are described in Table 7.13.

As shown in Table 7.13, the potential and past events of mine pollution by the Zletovo Mine consist of not only soil contamination, but also water (including groundwater) contamination and air pollution as dust. The potential of mine pollution and past contamination of downstream areas continuously exist and will influence the environment in future in the case where no appropriate mitigation actions are taken in the area.

Table 7.13 Main Potential Influences to the Environment Derived from the Zletovo Mine Area

Mine Facilities	Main Potential	Content of Influences to the Environment
1. Mine sites and facilities	1) Adit	- Outflows of mine water (acidic water) containing heavy metals: water and soil contamination, eco-system, etc. - Pumping groundwater: drawdown of groundwater level, etc.
	2) Tunnelling	- Occurrence of caves: influence to surface and subsurface. - Subsidence, collapse, etc.: safety, alteration of landscape. - Mine timber: deforestation, erosion, etc. - Wastes: disposing to the rivers, acidic water, etc.
	3) Construction of facilities	- Deforestation and occurrence of erosion, collapse deterioration of landscape, etc.
	4) Operation of mining facilities	- Exhaust gas: air pollution, deforestation, etc. - Waste water: soil, surface water and groundwater contamination, eco-system, etc. - Domestic waste.
	5) Others	- Alteration of surface water, traffic safety, etc.
2. Waste dump areas	1) Waste dump areas	- Location of dump area: alteration of landscape. - Occurrence of acidic water by oxidation: water contamination: influence to agricultural production, eco-system, etc. - Wastes: run out to the rivers, soil contamination. - Deforestation of areas: erosion, alteration of landscape.
	2) Dust	- Air pollution: SPM (*1), influence to agricultural production, etc. - Soil, surface water and groundwater contamination.
3. Processing plants	1) Waste water	- Outflow of waste water: influence to agricultural production, soil and water contamination by heavy metals.
	2) Dust	- Soil contamination, air pollution.
	3) Chemicals	- Outflow of chemicals: soil and water contamination.
4. Tailings dams	1) Spill out of tailings	- Location of dump area: alteration of landscape, eco-system, landscape, deforestation, etc. - Spill diseases in large and small scale: influence to agricultural production, soil and water contamination, eco-system, landscape, etc.
	2) Seepage water	- Occurrence of acidic water by oxidation: influence to agricultural production, water and soil contamination, eco-system, etc.
	3) Dust	- Soil contamination, air pollution, influence to agricultural production, etc.
5. Downstream (past events)	1) Spill out of tailings and diffusion of tailings in the past	- Advection and diffusion of tailings and soil and water Contamination.
	2) Dust flied in the past	- Diffusion: soil, water, groundwater and air contamination.
	3) Wastes	- Disposed wastes: soil, surface water and groundwater contamination.
	4) Others	- Eco-system, influence to agricultural production, etc.

(*1) SPM: Suspended particulate matter

7.2.3 Examination of Actions Against Soil and Groundwater Contamination in the Pilot Project Area

The potential of mine pollution and past contamination of downstream in the area were clarified by the P/P survey, including surface soil, surface water, groundwater, and drilling surveys. Although the survey particularly focused on the soil grid survey around the tailings dams and their downstream area in order to understand the soil and groundwater contamination in the area, the actions against soil contamination should be developed concerning not only soil but also water and groundwater.

(1) Objectives for the Actions against Soil and Groundwater Contamination

The objectives of the actions against soil and groundwater contamination should be selected based on the integrated risks, consisting of exposure risk to human health through soil and groundwater-human health pathway and agricultural risk to crops through soil-plant pathway, as shown in Figures 7.9 (1) and (2).

The objectives and order of actions against soil and groundwater contamination are selected based on the integrated risk and contamination mechanism in the area (Figure 7.10), and they are listed in Tables 7.14 and 7.15, respectively.

(2) Order of Priority of Objectives for the Actions against Soil Contamination

The factors of high priority for the actions against soil contamination based on the exposure risk assessment of soil and agricultural risk assessment of crops are shown as below.

a. Exposure risk assessment of soil

1) Exposure risk to human health : Higher level of risk
   - No. 1 : Level 4
   - No. 2 : Level 5
2) Contamination mechanism : Contamination sources
   - No. 1 : Primary sources of contamination
   - No. 2 : Secondary sources of contamination

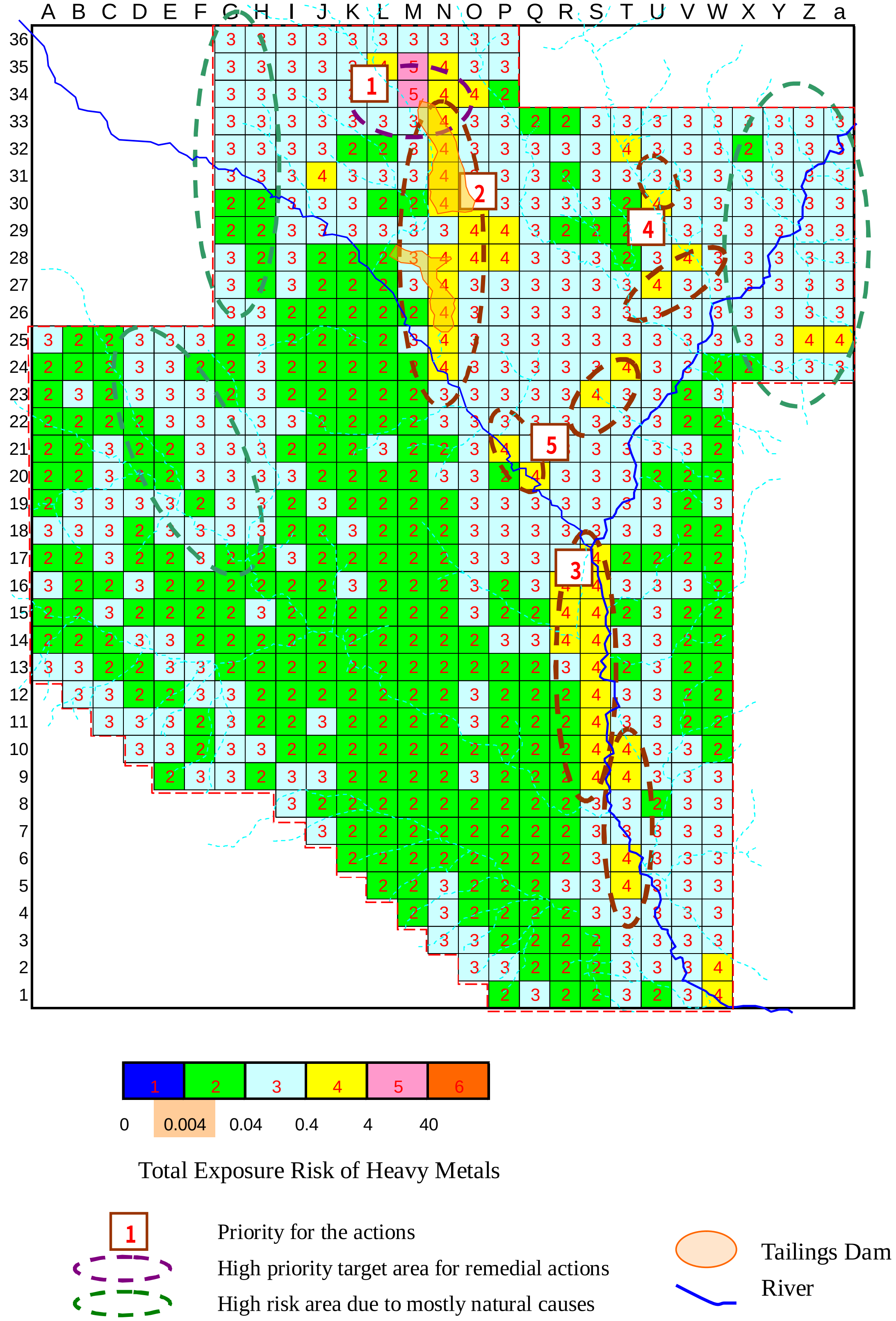


Figure 7.9 (1) Target Locations for Actions Based on the Exposure Risk Assessment (Soil)

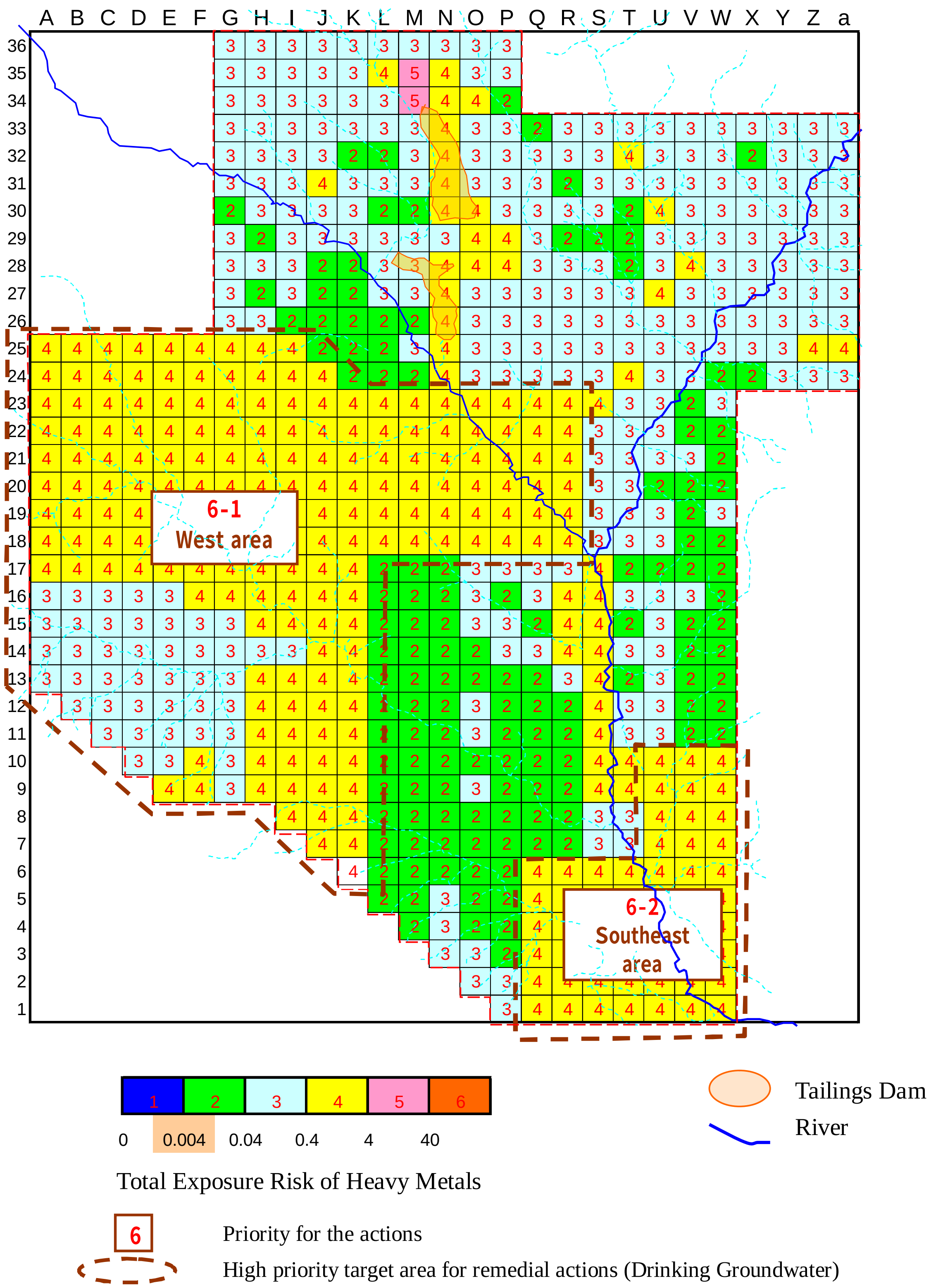


Figure 7.9 (2) Target Locations for Actions Based on the Exposure Risk Assessment (Groundwater)

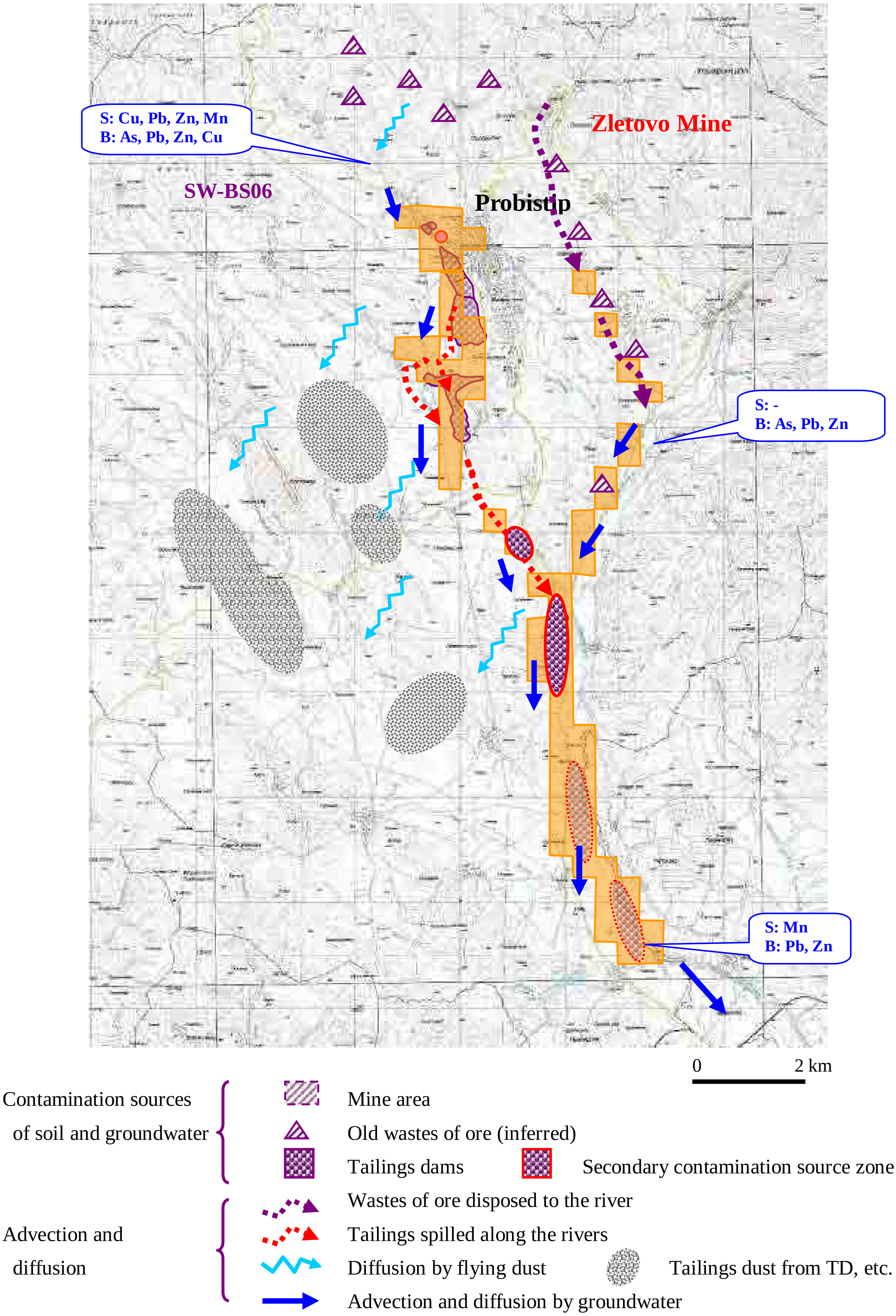


Figure 7.10 Soil and Groundwater Contamination Mechanism in the P/P Area

Table 7.14 Priority of Actions Against Soil and Groundwater Contamination Selected by Integrated Risk

Risk	Priority	Risk Level	Location and Characteristics (*1)	No. of grids	Remarks
(1) Exposure Risk of Soil	No.1	5	1) M34, M35 & N35: TD-I and TD-II (*2) and Processing plant of Zletovo Mine	3	Tailings
	No.2 (*3)	4	1) N30~N33 O30: TD-III, IV & V and their downstream	5	Tailings
			2) O28~O30, P29: Battery plant	4	Industrial wastes
			3) N24~N28: New TD and its downstream	5	Tailings
			4) V30, V27: Koritnica River, much wastes of ore along river	2	Ore wastes at mine site, secondary contamination source
			5) T24, S23, V27: hillside of Koritnica and Zletovska Rivers	3	Possibly by natural causes
			6) P21, Q20: Lower part of Kiselica River	2	Residual tailings, Secondary source
			7) S9~S17, T5~T10: Middle stream of Zletovska River	8	Residual tailings, Secondary source
	No.3	3	1) T5~T6: Lower stream of Zletovska River (4~3)	2	Secondary source (Irrigation)
			2) W1~W2: Lowermost stream of Zletovska River	6	Secondary source (Rice field)
			3) Southeast of Probistip	20	High concentration of As zone
			4) Southern part of the area	10	High concentration of Pb and Zn zone
(2) Exposure Risk of Ground-water	No.1	4~3	1) West area : West, Southwest and central parts of the area	221	Residents in the rural area are using groundwater for drinking.
		4~3	2) Southeast area : southeastern part of the area	62	Residents in the rural area are using groundwater for drinking.
(3) Agri-cultural Risk of Crops		Relatively high	Whole area of the P/P	94	It is not recommended to cultivate wheat in the area.

(*1): Location is same as the 400m grid of soil survey (1grid = 16ha)

(*2): TD = Tailings Dam

(*3): Numbered in the order of from north to south

Table 7.15 Objectives of Actions Against Soil and Groundwater Contamination Selected by Contamination Mechanism

Contamination	Location of Contamination Sources		Present Condition, etc.
1) Soil contamination	Old Tailings Dams	TD-I	Soccer pitches, covered by soil and grass
		TD-II	Sub-station, etc., covered by soil
		TD-III	Covered by soil and re-forestation
		TD-IV	Bare-ground
		TD-V	Bare-ground
	New Tailings Dam		In use at present
	Processing plant		In use at present
	Mine site		In use at present
	New wastes of ore		Dumping and disposal into river
	Old wastes of ore		Not clear
	Battery plant		Disposal of wastes
2) Groundwater contamination	West area River plain along the Kiserica and Zletovska Rivers		Contaminated groundwater by As, Co, Ni and Pb
	Southeast area		Contaminated groundwater by As, Co, Ni and Pb
3) Secondary sources of soil contamination	Lower stream of Kiselica River		River bottom sediments
	Around junction of Kiselica and Zletovska Rivers		Sediments
	Along the Koritnica River		River bottom sediments
	Middle stream of Zletovska River after junction with Kiselica River		Sediments
	Lower stream of Zletovska River		River bottom sediments
4) Surface water and groundwater contamination	Lower stream of Kiselica River		Pasture
	North of the P/P area		Pasture
	Pumping station of Probistip		Pasture
5) Origin of air pollution	Dust occurred from tailings dams		Bare-ground, influence to crops
	Dust occurred from secondary sources of soil contamination		Bare-ground, influence to crops
	Dust from mine sites (old and new wastes dump areas)		Bare-ground, influence to crops

b. Exposure risk assessment of groundwater

1) Exposure risk to human health : Higher level of risk

West area : Level 4 ~ 3

Southeast area : Level 4 ~ 3

c. Agricultural risk assessment of crops

Whole area: relatively high agricultural risk.

Based on above, the order of priority of actions against soil contamination, taking into account the local social condition, is shown in Table 7.16. Note that it is assumed that measures at land owned by private companies (e.g. mining company, battery company) is the obligation of the companies.

Table 7.16 Order of Priority of Actions Against Soil Contamination

Risk	Order of Priority	Location	Objectives	Remarks (Action, etc.)
(1) Exposure Risk of Soil	No.1	Tailings Dams TD-I and II	- Protection of tailings	- Land-use (e.g. planting)
	No.2	Tailings Dams TD-IV and TD-V	- Protection of tailings	- Land-use (e.g. planting)
	No.3	Middle stream of the Zletovska River	- Protection of secondary sediments of tailings	- Need more detailed survey of distribution of tailings
	No.4	Lower stream of the Koritnica River	- Protection of secondary sediments of ore wastes	- Need more detailed survey of distribution of tailings
	No.5	Lower stream of the Kiselica River	- Protection of secondary sediments of tailings	- Need more detailed survey of distribution of tailings
	Others	1) Mine site	- Water control and water treatment	- Responsibility of new mining company, etc.
		2) New Tailings Dam	- Covering slop of dike, water treatment	- Responsibility of new mining company, etc.
(2) Exposure Risk of Ground-water	No.1	1) West area: Drinking groundwater area	- Need to stop drinking contaminated groundwater - Arrangement of temporary water supply to the residents	- Need to take official procedure for drinking water (MoH)
		2) Southeast area: Drinking groundwater area	- Need to stop drinking contaminated groundwater - Arrangement of temporary water supply to the residents	- Need to take official procedure for drinking water (MoH)
(3) Agri-cultural Risk of Crops	-	Whole area of the P/P	- Crops (wheat, corn, rice, etc.)	- Changing land-use - Recommended to changing from wheat to other crops with low risk - Monitoring of crops

7.2.4 Priority of Actions

The priority of actions for soil and groundwater contamination should be determined by results of the risk assessment as shown in Table 7.14, considering soil, surface water and groundwater contamination mechanism, social priority, cost and benefits, etc. Based on these, the order of priority for the actions in the area is shown in Table 7.16 and as below.

(1) Exposure Risk Assessment of Soil)

a. **Priority: No. 1 :** Tailings Dams TD-I and TD-II

- Retaining wall located at northern side of dam, ditches/culverts for collecting seeped water from tailings, and water treatment. Removing tailings and re-use as ore, if possible.

No. 2 : Tailings Dams TD-IV and TD-V

- Covering by uncontaminated soil with re-forestation, retaining wall along foot of dike and ditches/culverts for collecting seeped water from tailings, and water treatment. Changing land-use to car parking area, etc.

No. 3 : Middle stream of the Zletovska River

- Removing tailings, tailings should be returned to the New Tailings Dam. Phyto-remediation/bio-diesel.

No. 4 : Lower stream of the Koritnica River

- Sand controlled dam to stop the contaminated fragment and gravels, installing culverts and water treatment.

No. 5 : Lower stream of the Kiselica River

- Removing tailings: Tailings should be returned to the New Tailings Dam. Phyto-remediation/bio-diesel.

b. Other important actions

1) Mine site

- Water control and water treatment of contaminated mine water.

2) New Tailings Dam

- Covering slope of dike, water treatment of contaminated seeped water.

3) Contaminated residential area of Probistip

- Residential area in the western and southwestern parts of Probistip belongs to Class 1 (Levels 5 and 4 of the exposure risk). Hence, actions for reducing risk and/or relocation of residents are necessary to be conducted at the contaminated area as soon as possible.

(2) Exposure Risk Assessment of Drinking Groundwater

West area and Southeast area in the P/P area

- Recommend to stop drinking groundwater from water wells and springs located in the rural area of Probistip. Also, need arrangement to deliver clean water to the residents.
- Recommend to take an official procedure for drinking water analysis conducting by MoH.

(3) Agricultural risk assessment of crops

Relatively high risk : Whole area of the P/P

- Recommended to change agricultural product from wheat to other products and recommended to promote phyto-remediation/bio-diesel cultivation.
- Recommended to conduct content analysis of crops and/or soil elution analysis.

7.2.5 Remedial Actions and Environmental Management of Soil Contamination Based on the Exposure Risk Assessment of Soil

The remedial actions, with some alternatives, as well as risk (environmental health) management of soil contamination, and approximate cost estimation for each priority, are listed up in Table 7.17 and described as below.

(1) Priority No. 1 : Tailings Dams TD-I and TD-II

Tailings Dam TD-I is presently covered by soil, however the soil has been already contaminated by heavy metals of tailings and partly eroded. In addition, the tailings of TD-I still partly contains high concentrations of Pb and Zn. Therefore, the tailings should be removed to the New Tailings Dam, because the TD-I is located in residential and industrial areas. The tailings could be treated by the floatation process, if possible.

If the TD-I remains in place, the tailings dam should be protected by retaining wall located at the northern side of dam, with construction of ditches/culverts for collecting seeped water from tailings, and water treatment (or pumping up to the processing plant for treatment).

Tailings Dam TD-II is also covered by soil, but tailings have been eroded. Therefore, the slope of dams should be covered by retaining walls with same drainage ditches as shown in Figure 7.11 (2).

In addition, collecting seeped water from tailings and water treatment of seeped water are required, or the collected seeped water could be pumped up to the processing plant and treated.

Table 7.17 (1) Remedial Actions and Alternatives in the Priority Sites (1)

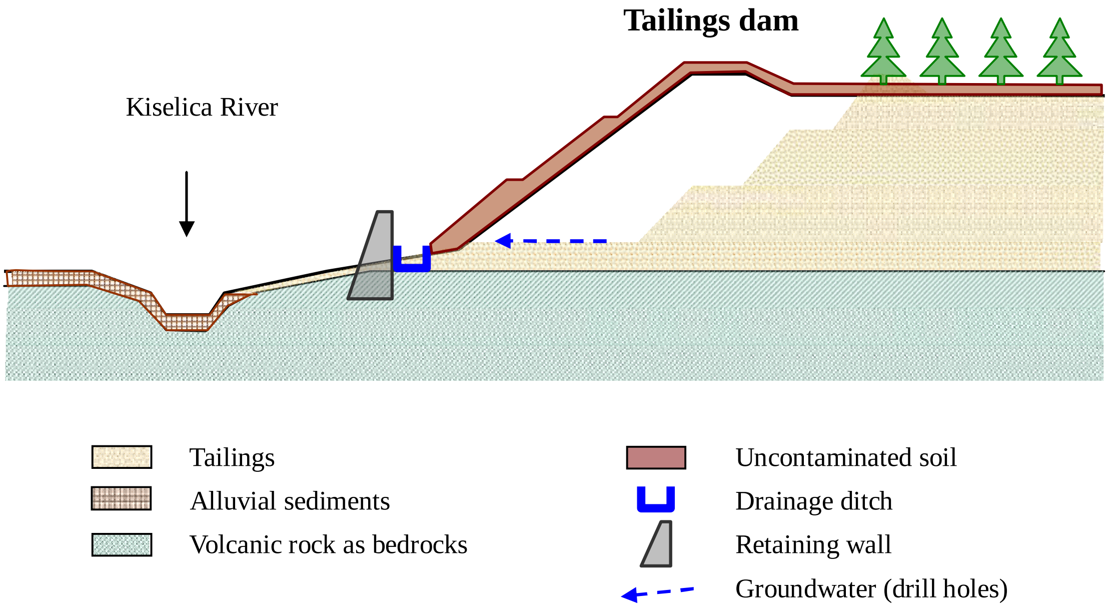
Priority sites	Location and area	Methods of Actions and Alternatives (**A**)	Environmental Risk Management	Cost	Remarks
1. Priority No.1	- Tailings Dams TD-IV and TD-V - Area: flat area 35.5ha slope 11.3ha Total 46.8ha	**A-1:** - Covering of surface and slope by clean soil, thickness: 1.5m (see Figure 7.11 (1)). - Vegetation/forestation: Surface of dams. - Slope: Steps and ditches in each 5m, covering by stones for protection against erosion. - Retaining walls: 1900m long x 10m high, reinforced concrete. - Drainage ditches: Collecting seepage and surface water, and treatment of water, settlement pond.	- Chemical analysis of Covering soil. - Monitoring of seepage water from tailings.	Very high (Obtaining uncontaminated soil is very costly.)	- Soil can probably be taken from hills located 6km southwest of TD-V. - Collected water needs checking quality of water before discharge. - Contaminated seeped water will be pumped back to processing plant for treatment. - Soil test is required for the planning of slope protection of dike.
		A-2: - Covering of surface and slope by uncontaminated soil, thickness: 1.5m (see Figure 7.11 (1)). - Vegetation/forestation: Surface of dams. - Slope: Steps and ditches in each 5m, covering by stones for protection of erosion.	- Chemical analysis of covering soil.	High	
		A-3: - Slope: Steps and ditches in each 5m, covering by uncontaminated soil. - Covering of surface by uncontaminated construction debris, thickness: 2m. - Vegetation/forestation, after covered.	- Chemical analysis of Water. - Monitoring of seepage water from tailings.	High/ Medium (Taking much time.)	- Gravels/rock fragments of relatively big size (>30cm in diameter)
		A-4: - Covering of slope by gravels after smoothing of slope surface (see Figure 7.11 (2)). - Covering of surface by uncontaminated construction debris, thickness: 2m. - Vegetation/forestation, after covered.	- Chemical analysis of Water. - Monitoring of seepage water from tailings.	Medium/ low	

Table 7.17 (2) Remedial Actions and Alternatives in the Priority Sites (2)

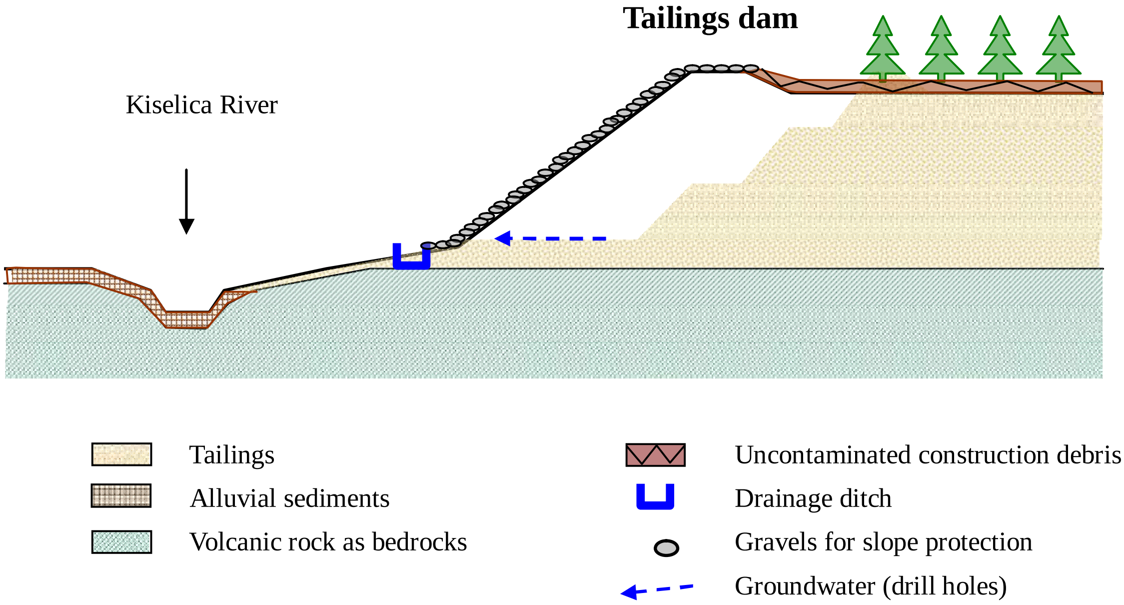
Priority sites	Location and area	Methods of Actions and Alternatives (**A**)	Environmental Risk Management	Cost	Remarks
2. Priority No.2	- Tailings Dams TD-I and TD-II - Area: 1.25ha + 0.5ha	**A-1:** - TD-1: Removing tailings to New Tailings Dam after dressing again, after that need to reclaim by fresh soil, 2m thick. - TD-2: Retaining wall located at western side of dam, ditches/culverts for collecting seeped water from tailings, and water treatment.	- Chemical analysis of covering soil. - Monitoring of seepage water from tailings.	High	1. Priority No.1
		A-2: - TD-1: Retaining wall located at northern side of dam, culvert for seepage water, ditches/culverts for collecting seeped water from tailings, and water treatment. - TD-2: Retaining wall located at western side of dam, ditches/culverts for collecting seeped water from tailings, and water treatment.	- Chemical analysis of covering soil. - Monitoring of seepage water from tailings.	Medium/low	
3. Priority No.3	- Middle stream of the Zletovska River - Area: 60ha	**A-1:** Removing tailings, tailings should be returned to the New Tailings Dam: 5km for transportation from site to New Tailings Dam. Average: thickness of tailings: 0.5m.	- Need more detailed soil survey. - Monitoring of surface water and groundwater.	High	- Removing secondary tailings to New Tailings Dam needs to be agreed by the new mining company. - In case of removing secondary tailings, measure should be taken to prevent extending secondary soil and water contamination.
		A-2: Same as A-1, half size of excavation area.	- Same as A-1.	Medium/ low	
		A-3: Phyto-remediation/bio-diesel.	- Wheat, corn, etc.	Low	
		A-4: Management measures to restrict use of land near the river for agricultural purposes.	- Monitoring of land use needed	Low	- Social implications need to be managed (e.g. compensation).
4-1. Priority No.4	Lower stream of the Koritnica River Area: 32ha	**A-1:** - Sand control dam to stop the contaminated fragment and gravels, install culverts and water treatment. Scale of dam: 15m high, 50m wide, 2 dams.	- Need more detailed survey of sediments, water, groundwater and basement of dam site. - Monitoring of surface water and groundwater.	Medium/ low	- Seeped water from dam should be periodically monitored, and water treatment is considered based on the water analysis.
		A-2: Same as A-1.	- Same as A-1.	Low	

Table 7.17 (3) Remedial Actions and Alternatives in the Priority Sites (3)

Priority sites	Location and area	Methods of Actions and Alternatives	Environmental Risk Management	Cost	Remarks
4-2. Priority No.4	Lower stream of the Koritnica River Area: 32ha	**A-3:** Management measures to restrict use of land near the river for agricultural purposes.	- Monitoring of water. - Monitoring of land use needed.	Low	- Social implications need to be managed (e.g. compensation).
5. Priority No.5	Lower stream of the Kiselica River Area: 32ha	**A-1:** - Removing tailings, tailings should be returned to the New Tailings Dam.	- Need more detailed soil survey. - Monitoring of surface water and groundwater.	High	- Removing tailings to New Tailings Dam needs to be agreed by the new mining company. - In case of removing secondary tailings, measure should be taken to prevent extending secondary soil and water contamination.
		A-2: Phyto-remediation/bio-diesel		Low	
		A-3: Management measures to restrict use of land near the river for agricultural purposes.	- Monitoring of land use needed.	Low	- Social implications need to be managed (e.g. compensation).
6. Other sites	1- Mine site: water	**A-1:** Control and water treatment, monitoring	- Water treatment	-	- Responsibility of mining company
	2- New Tailing Dam	**A-1:** Covering slope of dike, monitoring	- Water treatment	-	- Responsibility of mining company
	3) Lowermost stream of Zletovska River	**A-1:** Phyto-remediation/bio-diesel	- Pb, Zn, Mn :Rice	Low	- Crops analysis of wheat, corn and rice
		A-2: Management measures to restrict use of land near the river for agricultural purposes.	- Monitoring of land use needed.	Low	- Social implications need to be managed (e.g. compensation).
	4) South of Probistip	**A-1:** Phyto-remediation/bio-diesel	- As: Wheat	Low	- Crops analysis of wheat, corn and rice
		A-2: Management measures to restrict use of land near the river for agricultural purposes.	- Monitoring of land use needed.	Low	- Social implications need to be managed (e.g. compensation).



(1) Slope Protection and Covering of Surface of TD-IV and V



(2) Slope Protection by Gravels

Figure 7.11 Remedial Actions for Tailings Dams of TD-II, TD-IV and TD-V

(2) Priority No. 2 : Tailings Dams TD-IV and TD-V

Tailings Dams TD-IV and TD-V should be covered by uncontaminated soil and vegetation/ forestation for protection of advection of tailings by water and dust. As the slope of dikes of tailings dams are not stable and eroded at many places as gulley erosion, a retaining wall along the foot of the dike is needed as well as ditches/culverts for drainage, as shown in Figure 7.11 (1).

In the case of using uncontaminated construction debris for covering surface of tailings and gravels for slope protection as shown in Figure 7.11 (2), the mitigation cost is likely to be low.

In addition, collection of seeped water from tailings and water treatment of seeped water are required, or collected seeped water could be pumped up to the processing plant and treated.

(3) Priority No. 3 : Middle Stream of the Zletovska River

The secondary emplaced tailings widely exist in the middle stream of the Zletovska River. The secondary tailings contain much heavy metals and are causing not only soil contamination but surface water and groundwater contamination as shown in Figure 7.12. Therefore, they should be removed and they should be returned to the New Tailings Dam.

However, a more detailed survey for the tailings is required in the area to identify opportunities for reducing the cost of actions before removing the tailings.

In the case of removing secondary tailings, measuring works should be conducted for extending secondary soil and water contamination.

Meanwhile, management measures to restrict the use of the land near the river for certain high risk agricultural activities should be implemented. However, it should be noted that this does not address the environmental impacts and does not fully mitigate the health impacts, but management measures would reduce the health risks. Also, social implications would need to be managed (e.g. through compensation).

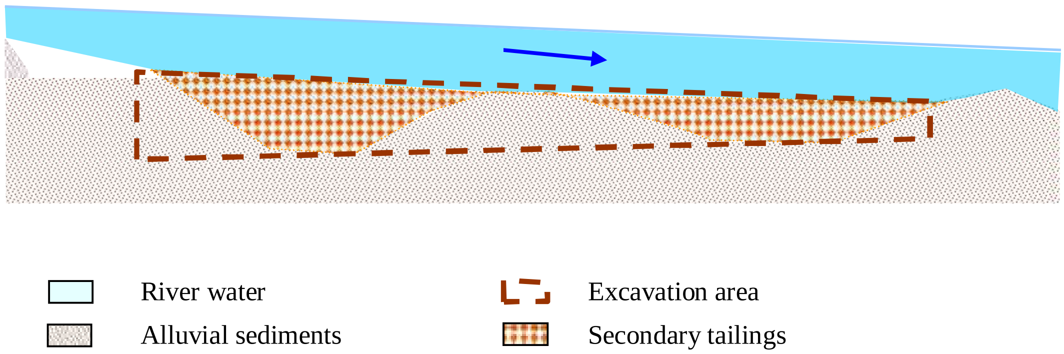


Figure 7.12 Secondary Emplaced Tailings in the Middle Stream of the Zletovska River

(4) Priority No. 4 : Lower Stream of the Koritnica River

Numerous fragments and gravels of ore wastes containing high concentrations of heavy metals remain in the lower stream of the Koritnica River. The contaminated sediments will be emplaced by the sand controlled dams with installed culverts as shown in Figure 7.13.

In the case that newly generated fragments of ore wastes will be disposed at the mine site in accordance with the environmental management in future, and the old fragments should be emplaced by the sand control dam as shown in Figure 7.13. The retention water behind the dam would be periodically taken from culvert and analysed, and treated if necessary.

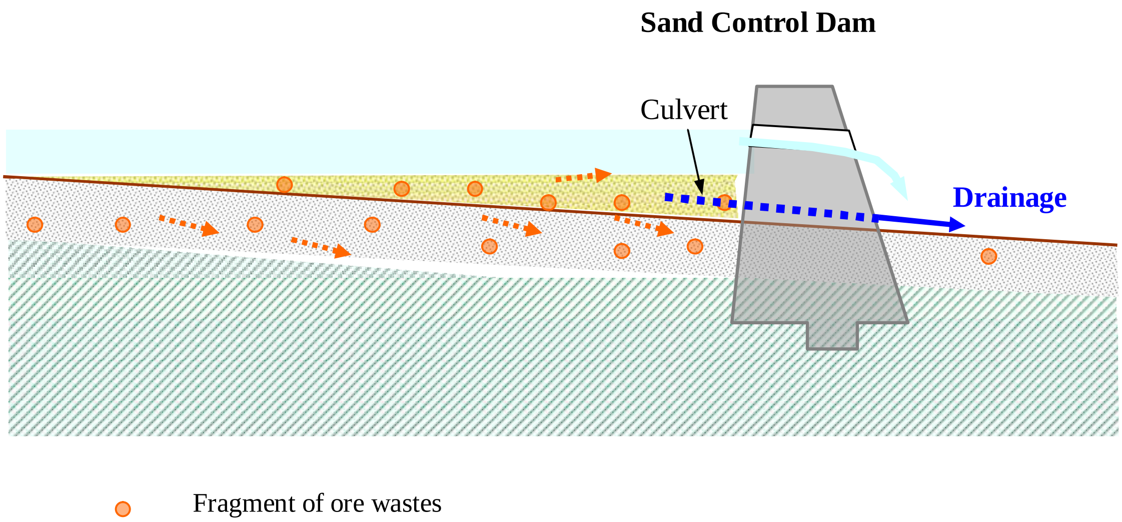


Figure 7.13 Sand Controlled Dam in the Lower Stream of the Koritnica River

In addition, management measures will be needed in some areas to restrict specific high risk agricultural land use. Although these management measures will reduce the health risks, the mitigation measures described above are also needed. The social implications of the management measures will need to be managed (e.g. through compensation).

(5) Priority No. 5 : Lower Stream of the Kiselica River

The secondary replaced tailings locally remain in the lower stream of the Kiselica River. The secondary tailings contain much heavy metals and cause not only soil contamination but also water contamination as shown in Figure 7.10. Therefore, these should be removed and returned to the New Tailings Dam.

However, a more detailed survey for the tailings is required in the area to identify opportunities for reducing the costs of actions before removing the tailings.

In the case of removing secondary tailings, measuring works should be conducted for extending secondary soil and water contamination.

This area is likely to be a suitable location for phyto-remediation and/or bio-diesel.

In addition, management measures to restrict the use of the land near the river for certain high risk agricultural activities should be implemented. However, as mentioned above, these will not address the environmental impacts and do not fully mitigate the health impacts, but would reduce the health risks. Also, social implications would need to be managed (e.g. through compensation).

(6) Other Important Actions

Other important actions consist of water control and water treatment in the mine site and operating tailings dam, which mostly are the responsibility of the mining company with respect to its environmental risk management.

a. Mine Site : Water Control and Water Treatment

Water quality control at the mine site, as well as the processing plant, is very important for environmental management. If the discharge water is contaminated (exceeding the environmental standards for water of Macedonia), it should be treated and discharged after the water quality is checked.

b. New Tailings Dam : Covering Slop of Dike, Water Treatment

Numerous tailings materials are scattered by wind from the New Tailings Dam; particularly down the slope of the dike there are much tailings. Therefore, it is necessary to cover the slope with gravel for protection of wind erosion and of small scale collapses. In addition, water control of seepage water from the tailings dam should be periodically carried out and reported. If the discharge water is contaminated (exceeding the environmental standards for water), it should be treated and discharged after checking the water quality.

c. Lowermost Stream of Zletovska River

Lowermost stream of the Zletovska River is dominated by rice field, but the crops are subject to heavy metals (Cd, Pb, etc.) contamination. This area is likely to be a suitable location for phyto-remediation and/or bio-diesel.

In addition, management measures to restrict the use of the land near the river for certain high risk agricultural activities could be implemented.

d. South of Probistip

South of Probistip is dominated by wheat fields, but the crops are subject to heavy metals (As, Pb, etc.) contamination. This area is also suitable location for phyto-remediation and/or bio-diesel.

In addition, management measures to restrict the use of the land near the river for certain high risk agricultural activities could be implemented.

(7) Risk Analysis of Remedial Actions of Soil Contamination

Risk analysis in relation to implementation of the remedial actions of soil contamination by each alternative has been re-calculated and rough cost estimations are shown in Tables 7.17.

a. Case - 1: Implementation of Alternative-1 in All Areas of Priority No.1 to No.5

- Priority No. 1: A-1 : Removing TD-I, retaining walls for TD-II with drainage
- Priority No. 2: A-1 : Complete covering of surface and slope of TD-IV to V with drainage
- system and retaining walls for protection of slope erosion
- Priority No. 3: A-1 : Removing secondary tailings
- Priority No. 4: A-1 : Sand control dams (2 sets)
- Priority No. 5: A-1 : Removing secondary tailings

In case of implementation of A-1 actions, Level 5 (1000 to 100 x TDI) and Level 4 (100 to 10 x TDI) would disappear as shown in Figure 7.14 and total risk of heavy metals would be extremely reduced in the area. However the mitigation cost is very high, even if the mitigation method is simple.

b. Case - 2: Implementation of Alternative-2 in Area of Priority No.2

- Priority No. 1: No measure.
- Priority No. 2: A-2 : Covering of surface and slope of TD-IV to V with drainage system
- Priority No. 3: No measure.
- Priority No. 4: No measure.
- Priority No. 5: No measure.

In case of implementation of A-2 actions in Priority No.2, Level 4 of risk in the TD-IV and V would disappear. However, Levels 5 and 4 around the TD-IV and V would be not reduced (Figure 7.15) and the actions would still be costly.

c. Case - 3: Implementation of Alternative-2 in Area of Priority No.1 to No.5

- Priority No. 1: A-2 : Retaining walls for TD-I and TD-II with drainage
- Priority No. 2: A-2 : Covering of surface and slope of TD-IV to V with drainage system
- Priority No. 3: A-2 : Removing secondary tailings (half area)
- Priority No. 4: A-2 : Sand control dam (1 set)
- Priority No. 5: A-2 : Phyto-remediation

In case of implementation of A-2 actions, level 5 of risk would disappear and level 4 would be reduced in many areas. Hence, it is possible to say that the Alternative-2 is effective in case of total implementation of actions in the area (Figure 7.16). However, the mitigation cost is relatively high, because covering of tailings and sand control dam are still costly.

d. Case - 4: Implementation of Alternative-3 in the Priority No.1, No.3 to No.5

- Priority No. 1: A-3 : Retaining walls for TD-I and TD-II with drainage
- Priority No. 2: A-2 : Covering of surface of TD-IV to V by construction debris and slope protection by fresh soil with drainage system
- Priority No. 3: A-3 : Phyto-remediation
- Priority No. 4: A-3 : Monitoring and management measures
- Priority No. 5: A-3 : Phyto-remediation

In case of implementation of mainly A-3 actions, Level 5 of risk would disappear and Level 4 would be reduced in some areas same as Case-3. The mitigation cost is relatively low. Hence, it is possible to say that the Alternative-3 is effective in case of total implementation of actions in the area, but it will require much time.

e. Case - 5: Implementation of Alternative-4 in Priority No.1 and No.3

- Priority No. 1: A-4 : Retaining walls for TD-I and TD-II with drainage
- Priority No. 2: A-2 : Covering of surface of TD-IV to V by construction debris and slope protection by gravels with drainage system
- Priority No. 3: A-4 : Management measures
- Priority No. 4: A-3 : Monitoring and management measures
- Priority No. 5: A-3 : Phyto-remediation

In case of implementation of mainly A-4 actions, Level 5 of risk would disappear and Level 4 would be reduced in some areas same as Case-3. The mitigation cost is lower than that of others. Hence, Case-5 is recommendable, but it will require much time.

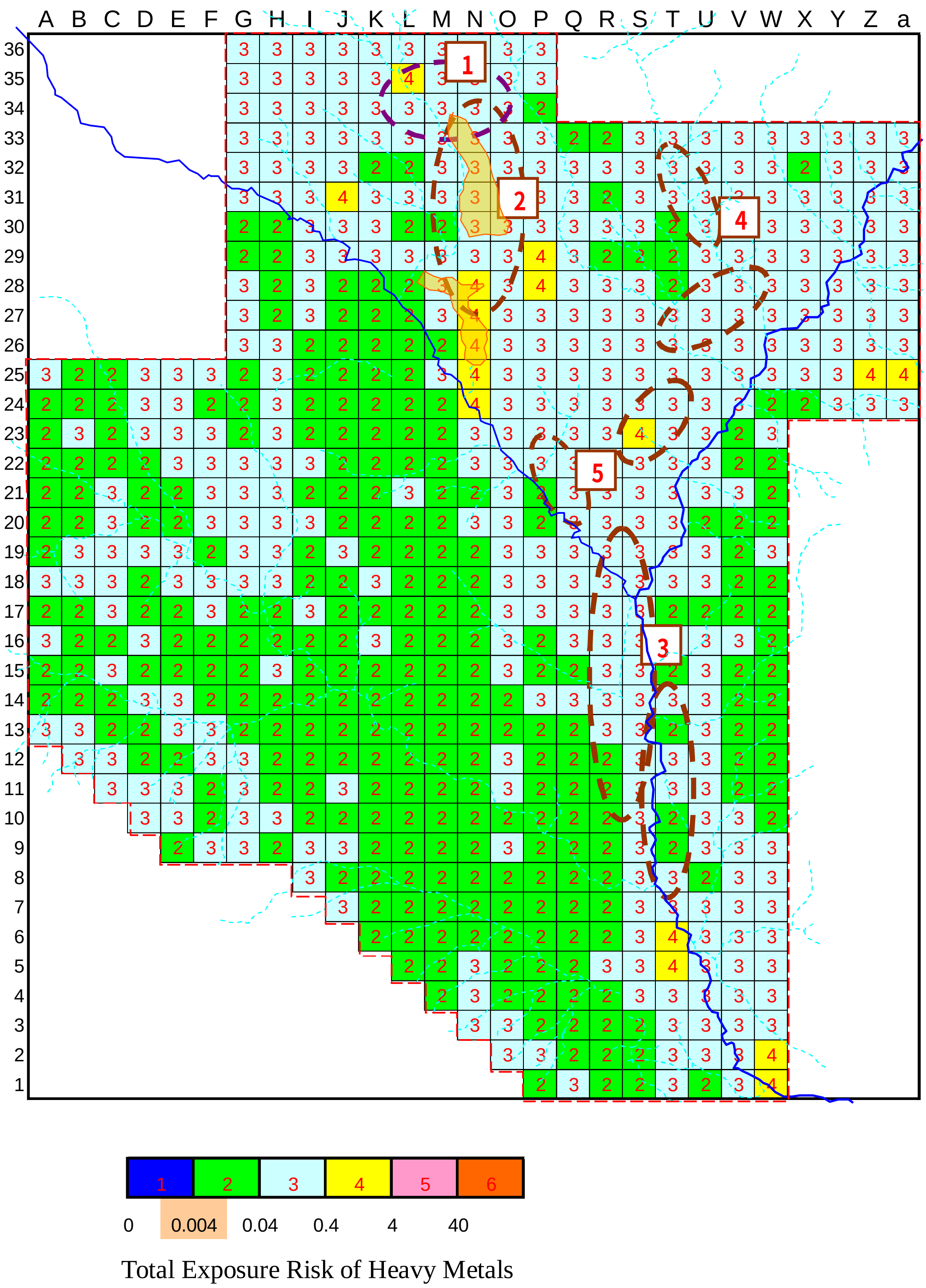
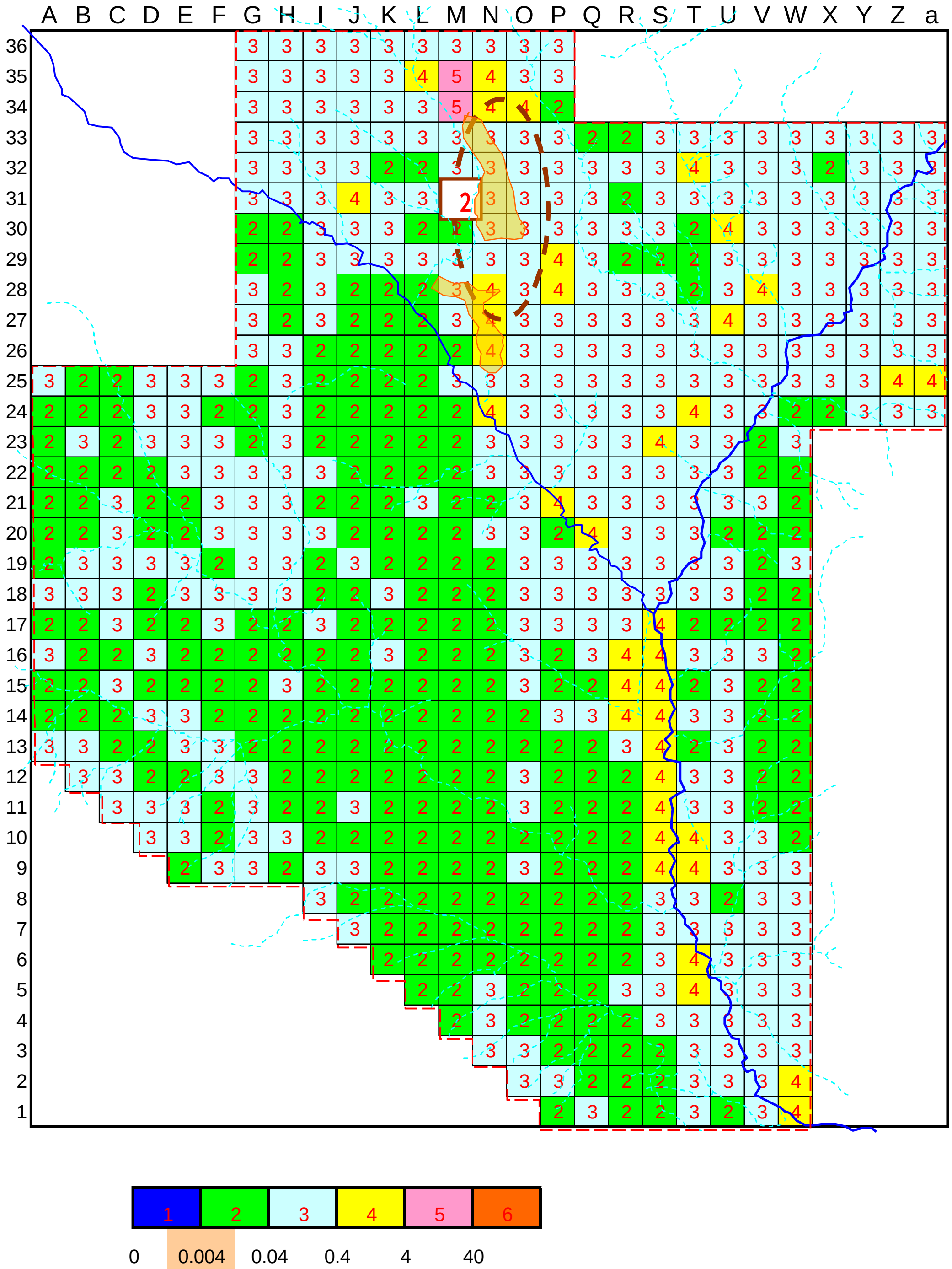


Figure 7.14 Case -1: Implementation of Alternative-1 in All of the Priority No.1~No.5 Areas



Total Exposure Risk of Heavy Metals

Figure 7.15 Case -2: Implementation of Alternative-2 in Area of Priority No.2 Area

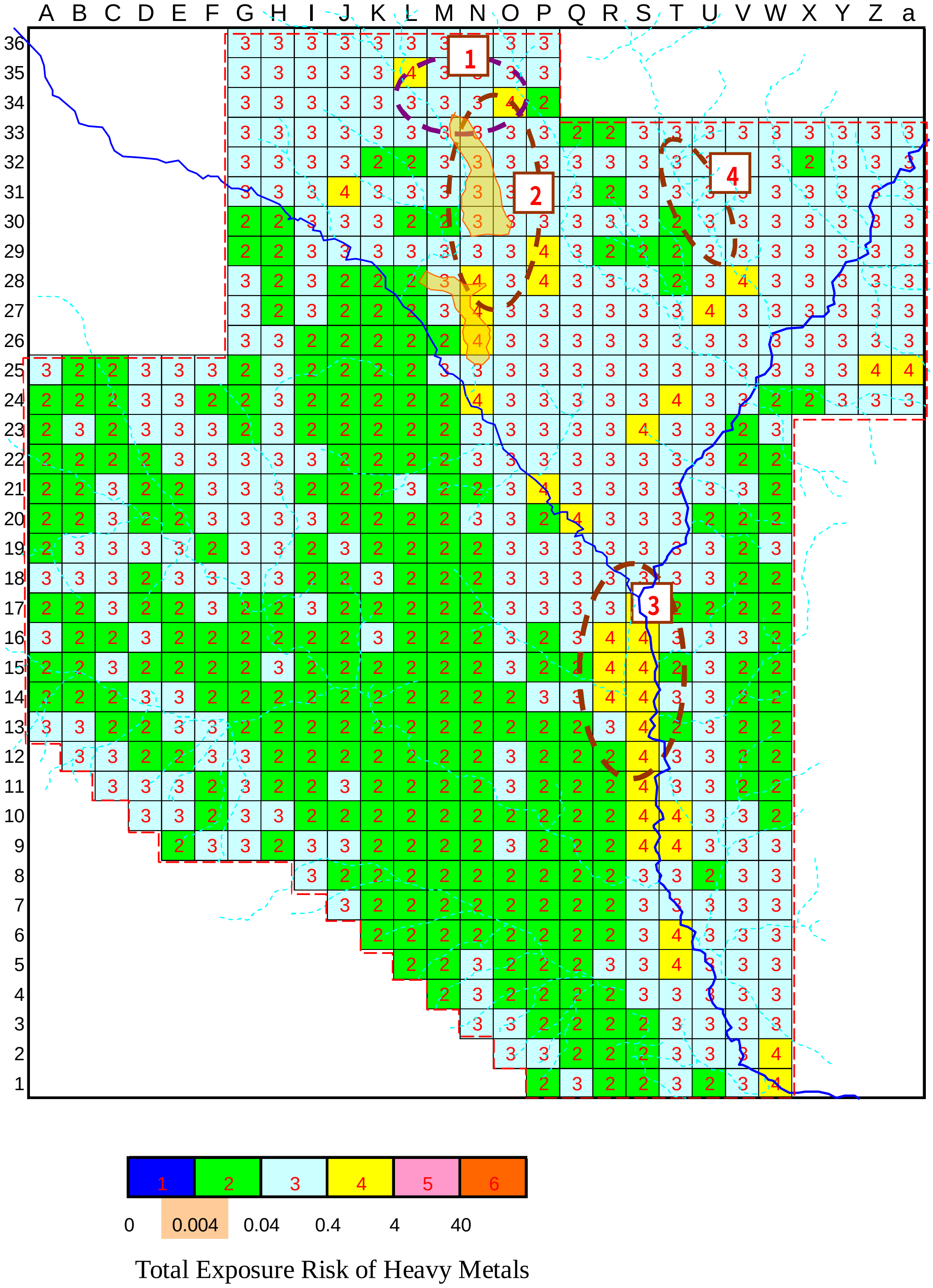


Figure 7.16 Case -3: Implementation of Alternative-2 in All of the Priority No.1 to No.5 Areas

7.2.6 Actions and Environmental Management of (drinking) Groundwater Contamination Based on the Exposure Risk

As results of the Additional Groundwater Survey in the P/P area, groundwater in the area is clarified to be contaminated by harmful heavy metals, including As, Co, Ni and Pb. Almost half of residents living in the west and southeast of the P/P area are drinking groundwater with high heavy metal concentrations from water wells.

As an action against the contaminated groundwater, it is necessary to take an official procedure for checking water quality of drinking water by MoH. In case that the drinking groundwater in the area is confirmed to be contaminated by the official procedure, it is necessary to take promptly the following actions.

(1) Contaminated Groundwater in the Area

1 Confirmation of contaminated groundwater by the official procedure
2 Announce to the residents to stop drinking groundwater
3 Holding the Explanatory Meeting to the residents in the area
4 To stop drinking groundwater and to deliver clean drinking water to the residents as emergency counter-measures
5 Implementation of permanent counter-measures to deliver water supply

The best counter-measure for the drinking groundwater is to stop drinking it as this would reduce the direct exposure risk by harmful heavy metals. Concerning indirect exposure risk of contaminated groundwater such as irrigation, livestock and living water, this water is thought to be indirectly affecting human health. Therefore, it is better not to use contaminated groundwater in the area. Alternative water supplies will need to be provided

(2) Counter-measures for Contaminated Groundwater in the Area

Counter-measures for contaminated groundwater by harmful heavy metals, including As, Co, Ni and Pb, mainly consist of pumping and water treatment off site, water treatment in site, etc.

- Water treatment off site (after pumping) : Coagulating precipitation method, absorption method by zeolite, substitution method, etc.
- Water treatment in site : Reaction wall method by zeolite, etc.

However, the area of contaminated groundwater in Probistip is too wide and contamination sources of groundwater are extensively scattered in the area. Also, water treatment is costly, hence, water treatment off and/or in site in the P/P area is thought to be not feasible.

7.2.7 Actions and Environmental Management of Soil Contamination Based on the Agricultural Risk of Crops

The wheat samples exceeding the Standard Value of Pb content is widely scattered in the area。 Thus, ,the agricultural risk in the area is relatively high. However, the agricultural risk cannot be clearly divided into agricultural high risk and low risk zones in the area due to the limitation of present survey. As the difference between results of crop analysis in 2006 and 2007 demonstrates annual variation of Pb concentration probably caused by climate conditions and etc., it is necessary to continuously monitor the quality of crops for clarifying the agricultural risk in the area.

Due to the relatively high agricultural risk in the area, the P/P area is thought to be not appropriate agricultural land for wheat. Therefore, it is necessary to examine the mitigation of agricultural risk, including changing of crops, etc. and mitigation counter-measures, including covering of tailings dams, etc. as well as conducting the monitoring of crop analysis for confirming the agricultural risk during the implementation of the counter-measures in the area are necessary. Examples of possible appropriate crops other than wheat are;

- Oil beat (for production of bio-diesel fuel)
- Plants with different purpose and ability to extract heavy metals
- Orchard

7.2.8 Cost and Benefit Analysis

The cost is approximately estimated in Table 7.18, and the benefit of actions can be related to the reduction of risk. Because of unknown factors, only rough cost estimation for actions was done using four ranks of cost: very high, high, medium and low. The actions for the four ranks are given in Table 7.18.

The benefits of the actions were calculated from the reduction of risk. Since the level of risk (Level 1 to 5) for each grid is classified using logarithm number, the weighted value shown below was used for calculation of the risk of the each grid. The benefit of the actions (reduction of risk) is obtained by subtracting the total of weighted value from the original benefit level. The amount of risk is related to the number of levels as shown in Table 7.19. Hence, the approximate analysis of cost and benefit is shown in Table 7.19 and Figure 7.17.

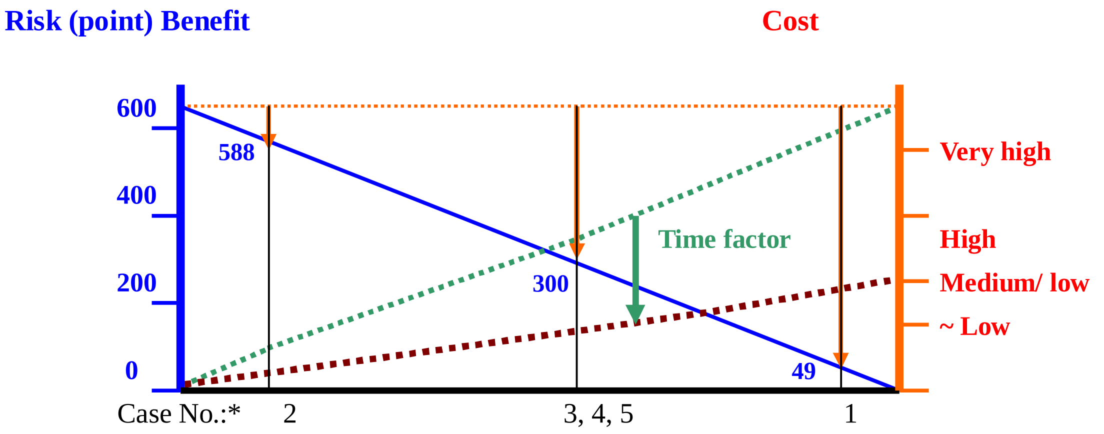
Original benefit level:	Level-5:	1 grid	x 100	= 100
	Level-4:	32 grids	x 10	= 320
	Level-3:	214 grids	x 1	= 214
		Total		634 points

Table 7.18 Approximate Cost and Actions

Cost	Approximate Cost (see Appendix - 14)	Actions	
		Tailings Dam	Along the Zletovska and Kiselica Rivers
Very high	6 million Euro	Covering of surface and slopes by uncontaminated soil, construct retaining wall.	Removing contaminated materials, construct sand control dam
High	1.6 to 2.5 million Euro	Covering of surface and slopes by uncontaminated soil.	
Medium	~ 1.0 million Euro	Coverage of surface by construction debris and slope protection by gravels.	Phyto-remediation
Low	~ 0.6 million Euro	Coverage of surface by construction debris and slope protection by gravels, re-use of tailings material as ore..	Phyto-remediation

Table 7.19 Cost-Benefit Analysis of Remedial Actions

Case	Content	Cost	Benefit (Risk)	Counter-measures Time
Case-1	- Alternative - 1 in all areas of Priority No.1 to No.5	Very high	Level-5: 1 x 100 = 100 Level-4: 27 x 10 = 270 Level-3: 218 x 1 = 218 588 points	Relatively short time
Case-2	- Alternative - 2 in Priority No.2 area	High	Level-5: 0 x 100 = 0 Level-4: 0 x 10 = 0 Level-3: 49 x 1 = 49 49 points	Relatively short time
Case-3	- Alternative - 2 in all areas of Priority No.1 to No.5	High	Level-5: 0 x 100 = 0 Level-4: 8 x 10 = 80 Level-3: 225 x 1 = 225 Approx. 300 points	Relatively short time
Case-4	- Alternative - 3 in areas of Priority No.1, No3, No4 and No.5	Medium/ low	Level-5: 0 x 100 = 0 Level-4: 8 x 10 = 80 Level-3: 225 x 1 = 225 Approx. 300 points	Long time
Case-5	- Alternative - 4 in areas of Priority No.1 and No.3	Low	Level-5: 0 x 100 = 0 Level-4: 8 x 10 = 80 Level-3: 225 x 1 = 225 Approx. 300 points	Long time



Risk (original risk: 634 points)
Cost of risk mitigation by removing contaminated materials along the rivers
Cost of risk mitigation by phyto-remediation
Benefit by risk mitigation
Time factor necessary for photo-remediation
*: Case No: alternatives of remediation actions

Figure 7.17 Cost Benefit (Risk) Analysis of Remedial Actions

As a result of cost and risk (benefit) analysis, it is possible to say as follows:

1. Composite actions implemented in many places seem to be more benefit than single counter-measures in the P/P area.
2. Alternative-3 of actions is less costly than Alternative-1 and Alternative-3 is thought to be more effective than Alternative-2.

In addition, phyto-remediation is thought to be effective in areas the priority No. 3, No. 5 and other sites, including lower stream of the Zletovska River and south of Probistip.

Also, management measures should be considered to restrict specific agricultural use in some areas of land. However, the social implications of such measures would need to be managed.

Economic analysis of land-use and benefit was not conducted. The discussion of actions against soil contamination can be important information when considering the risk communication. The actual and specific actions for soil contamination must be discussed through the risk communication including stakeholders.