

Appendix

Procedure of pollution potential area establishment and origin evaluation of groundwater arsenic

1. Establishment of potential areas for groundwater arsenic (As) pollution

- 1.1 According to the results of worldwide previous investigations on As-polluted groundwater, the geochemical characteristics of As-polluted groundwater and sedimentary can be summarized as follow:
 - 1.1.1 Most of Long-term groundwater As concentrations exceeds Groundwater Pollution Monitoring Standards: Due to the slow velocity of groundwater flow, the variation of groundwater As concentration is slight within the undisturbed groundwater As potential area. Groundwater As concentrations over the years mostly exceeded Groundwater Pollution Monitoring Standards.
 - 1.1.2 Relatively higher As contents are found in geological sediments: due to great As contents deposited in geological sediments, and is the main source of As-polluted groundwater, thus the monitoring wells with higher As concentration groundwater, their screens' interval sediments also have higher As concentration. Generally, background As concentrations of non-polluted sediments are mostly lower than 20 mg/L.
 - 1.1.3 Geological sediment is mostly composed of silty clay with fine-sand: The fine sediment with silty clay facilitates for reduction reaction and As enrichment in subsurface environment. The sediment profile of geological drilling by setting the monitoring wells can be adopted for evaluating the potential of groundwater As pollution.
- 1.2 According to the results of periodical groundwater quality monitoring,

the catchments with aforementioned hydrogeological characteristics in Taiwan are Choushui river alluvial fan, Chianan plain, Pingtung Plain, Lanyang Plain. The groundwater As pollution potential areas of these 4 catchments are shown in Appendix Table 1.

- 1.3 If the groundwater As concentration is detected and exceeds the Groundwater Pollution Monitoring Standards in aforesaid potential areas, the emergency measure is not necessary. The origin of groundwater As then can be referred to hydrogeological conditions and environmental background.
- 1.4 The aforesaid groundwater As pollution potential areas should be adjusted based on the results of periodical groundwater quality monitoring.

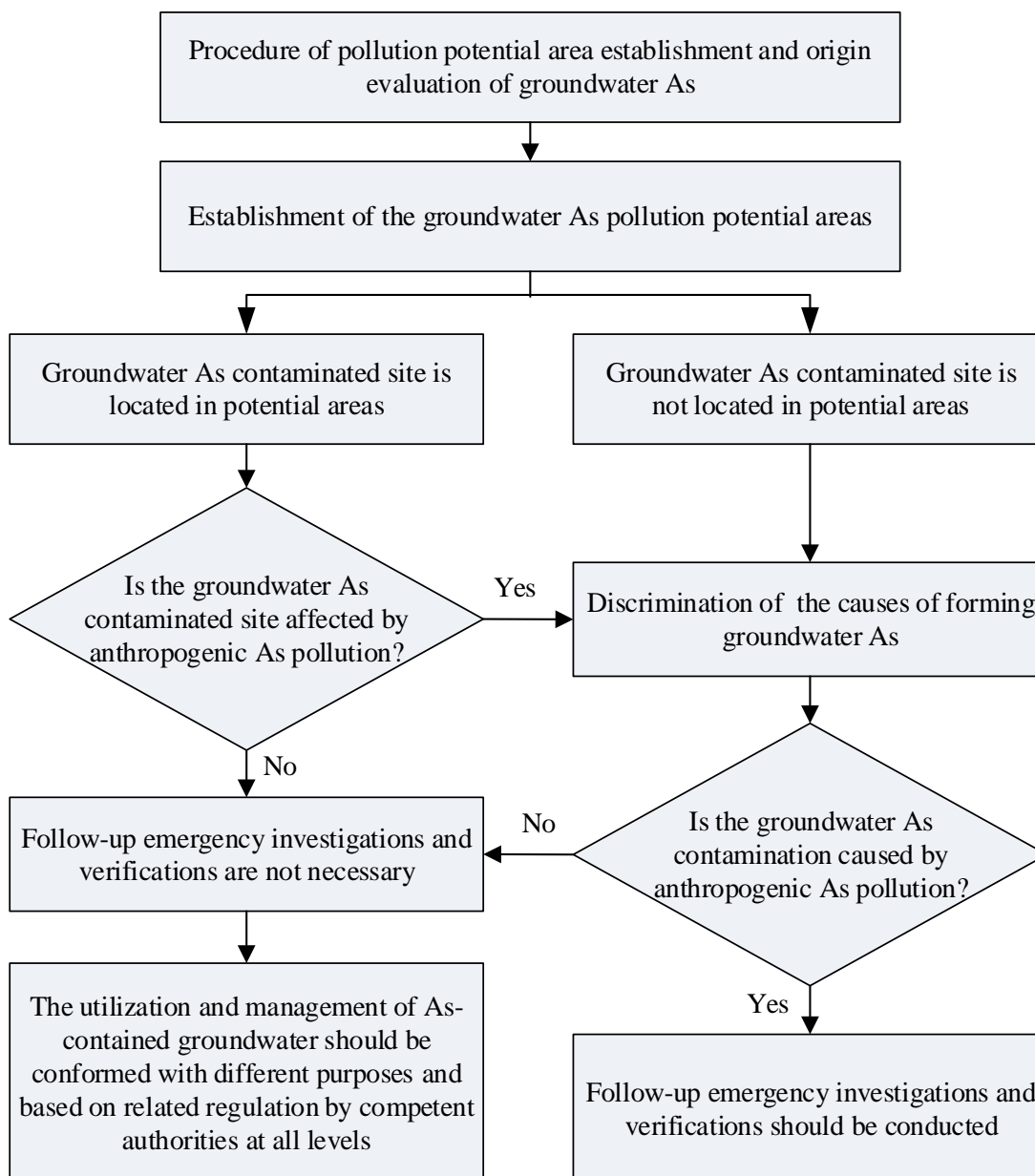
2. Evaluating the origin of groundwater As

- 2.1 Origin of groundwater As should be investigated under the following situations (Appendix Figure 1):
 - 2.1.1 Groundwater As contaminated sites are not located in aforesaid potential areas.
 - 2.1.2 Groundwater As contaminated sites are located in aforesaid potential areas and maybe affected by external As pollution.
- 2.2 Under the aforementioned situations, the procedure of evaluating the origin of groundwater As should be considered (Appendix Figure 2) to discriminate the causes of forming groundwater As. The procedure includes at least following steps:
 - 2.2.1 The hydrogeological characteristics and human activities of the contaminated site should be collected. The investigation coverage of groundwater As pollution should be established.
 - 2.2.2 The groundwater levels variation, groundwater quality data, geological characteristics of the existed wells around the contaminated site should be collected to preliminary evaluate the possibility of reaching for reasons not attributable to external pollution.

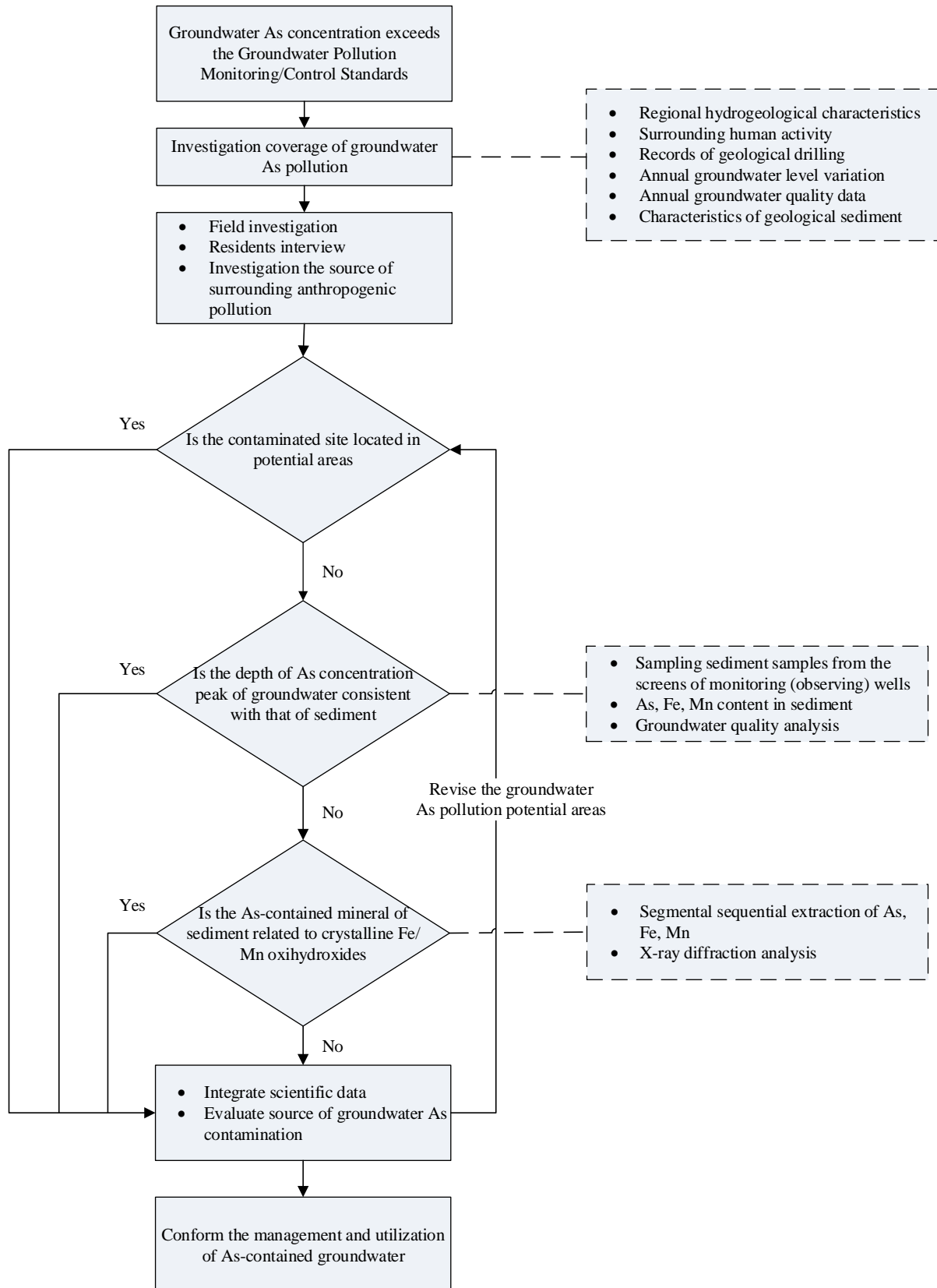
- 2.2.3 The field investigation and residents interview should be conducted to evaluate the possibility of the source of surrounding anthropogenic pollution.
 - 2.2.4 According to the aforementioned groundwater As pollution potential areas, if the contaminated site is located in potential areas and is reached for reasons not attributable to external pollution, then the follow-up emergency investigations and verifications are not necessary.
 - 2.2.5 If the contaminated site is not located in potential areas, it needs to collect the groundwater and sediment samples from the screens of monitoring wells to conduct the analysis of total As-content; in addition, if the depth of As concentration peak of groundwater is consistent with that of sediment, and is reached for reasons not attributable to external pollution, then the follow-up emergency investigations and verifications are not necessary.
 - 2.2.6 If the depth of As concentration peak of groundwater is not consistent with that of sediment, the segmental sequential extraction and X-ray diffraction analysis are necessary to confirm the As-contained mineral phases, and Fe/Mn minerals; in addition, if it relates to crystalline Fe/Mn oxihydroxides, and are reached for reasons not attributable to external pollution, then the follow-up emergency investigations and verifications are not necessary.
 - 2.2.7 Emergency investigations and verifications of soil and groundwater are necessary if the As-contained mineral phases of sediment are not related to crystalline Fe/Mn oxihydroxides to verify the source of groundwater As contamination.
- 2.3 According to 1.4, 2.2.5~7 in this appendix, the groundwater As pollution potential areas should be revised based on the results of periodical groundwater quality monitoring or investigations of groundwater As sources.

3. Management and utilization of As-contained groundwater

The utilization of As-contained groundwater in the groundwater As pollution potential areas (Appendix Table 1) should be conformed with different purposes. The appropriate treatment of water quality purification and depths and amounts of groundwater pumping should be proposed by competent authorities at all levels according to related water quality standards and groundwater demands.



Appendix Figure 1 Procedure of pollution potential area establishment and origin evaluation of groundwater arsenic



Appendix Figure 2 Procedure of evaluating the origin of groundwater As

Appendix Table 1 Groundwater As pollution potential areas of Taiwan

| Catchment | County/City | Township/ District | Village |
|--------------------------------|--------------------|-----------------------|--|
| Choushui river alluvial fan | Changhua County | Dacun | Dacun, Daqiao, Jiayi, Pinghe, Tianyang, Cunshang, Nanshi, Meigang, Jiadong, Gongqi, Huangcuo, Xinxing, Guogou, Fuxing, Baitang |
| | Changhua County | Yongjing | Wubian, Yongxing, Dongning, Lunzi |
| | Changhua County | Xiushui | Andong, Anxi, Xiushui, Jinxing, Xiaxi, Moxing, Zhuangya, Zengcuo, Yixing, Fu'an, Heming |
| | Changhua County | Shetou | Xiehe, Nandi, Nanya, Xincuo, Qiaotou |
| | Changhua County | Fenyuan | Dapu, Zhulin, hekou, Fenyuan, Jinfen, Fengkeng, Jiushe |
| | Changhua County | Huatan | Sanchun, Zhongkou, Zhongzhuang, Wende, Beikou, Yongchun, Baisha, Yanzhu, Huatan, Jindun, Changsha, Changchun, Nankou, Lunya, Liucuo, Qiaotou, Wandong, Wanya |
| | Changhua County | Yuanlin | Sanduo, Sanhe, Sanxin, Santiau, San'ai, Sanyi, Sanqiao, Daming, Dapu, Darau, Zhongshan, Zhongyang, Zhongzheng, Renmei, Chushui, Minsheng, Guangming, Xidong, Heping, Dongbei, Donghe, Lincuo, Nanping, Nanxing, Lunya, Huilai, Xinsheng, Xinxing, Yuantan, Gouzao, Wannian, Liming |
| | Changhua County | Puxin | Taiping, Wazhong, Wabei, Wanan, Dongmen, Youche, Jingkou, Yimin |
| | Changhua County | Lukang | Dongqi, Yangcuo, Pulun, Haipu, Caozhong, Dingcuo, Zhao'an, Liaucuo |
| | Changhua County | Changhua City | Pinghe, Yanhe, Dongfang, Nan'an, Nanmei, Nanxing, Citong |
| | Changhua County | Fuxing | Dalun, Fanpo |
| | Yunlin County | Kouhu | Xialun, Shuijing, Chenglong, Houcuo, Pubei, Lunzhong, Lundong, Wubei, Wunan, Keliau, Gangxi, Gangdong, Hukou, Hudong, Guogang, Taizi, Xiecuo |
| | Yunlin County | Dapi | Dade, Beizhen, Xizhen, Yiran, Xing'an |
| | Yunlin County | Yuanchang | Lunan, Xinji |

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|--|---------------|---------|---|
| | Yunlin County | Shuilin | Tucuo, Dashan, Dagou, Shanjiu, Shuibei, Shuinan, Jianshan, Xijing, Chegong, Songzhong, Songbei, Songxi, Houliu, Chunpu, Haipu, Shunxing, Wendi, Xiqian, Wanxing, Fanshu, Qiongpu, Suqin, Wanxi, Wandong |
| | Yunlin County | Beigang | Shuipu, Haushou, Fuchau, Shujiau |
| | Yunlin County | Sihu | Sanxing, Neihu, Sihui, Yangdiao, Lindong, Lincuo, Shihu, Feisha, Feidong, Lunbei, Lunnan, Luchang, Huxi, Huliao, Xinzhuang, Xiwei, Xidi, Guanggou, Caicuo |
| | Yunlin County | Dongshi | Simei, Annan, Changnan, Dongbei, Dongnan, Fuxing, Chenghai, Jialong, Longtan |
| | Yunlin County | Mailiao | Haifeng |
| | Yunlin County | Taizi | Shanliu, Wugang, Wulang, Niucuo, Yongfeng, Guanghua, Hefeng, Quanzhou, Haikou, Haibei, Hainan, Wengang, Fuqi, Xiding, Taizi |
| | Chiayi County | Dongshi | Xiayi, Haipu Vil, Fulai, Dingyi, Weitan, Gangkou, Xixia, Niausong, Longgang, Aogu |
| | Chiayi County | Liujiu | Gongchang, Gulin, Yongxian, Zhuben, Bengshan, Yuliao, Suandong, Suantou, Wanbei, Wannan |
| | Chiayi County | Dalin | Sancun, Sanhe, Shanglin, Zhonglin, Neilin, Pinglin, Jilin, Xilin, Xijie, Minghe, Minghua, Donglin, Pailu, Yihe |
| | Chiayi County | Xikou | Bencuo, Miaulun, Pingding, Linjiu, Liugou, Meibei, Meinan, Chailin, Youxi, Youdong, Xibei, Xixi, Xidong, Diexi |
| | Tainan City | Central | All |
| | Tainan City | North | All |
| | Tainan City | West | All |
| | Tainan City | North | All |
| | Tainan City | South | All |
| | Tainan City | Anping | Wenzhu, Shimen, Anzhong Vi Ximen, Miaushou, Jincheng, Xiaoqian, Haixing, Pusa |
| | Tainan City | Annan | Sicao, Anxi, Xingfu, Qingcao, Chengxi, Chengnan, Haixi, Haidian, Hainan, Yuanzhong, Lixiang, Lu'er, Xidong, Xiqian, Xiangong, Yantian |
| | Tainan City | Qigu | Qigu, Shifen, Sangu, Datan, Zhongliu, Yucheng, Xiliao, Chengnei, Hougang, Dingshan, Xinan, Dujia, Longshan, Yancheng |
| | Tainan City | Xiaying | Dapi, Renli, Hejian |

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|--|---------------|-----------|--|
| | Tainan City | Rende | Taizi |
| | Tainan City | Beimen | Jinhu 、Shuangchun |
| | Tainan City | Yongkang | Dawan, Wangxing, Beiwan, Yongkang, Xishi, Xiwan, Dongwan, Nanwan, Puyuan, Wuzhu, Kunshan, Xinshu, Niausong, Longtan |
| | Tainan City | Xigang | Xigang, Gangdong |
| | Tainan City | Jiali | Sanxie, Zilong, Anxi, Jiahua, Haicheng, Dingkuo, Xizhou, Jiafu, Zhangzhou, Xinghua, Yingding, Lihua |
| | Tainan City | Guantian | Balin, Dongzhuang, Dutou |
| | Tainan City | Houbi | Shi'an, Zhuxin, Houkuo, Dingchang, Jingliau, Xinjia |
| | Tainan City | Liuying | Danong 、Guoyi |
| | Tainan City | Jiangjun | Sanji, Renhe, Beipu, Yushan, Xihe, Xihua, Zhongxing, Changrong, Bauyuan, Jiangfu, Jianggui, Jiachang, Kunming, Kunshen |
| | Tainan City | Madou | Xiaopi, Beishi, Youche, Pitou Zhuangli, Xinjian, Zhuanjing, Xingnong, Longquan |
| | Tainan City | Shanhua | Xiaoxin, Liufen, Liude, Wenchang, Niuzhuang, Guangwen, Xiguan, Zuojia, Dongchang, Donglong, Nangan, Hujia, Ximei, Jiabei |
| | Tainan City | Xinhua | Shanjia, Taiping, Beishi, Quanxing, Xiexing, Fengkou, Lunding, Fengrong |
| | Tainan City | Xinshi | Sanshe, Dazhou, Daying, Yongjiu, Shenei, Gangqian, Xinshi, Xinhe, Fenghua |
| | Tainan City | Xuejia | Hongjia, Dingzhou |
| | Tainan City | Guiren | Damia, Xipu, Mamiau |
| | Tainan City | Guanmiao | Pitou |
| | Tainan City | Yanshui | Xiazhong, Dazhuang, Jingshui, Houzhai, Suncuo, Tongliau, Jiuying, Huanya |
| | Chiayi City | West | All Dist. |
| | Chiayi City | East | All Dist. |
| | Chiayi County | Taibao | Taibao, Tianwei, Anren, Dongshi, Qiantan, Houzhuang, Houtan, Chunzhu, Pixiang, Lunding, Meipu, Maliau, Gangwei, Xinpi, Guogou, Jiupi |
| | Chiayi County | Shuishang | Dalun, Zhonghe, Guoxing, Cuxi, Tugou |
| | Chiayi County | Budai | Yong'an, Guangfu, Haumei, Jiangshan, Kaushi, Daijiang, Fuxing, Caipu, Xinmin, Xincen |
| | Chiayi | Minxiong | Dinglun, Fuquan, Liauding, Fongshou, Zhenbei |

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| | County | | |
| | Chiayi County | Zhongpu | Hemu, Hexing, Fushou |
| | Chiayi County | Puzi | Meihua, Xinzhuang, Dejie |
| | Chiayi County | Lucao | Sanjiao, Xiaman, Xiatao, Guangtan, Zhushan, Xijing, Songzhu, Houjue, Houliu, Shijia, Chongliu, Ludong, Lucao, Bitan, Fongchou |
| | Chiayi County | Yizhu | Zhongping, Beihua, Pingxi, Xiguo, Guanhe 、Guanshun, Dongguo, Dongrong, Houzhen, Piqian, Xindian, Xinfu, Xizhou, Touzhu, Longjiao |
| | Kaohsiung City | Yong'an | Yong'an, Bauning, Xingang, Yantian |
| | Kaohsiung City | Gangshan | Dazhuang, Daliau, Ren'ai, Baimi, Shitan, Zhuwei, Xierong, Gangshan, Houxie, Weisui, Huagang, Jiafeng, Jiaying, Shoutian, Fuxing, Taishang, Liucuo, Tandi |
| | Kaohsiung City | Alian | Yuku, Gangshan, Fu'an, Ganghou |
| | Kaohsiung City | Qiding | Dading, Baiyun, Guangding, Jiding, Hexie, Bauding, Qilou, Jia'an, Jiading, Jiatai, Jiafu, Jiale, Jiasi |
| | Kaohsiung City | Ziguan | Zhonglun, Zixin |
| | Kaohsiung City | Hunei | Zhongxian, Zhongxing, Haishan, Yixian, Yecuo, Liujia |
| | Kaohsiung City | Luzhu | Sanye, Xiakeng, Zhuyuan, Shedong, Dingliu, Xinda, Yaliau |
| | Kaohsiung City | Qiaotou | Zhongqi, Shihe, Shilong, Shifeng, Jiabei, Jianan, Baishu, Xilin, Yuliau, Donglin, Dingyan, Bixiu, Xinzhuang, Desong, Qiaotou |
| | Kaohsiung City | Yanchao | Jiausu |
| | Pingtung County | Jiadong | Liugen, Jiadong, Wenfeng, Yanwen, Laijia |
| | Pingtung County | Donggang | Datan |
| | Pingtung County | Fangliao | Dazhuang, Dili, Donghai, Xinlong |
| | Pingtung County | Linbian | Renhe, Shuili, Yongle, Tiancuo, Guanglin, Chifen, Zhen'an |

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| | Yilan County | Wujie | Erjie, Sanxing, Shangsi, Daji, Zhongxing, Wujie, Sijie, Chengxing, Lize, Xiehe, Jixin, Fuxing |
| | Yilan County | Dongshan | Sanqi, Daxing, Taihe, Dongshan, Anping, Dongcheng, Wuyuan, Nanxing, Zhenzhu, Xianghe, Bucheng |
| | Yilan County | Zhuangwei | Meifu, Xinnan |
| | Yilan County | Yilan City | Dadau、Zhongshan、Zhongzheng、Wenhua、Beimen、Beijin、Minsheng、Minzu、Minquan、Ximen、Xiaolian、Hemu、Shengping、Dongmen、Nanmen、Jianjun、Siyuan、Fuguo、Shennong、Jiaubai、Meizhou、Fuxing、Jinshi、Ewang、Xinmin、Xinsheng、Qinghe |
| | Yilan County | Yuanshan | Yonghe、Tongle、Shangde、Zhenshan、Yuanshan、Huihau、Toufen |
| | Yilan County | Jiaoxi | Erjie, Yutian, Yuguang |
| | Yilan County | Luodong | Daxin, Zhulin, Dong'an, Xinyi, Xinqun |
| | Yilan County | Su'ao | Yongguang, Yongchun, Yongle, Cunren, Yueming, Chang'an, Gangbian, Xincheng, Shenghu, Aiding, Longde Vil, Subei, Suxi, Sudong, Sunan |

The groundwater As pollution potential areas are evaluated by geostatistics method. The average groundwater As concentrations investigated by Water Resource Agency (2001-2011) and Environmental Protection Administration (2001-2011) are adopted for estimating the distribution of contaminated probability >75%, which the concentrations exceed the Groundwater Pollution Monitoring Standards Category 1 (0.025 mg/L).