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新型小城镇地质环境综合调查服务
——以江苏丹阳2016 年数据集为例

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摘要：成果的有效应用服务是城市地质调查工作的核心驱动力，城市地质数据集作为城市地质调查工作的核心成果，是决定城市地质调查研究成果应用服务有效性的关键。中国地质调查局部署开展丹阳小城镇地质环境综合调查试点，本次共完成遥感解译 1 047 km^2 (3 期数据)，调查点 767 个，钻探 115 个，累计钻探进尺 8 720 m (其中第四系孔 915 m，水文孔 2 366 m，工程孔 5 439 m)，采集第四纪地质样品 2 904 组，地下水样品 240 组，原状土样 1 108 组，土壤样 2 482 组，地下水位统测点 70 个，抽水试验 18 组等。查清了丹阳市水文地质、工程地质、地质灾害等分布规律，并围绕丹阳市规划建设对地质工作的实际需求，对各类调查原始数据进行了专项加工，建立了数据集，为丹阳市规划建设提供了良好的支撑服务。文章对数据来源、数据收集方法、处理技术等方面进行了整理和归纳，形成了小城镇地质调查应用服务地质数据集的构建方法，为今后小城镇地质调查和数据集处理及应用提供参考。

关键词：小城镇；地质环境；综合调查；水文地质；遥感地质；城市地质调查工程；丹阳；江苏省

数据服务系统网址：http://dcc.cgs.gov.cn

1　引言

走新型城镇化道路，对全面建成小康社会、加快社会主义现代化建设进程、实现中华民族伟大复兴的中国梦，具有重大现实意义和深远历史意义。中国地质调查局主动服务国家城镇化发展战略，部署开展丹阳小城镇地质环境综合调查试点，探索新形势下，地质调查数据与政府管理流程的深度融合方式，提升地质调查成果社会化应用效率，为科学引导城乡空间布局，优化城市布局结构，高效利用土地，提高综合防灾能力，加强生态环境保护，改善城市人居环境提供地质科学支撑。

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项目围绕丹阳市城镇发展规划，在充分收集已有地质资料的基础上，以调查研究城镇化、工业化与地质环境的相互作用和影响为主线，分析丹阳城镇发展所面临的或亟待解决的地质资源与环境问题，开展多学科、多方法、多手段的综合水工环地质调查，查明了丹阳市第四纪地质、水文地质、工程地质等条件，构建了三维地质结构模型、水文地质结构模型、工程地质结构模型，提高了第四系土体结构划分精度；查清了丹阳市地下水资源、浅层地热 (温) 能资源、地下空间资源、富硒土地资源等地质资源禀赋，圈定了地下水应急水源区、富硒土地集中区，评价了浅层地热 (温) 能适宜性分区，提出了合理开发利用与保护建议；探明了丹阳市地下水质量状况、土地质量状况、已建垃圾填埋场地质环境影响状况及地质灾害问题，提出了地下水污染防治区划和土地利用调整建议、地质灾害防治建议，为生态环境安全提供了支撑服务。丹阳市地质简图见图 1。

图 1　丹阳市地质简图

项目在地层沉积结构、沉积环境、地下水含水层空间展布、富水性、渗透系数、单井涌水量、岩土体物理力学性质、地基承载力等方面获取了大量的原始数据，建立了丹阳市地质数据集，为地质研究工作提供了基础数据 (姜月华等，2019；常晓军等，2019；张庆等，2018)，为丹阳市地质资源开发、工程建设等提供了科学数据参考。数据集基本信息如表 1 所示。

表 1　数据库 (集) 元数据简表

条 目	描述
数据库(集)名称	2016年江苏丹阳小城镇地质环境综合调查数据集
数据库(集)作者	葛伟亚，中国地质调查局南京地质调查中心 常晓军，中国地质调查局南京地质调查中心 贾军元，中国地质调查局南京地质调查中心 雷　廷，中国地质调查局南京地质调查中心
数据时间范围	2014年4月−2016年10月
地理区域	江苏省丹阳市
数据格式	*.xls
数据量	6 676条
数据服务系统网址	http://dcc.cgs.gov.cn
基金项目	中国地质调查局地质调查项目“江苏镇江丹阳市小城镇水工环地质综合调查”(项目编码12120114023101)，丹阳市人民政府和南京地质调查中心合作项目“丹阳城镇地质环境综合调查”
语种	中文
数据库(集)组成	本数据集由图件、表格等组成，主要内容包括钻孔分布图1张，数据表18个，总记录数6 676条。数据表包括：调查点基础数据表、野外地质综合调查表、机民井调查表、野外水样采集记录表、水质分析综合成果表、地下水有机污染分析成果表、第四纪地质钻孔表、水文地质钻孔表、工程地质钻孔表、岩土工程样品测试表、抽水试验记录表、第四纪生物数据表、第四纪测年成果数据表、第四纪粒度参数数据表、原位测试记录表、工程地质标贯试验记录表、地下水观测井基本情况表、地下水位统测记录表

2　数据采集和处理方法

2.1　数据采集

本次工作是地质调查为新型城镇化服务的试点，工作内容比较全面、工作手段多样，采集数据量较大。综合应用遥感、地面调查、物探、钻探，以及各类原位试验及水土样品室内测试等方法进行数据采集。在开展 1：50 000 第四纪地质、水文地质、工程地质等综合调查填图过程中，针对城镇化需要开展专题研究工作。工作依据《环境地质调查规范 (1：50 000)》设计、部署实物工作量，严格按照钻探、采样、试验等相应的规范或技术规程要求进行施工和试验工作。本次共完成遥感解译 1 047 km^2 (3 期数据)，调查点 767 个，钻探 115 个，累计钻探进尺 8 720 m (其中第四系孔 915 m，水文孔 2 366 m 工程孔 5 439 m)，采集第四纪地质样品 2 904 组，地下水样品 240 组，原状土样 1 108 组，土壤样 2 482 组，地下水位统测点 70 个，抽水试验 18 组等。

2.1.1　区域环境地质调查数据采集方法

综合应用遥感、地面调查、物探、钻探等手段，开展区域环境地质调查，各类调查手段的数据采集方法如下：

（1）遥感解译

依据《遥感影像平面图制作规范》、《遥感地质解译技术指南》进行遥感解译工作，其中遥感数据主要采用购买自中国地质调查局自然资源航空物探遥感中心的 SPOT 卫星数据，并以 Landsat 7、8 卫星数据作为辅助数据，其中 Landsat 系列卫星数据轨道号为 11938，时相为 2002-7-13，2006-9-18 和 2013-8-11。

（2）地面调查

地面调查主要是采用槽型钻揭露 2 ~ 5 m 地表岩性，采用手持 GPS 进行定位，按照地质单元部署钻探揭露深部地层岩性，并辅助原位测试和取样室内测试。采用高精度 RTK 进行钻孔位置及高程测量。

（3）物探

物探工作主要采用高密度电阻率法勘探、高频大地电磁法和电阻率测深法，上述 3 种物探方法的数据采集，严格按照《电阻率测深法技术规程》、《电阻率剖面法技术规程》、《大地电磁测深法技术规程》进行数据采集。

（4）钻探

第四纪地质钻探、水文地质钻探、工程地质钻探等钻探工作，是以《城乡规划工程地质勘察规范》（CJJ 57−2012）为基本要求布置钻孔，以《工程地质钻探规程》(DZ/T 0017−1991) 及《岩土工程勘察规范》(GB 50021−2001)（2009 年版) 的要求进行施工的，按照《区域水文地质工程地质环境地质综合勘查规范 (比例尺 1：50 000)》(GB/T 14158−93) 的要求进行数据采集，并利用高精度 RTK 进行钻孔位置及高程测量，采用 MapGIS 绘图功能，编制了钻孔分布图。

2.1.2　第四系地层年代及古环境数据采集方法

第四纪地质研究主要通过钻孔揭露地层结构、岩性，年代学、古生物学、环境磁学等样品采集测试划分岩石地层、反演古地理、古气候。分析测试样品主要集中在钻孔岩芯，样品均按相关技术要求进行采集、挑选和测试。所有分析测试样品均由国家认证的或国家级、省部级开放实验室完成。粒度分析及古地磁测试样品由国土资源部华东矿产资源监督检测中心 (南京地质调查中心实验测试中心) 测试完成。孢粉及有孔虫、介形虫样品泡制和鉴定由中国科学院南海海洋研究所完成。同位素测年 (^{14}C) 由中国科学院地球环境研究所西安加速器质谱中心完成。ESR 样品由中国原子能科学研究院测试完成。

2.1.3　地下水化学数据采集方法

依据水文地质调查规范、地下水污染调查规范，进行全分析、有机污染、同位素水样采集。同位素样品由中国地质科学院水文地质环境地质研究所实验测试中心完成，其他水样均由国土资源部华东矿产资源监督检测中心 (南京地质矿产研究所实验测试中心) 完成。根据项目的要求，所有分析方法均采用了相关的国家和行业的标准方法的技术参数，均达到或优于相应标准的要求。测试选择的分析方法的检出限也均达到或优于项目和规范的要求。

2.1.4　土壤地球化学数据采集方法

在充分利用已有的调查成果和资料的基础上，按照《多目标区域地球化学调查规范 (1：250 000)》(DZ/T 0258−2014) 和《土地质量地球化学评价规范》等技术规范，以实地调查为基本手段，完成面积性土壤地球化学样品的采集及加工，先后开展并完成了土壤地球化学调查、灌溉水环境质量调查等野外调查工作，并完成土壤和灌溉水样品的采集、加工和部分样品的分析测试工作。土壤化学分析由国土资源部合肥矿产资源监督检测中心完成，灌溉水样由国土资源部华东矿产资源监督检测中心完成。

2.1.5　浅层地热能数据采集方法

在丹阳滨江地区和中心城区调查浅层地热能赋存特征，采用钻孔内热响应试验和原状土样的热物性测试，确定地层的热传导率和热扩散率，建立其热传导的物理模型和数

学模型。利用已有水文地质钻孔进行抽、回水试验，确定其回灌率。相关原位试验和室内试验由河海大学、南京大学完成。

2.1.6 地下水含水层与水资源数据采集方法

地下水含水层厚度、结构、分布、岩芯等基本特征主要依据钻孔获取，不同含水层渗透性、富水性及水资源特征主要通过抽水试验获取，抽水过程中采集地下水样进行水质相关指标的测试。抽水试验按照相关技术要求进行。

2.1.7 岩土体工程地质特征数据采集方法

岩土体工程地质性质相关参数主要通过原位试验和岩土样品物理力学测试获取。原位试验在钻探施工过程中进行，主要有标准贯入试验、十字板剪切试验、静力触探、波速测试等，岩土样品集中于工程地质钻探采取，样品类型主要为常规土工试验，土工试验由江苏南京地质工程勘察院承担，严格按《土工试验方法标准》的规定执行。

2.2 数据处理方法

2.2.1 第四系结构与岩相古地理

为查明丹阳市三维地质结构特征，构建丹阳市三维地质结构模型，形成丹阳市地质科普成果系列产品，确定开展丹阳市第四系结构与岩相古地理研究。

采用年代地层、岩石地层、层序地层、生物地层、磁性地层、气候地层等多重地层划分对比方法，重新厘定了丹阳市第四纪地层单位和沉积序列，按成因类型及岩性组合在地表划分了填图单位，查明了第四系的时空分布规律、岩性组合特征和沉积环境。建立了测区第四纪沉积结构模型，划分出山前岗地、太湖冲湖积平原及长江冲积平原 3 个第四纪以来的沉积单元；依据微体古生物、孢粉等测试结果分析了不同沉积单元的沉积结构及古地理、气候、沉积环境演变。

2.2.2 地下水资源量计算

通过与丹阳市水务集团进行深入的需求对接，确定水文地质调查以评价丹阳市地下水资源量为主要目标。

根据所得水文地质参数及观测数据，查明区内不同水体之间 (大气降水、地表水、地下水，以及地下水浅、深层之间) 的水力联系，研究三水之间的转化关系；揭示地下水的形成条件及循环过程；确定区内不同区域水文地质条件，划分水文地质分区，分精度利用不同方法进行地下水评价，其中主要针对浅部地下水 (包括潜水和微承压水)、南部平原区第 II 承压含水层组和北部沿江地区地下水。

(1) 浅部地下水和南部平原区第 II 承压含水层组资源评价

主要采用水均衡法进行计算，其中南部平原区地下水补给排泄较弱，本次地下水资源量评价主要计算地下水资源储存量。

① 浅部地下水利用均衡法计算地下水可采资源量

水均衡法基本原理是一个均衡区内的含水层系统，在任一时段 Δt 内补给量与排泄量之差，恒等于此含水层系统中水体积的变化量。据此可以建立水均衡方程式：

$$Q_{补}-Q_{排}=\pm\mu F\frac{\Delta h}{\Delta t}(潜水) \tag{1}$$

$$Q_{补}-Q_{排}=\pm\mu^{*}F\frac{\Delta h}{\Delta t}(承压水) \tag{2}$$

$$Q_{补}=Q_{流入}+Q_{越入}+Q_{河渗}+Q_{雨渗}+Q_{入补}\left(\mathrm{m^3/d}\right); \tag{3}$$

$$Q_{排} = Q_{流出} + Q_{越出} + Q_{溢出} + Q_{蒸发} + Q_{实开}\left(m^3/d\right); \tag{4}$$

式中：$\Delta Q_{排}$减少的排泄量；$\Delta Q_{补}$为开采时增加的补给量。

② 南部平原区第 II 承压含水层地下水资源量计算

本区地下水补径排动态较弱，地下水资源量计算对象主要为储存量，采用水均衡法计算，其中补给排泄量均不作考虑，则计算主要针对含水层中地下水弹性储量。

在承压含水层中，压力水头的变化主要反映弹性水的释放，称为弹性储存量，可按下式计算：

$$W_{弹} = \mu^* \cdot F \cdot h \tag{5}$$

式中：$W_{弹}$—承压水的弹性储存量 (m^3)；

μ^*—贮水 (或释水) 系数；

F—承压含水层的面积 (m^2)；

h—承压含水层自顶板算起的压力水头高度 (m)。

(2) 北部沿江地带地下水资源计算

北部沿江地带地下水资源相对丰富，是良好的地下水水源地建设选址区，采用地下水数值模拟法，建立地下水数值模拟概念模型，利用计算机软件建立地下水数值模型，计算区内地下水资源量和允许开采量，预测地下水开采条件下地下水动态变化趋势。

根据水质分析结果（表 2）对区内地下水进行水质评价，根据地下水资源量进行分区评价，结合目前地下水开采量与评价的地下水可开采资源量，进行地下水开采潜力评价，收集区域水资源需求与供给资料，进行区域水资源供需平衡分析，预测地下水开采可能产生的地质环境问题，提出地下水资源可持续开发利用战略方案和保护对策。

表 2　丹阳市地下水水化学类型统计表 (舒卡列夫分类，单位: 个)

当量 > 25%	HCO_3	HCO_3+SO_4	HCO_3+SO_4+Cl	HCO_3+Cl	SO_4	SO_4+Cl	Cl
Ca	17	3	0	0	0	0	0
Ca+Mg	29	3	1	1	0	0	0
Mg	0	0	0	0	0	0	0
Na+Ca	43	10	3	10	0	0	0
Na+Ca+Mg	37	8	1	8	0	0	0
Na+Mg	0	0	0	1	0	0	0
Na	0	0	0	0	0	0	0

2.2.3　地下水质量评价

通过与丹阳市水利局进行深入的需求对接，确定水文地球化学调查以评价丹阳市地下水质量状况为主要目标。

地下水质量评价要求以地下水的质量变化和环境地质的质量变化为重点，结合评价区的水文地质条件分析来进行。评价的重点为地下水质量、地下水污染程度、地下水污染趋势 3 个方面。

根据《地下水质量标准》(2007 版) 和《地下水污染调查评价规范》，并根据地调局统一颁布的相关技术标准，确定参评基础指标共 56 项，其中常规指标 25 项、非常规指标 31 项。

地下水质量分级，按《地下水质量标准》(GB/T 14848−2007)(报批稿) 中我国地下水

质量状况和人体健康基准值，参照生活、工业、农业等用水水质要求，将地下水质量划分为五类。此分类适用于除地下热水、矿水、盐卤水以外的地下水。

Ⅰ类：地下水化学组分含量低，适用于各种用途；Ⅱ类：地下水化学组分含量较低，适用于各种用途；Ⅲ类：以生活饮用水卫生标准为依据，主要适用于集中式生活饮用水水源及工农业用水；Ⅳ类：以农业和工业用水质量要求以及一定水平的人体健康风险为依据，适用于农业和部分工业用水，适当处理后可作生活饮用水；Ⅴ类：不宜做生活饮用水，其他用水可根据使用目的选用。

地下水质量评价方法：本次地下水质量评价分单指标地下水质量评价、分类指标地下水质量评价和地下水质量综合评价 3 种。单指标质量评价采用“从优不从劣”方法，分类指标质量评价和质量综合评价采用“从劣不从优”的一票否决法进行评价。

2.2.4 工程地质层与工程地质分区

通过与丹阳市建委及主要勘察单位进行深入的需求对接，确定工程地质调查以构建丹阳市工程地质层及划定工程地质分区为主要目标。

依据《岩土工程勘察规范》(GB 50021−2001)(2009 版)，结合丹阳具体情况，平面上分不同沉积单元、垂向上分地质时代，参照岩土试验参数根据岩性、岩土体性质和状态进行工程地质层的划分。考虑工程地质层组在测区同一地貌单元内分布的连续性、普遍性，参考岩性地层中各组别内段的划分，对所分亚组的部分土体进行进一步划分和合并。

工程地质区的划分原则是，考虑对工程地质条件起主导作用的因素，按照地貌成因类型进行划分。根据测区内地貌特征，将工作区划分为太湖冲湖积平原工程地质区 (Ⅰ)、长江冲积平原工程地质区 (Ⅱ)、山前岗地工程地质区 (Ⅲ) 和剥蚀残丘工程地质区 (IV)。

工程地质亚区的划分原则是：(1) 剥蚀残丘工程地质区按岩体工程地质建造类型及特征，划分为 3 个工程地质亚区；(2) 重点考虑对工程建设影响较大 (天然浅地基工程地质条件、短桩持力层工程地质条件) 的工程地质层 (滆湖组硬土层和下蜀组硬土层及是否含有影响工程建设的软土层) 的分布情况，对太湖冲湖积平原工程地质区、山前岗地工程地质区和长江冲积平原工程地质区进行工程地质亚区的划分。

2.2.5 土壤环境质量评价

通过与丹阳市农业部门进行深入的需求对接，确定土地质量地球化学调查以评定丹阳市土壤环境质量为主要目标。

依据国家《土壤环境质量标准》(GB 15618−1995)，Cd、Hg、As、Pb、Ni、Cr、Cu、Zn 等为目前有依据的土壤环境质量评价指标，依据该标准对土壤环境质量和功能进行评价。

按照《土壤环境质量标准》(GB 15618−1995)，单一元素主要考虑土壤 pH 条件 (表 3)，按照表 3 式子计算质量指数。

在每个评价单元内根据土壤 pH、Cd、Hg、Cu、As、Pb、Cr、Zn、Ni 等指标的测定值，直接与国标中评价标准对比，确定单因子土壤环境质量级别。在此基础上，在各评价单元内将上述指标归属的土壤类别进行汇总，按最大值 (“一票否决”) 法确定各评价单元土壤环境质量级别，圈定Ⅰ、Ⅱ、Ⅲ类、超Ⅲ类土壤。

2.2.6 浅层地热能适宜性分区

通过与丹阳市政府及相关企业进行深入的需求对接，确定浅层地热能调查以划分丹

表 3　土壤环境质量标准值 (mg/kg)

级别	一级		二级		三级
土壤pH值	自然背景	<6.5	6.5 ~ 7.5	>7.5	>6.5
项目			数值		
镉≤	0.20	0.30	0.30	0.6	1.0
汞≤	0.15	0.30	0.50	1.0	1.5
砷水田≤旱地≤	1 515	3 040	2 530	2 025	3 040
铜农田等≤果园≤	35—	50 150	100 200	100 200	400 400
铅≤	35	250	300	350	500
铬水田≤旱地≤	9 090	250 150	300 200	350 250	400 300
锌≤	100	200	250	300	500
镍≤	40	40	50	60	200

注：①重金属(铬主要是三价)和砷均按元素量计，适用于阳离子交换量>5 cmol(+)/kg的土壤，若≤5 cmol(+)/kg，其标准值为表内数值的半数。②水旱轮作地的土壤环境质量标准，砷采用水田值，铬采用旱地值。

阳市浅层地热能适宜性分区为主要目标。

在全面收集资料基础上，结合本次工作的现场试验等成果，采用层次分析法进行浅层地热能的适宜性分区 (徐晓等，2017；于丹丹和骆祖江，2015；骆祖江和杜菁菁，2018)。地埋管地源热泵系统适宜性分区是根据地质单元和沉积形成机理，将整个研究区进行典型区域的划分，结合现场热响应试验和室内热物性试验测得的热物性参数，对典型单元逐一赋值，对于没有进行现场热响应试验测试的典型单元，采用相同地层岩性类比法，结合室内热物性试验所得数据进行典型单元赋值，在对各单要素图进行矢量化后，应用 MapGIS 软件对各单要素图进行属性赋值，而后采用 ArcGIS 软件对各要素进行叠加，根据地区特点的分区标准进行地埋管地源热泵适宜性分区；地下水地源热泵系统适宜性分区是根据水文地质单元，结合各水文地质单元的含水层的性质、富水性、允许开采量及抽水回灌试验数据等，将整个研究区进行典型单元区划，而后也是对不同代表性的、典型的单元进行单要素的赋值，与地埋管地源热泵系统的适宜性分区步骤一样，在对各单要素图进行矢量化后，应用 MapGIS 软件对各单要素图进行属性赋值，而后采用 ArcGIS 软件对各要素进行叠加，根据地区特点的分区标准进行地下水地源热泵适宜性分区。

适宜性分区分为：适宜区、较适宜区和不适宜区。

3　数据样本描述

数据类型主要为数据集，数据集由图件和表格组成。其中，图件 1 张，为钻孔分布图，JPG 格式；数据表 18 张，各数据表名称见表 4。其中，水质分析综合成果表、地下水有机污染分析成果表、第四纪地质钻孔表、水文地质钻孔表、工程地质钻孔表、岩土工程样品测试表、抽水试验记录表、第四纪生物数据表、第四纪测年成果数据表、第四纪粒度参数数据表、原位测试记录表、工程地质标贯试验记录表、地下水位统测记录表等 13 张数据表中的信息暂时不能对外公开。

表 4　原始资料数据

序号	数据表名称	记录数
1	调查点基础数据表	1 449
2	野外地质综合调查表	436
3	机民井调查表	397
4	野外水样采集记录表	251
5	水质分析综合成果表	204
6	地下水有机污染分析成果表	37
7	第四纪地质钻孔表	11
8	水文地质钻孔表	19
9	工程地质钻孔表	89
10	岩土工程样品测试表	1 396
11	抽水试验记录表	11
12	第四纪生物数据表	819
13	第四纪测年成果数据表	19
14	第四纪粒度参数数据表	311
15	原位测试记录表	65
16	工程地质标贯试验记录表	810
17	地下水观测井基本情况表	31
18	地下水位统测记录表	321

4　数据质量控制和评估

本次工作按照中国地质调查局审定的工作方案及单项工作设计书开展野外调查、钻探施工、样品采集、分析测试等工作。工作量定额按照《环境地质调查规范 (1：50 000)》的要求，水文地质、工程地质调查满足 1：50 000 工作精度要求。

工作中严格执行国家和行业相关的标准、规范。其中第四系划分依据年代和古生物鉴定结果，含水层富水程度划分主要依据抽水试验，工程地质层划分在年代地层框架下依据岩土体岩性和力学性质确定。各项试验均在具备相应资质的实验室完成，按照不同的测试内容选择正确的方法、依据相应的试验规程及要求进行试验测试，样品测试过程采用国家一级标准物质监控、实验室空白和重复样、送样单位密码样以及质量监控样等质量监控手段，样品分析质量合格，获取数据可靠。

为保证数据采集质量，严格按照中国地质调查局《地质调查项目管理办法》的要求，严格执行“三级质量检查制度”，做到数据自检、互检率 100%，项目负责人检查率大于 30%，质量检查组抽检率超过 10%。项目所有原始数据在抽检、质量检查和野外验收阶段的评级均为“优秀”。同时，在项目开展过程中，对项目技术人员进行专业技术培训，保证相关工作技术合格、操作得当。

以上措施和方法都保证了本次工作所有原始资料真实可靠，符合相关规范的要求，保证了成果的准确性。

5　结论

本次以丹阳市域范围为研究区，以服务城镇化为目标，以地方和中央经费配合方式，系统开展了包括第四纪地质、水文地质、工程地质、水土环境质量等综合地质调

查，查明了丹阳市第四纪地质、水文地质、工程地质等条件，构建了三维地质结构模型、水文地质结构模型、工程地质结构模型，提高了第四系土体结构划分精度；查清了丹阳市地下水资源、浅层地温能资源、地下空间资源、富硒土地资源等地质资源禀赋，圈定了地下水应急水源区、富硒土地集中区，探明了丹阳市地下水及土地环境质量状况；依据上述调查评价信息构建了丹阳小城镇地质调查数据集，该数据集有效地扩大了地质调查成果服务规模、提升了地质数据社会化应用效率，为丹阳市城镇规划建设、土地资源利用、地下空间开发、地质资源利用、地质环境保护等方面提供了参考资料和科学依据，为相关领域研究提供了基础数据。

致谢：本数据的获取得到丹阳市人民政府、丹阳市自然资源和规划局 (原丹阳市国土资源局) 及规划、农业、住建、水利、民防、环保等相关单位的大力支持和帮助，江苏省地质环境勘查院、江苏省地质勘查技术院、江苏省地矿局第一地质大队、第三地质大队等单位参与了野外地质数据采集工作，在此一并表示衷心感谢。

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Comprehensive Geological Environmental Survey in New Small Towns — A Case Study of the Geological Dataset of Danyang City, Jiangsu in 2016

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Abstract: Effective application of survey results in social service is a core driving force of urban geological survey. As the key result of urban geological survey, the urban geological dataset is critical to the effective application of geological survey results in service. The China Geological Survey (CGS) has deployed a pilot project for comprehensive survey of geological environment in small towns of Danyang. The workload of the comprehensive survey involves the interpretation of remote sensing images covering an area of 1 047 km^2 (including data from three phases), 767 survey points, 115 boreholes, accumulated footage of 8 720 m (including 915 m for the Quaternary boreholes, 2 366 m for hydrological boreholes, and 5 439 m for engineering boreholes), 2 904 Quaternary geological samples, 240 groundwater samples, 1 108 undisturbed earth samples, 2 482 groups of soil samples, 70 points for simultaneous measurement of groundwater levels and 18 pumping tests. In this work, the distribution laws of the hydrogeology, engineering geology, and geologic disasters in Danyang City were ascertained. Furthermore, in view of the geological demand in the planning and construction of Danyang City, the original data obtained from various surveys were specially processed and a dataset was developed accordingly, thereby, providing strong support for the planning and construction of Danyang City. In this paper, the method of developing a geological survey dataset of small towns for the purposes of application and social service was established by collating and summarizing data sources, data collection methods and data processing techniques, in order to provide references for a geological survey in other small towns as well as the processing and application of the geological dataset in the future.

Key words: small town; geological environment; comprehensive survey; hydrogeological

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survey; remote sensing geological survey; urban geological survey engineering; Danyang; Jiangsu
Data service system URL: http://dcc.cgs.gov.cn

1 Introduction

New urbanism in China has great practical significance and profound historical significance for the building of a moderately prosperous society in all respects, the acceleration of a socialist modernization and the realization of the Chinese dream of the great rejuvenation of the Chinese nation. To actively serve this national development strategy, the China Geological Survey (CGS) has deployed and conducted a comprehensive pilot survey of the small town geological environment in Danyang City, in order to explore the deep integration of geological survey data with the governmental administration process in the new era and to improve the efficiency of the application of geological survey results into society. In this way, geological support can be provided in aspects of scientific guidance on the spatial layout of urban and rural areas, optimization of urban structure and layout, efficient utilization of land, comprehensively increase the capability to prevent geological disasters, enforcement of eco-environmental protection and improvement of all urban living environments.

The comprehensive survey of the geological environment in Danyang City, which is based on the full collection of existing geological materials and centers on the development and planning of Danyang City, is mainly focused on the investigation and research of the interplay between geological environment and urbanism and industrialization. It mainly aims to analyze the urgent issues of geological resources and environmental issues faced by the development of Danyang City. The Quaternary geological, hydrogeological and engineering geological conditions in Danyang City were ascertained from a comprehensive survey of hydrogeology, engineering geology and environmental geology that involved multiple disciplines, means and methods. This also led to the production of the 3D models of the geological structure, the models of the hydrogeological structure and the engineering geological structure of Danyang City. These help to increase the division precision of the Quaternary rock and soil mass structures. Furthermore, the endowments of geological resources such as groundwater, shallow geothermal energy, underground space resources and Se-rich land sources were identified, and emergency groundwater sources and concentrated areas of Se-rich land were delineated. The suitability-based zones of shallow geothermal energy were assessed, and recommendations for reasonable development, utilization and protection of the natural resources were proposed. Additionally, water quality of the groundwater, land quality, the impact of the dumps on the geological environment and geological disasters in Danyang City were verified; with zoning recommendations for the prevention and control of groundwater pollution, utilization and adjustment of lands, and the recommendations for the prevention and control of geological disasters were put forward, thus providing support for the safety of the ecological environment. The brief geologic map of Danyang City is shown in Fig. 1.

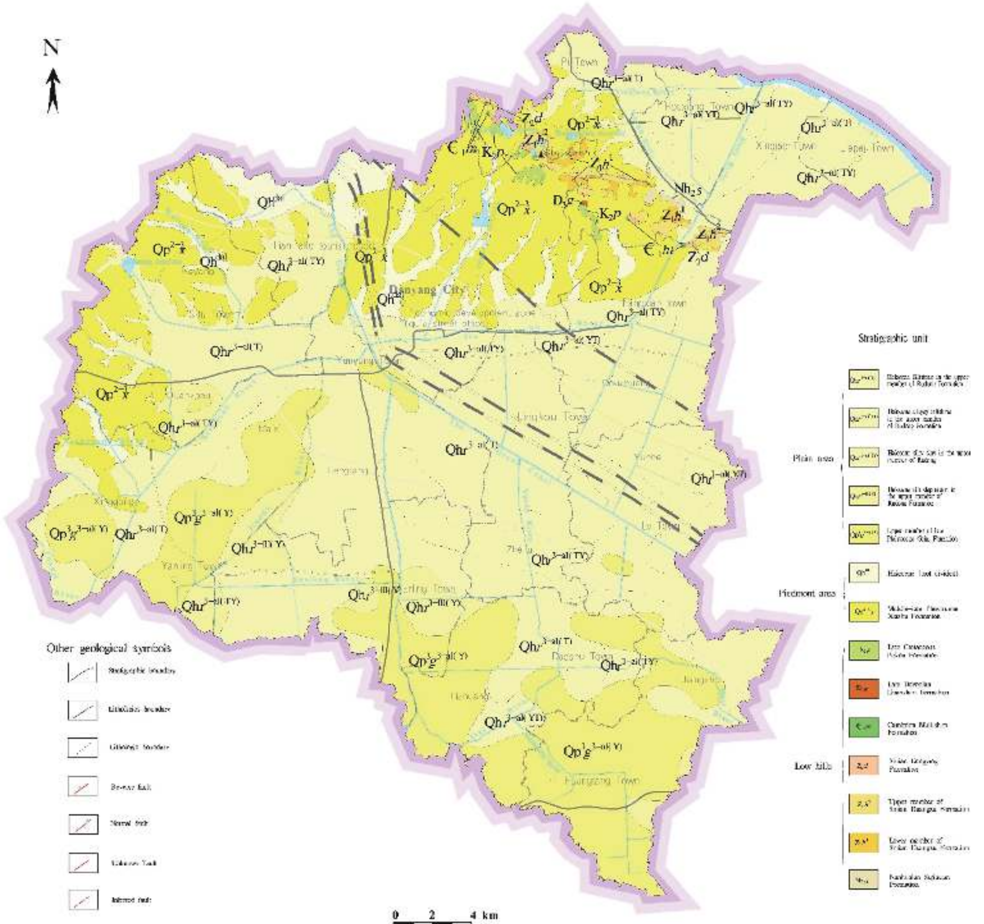

Fig. 1 Brief Geologic Map of Danyang City

The geological dataset of Danyang City was established based on a large quantity of original data obtained such as the data on settlement structure and settlement setting of strata, spatial distribution, water-yield property, permeability coefficient and single well water yield of aquifers, physical and mechanical properties of rock and soil masses and foundation bearing capacity. This provided basic data for geological research (Jiang YH et al., 2019; Chang XJ et al., 2019; Zhang Q et al., 2018), and also offered scientific data for references for the development of geological resources and the engineering and construction in Danyang City. The basic information regarding the dataset is shown in Table 1.

2 Methods for Data Acquisition and Processing

2.1 Data Acquisition

As a pilot geological survey to serve new urbanism, the comprehensive geological environment survey involved complete work and diverse methods. Therefore, a large amount of data was collected by the comprehensive application of remote sensing, ground investigation, geophysical prospecting, drilling, various in-situ tests and indoor tests of water and soil samples. During the comprehensive survey and mapping of the Quaternary geology,

Table 1 Metadata Table of Database (Dataset)

Items	Description
Database(dataset) name	Dataset of Comprehensive Geological Environmental Survey of Small Towns in Danyang City, Jiangsu in 2016
Database(dataset) authors	Ge Weiya, Nanjing Center, China Geological Survey Chang Xiaojun, Nanjing Center, China Geological Survey Jia Junyuan, Nanjing Center, China Geological Survey Lei Ting, Nanjing Center, China Geological Survey
Data acquisition time	Apr. 2014–Oct. 2016
Geographic area	Danyang City, Jiangsu Province
Data format	*.xls
Data size	6 676 entries
Data service system URL	http://dcc.cgs.gov.cn
Fund project	China Geological Survey project titled “Comprehensive Survey of Hydrogeology, Engineering Geology, and Environment Geology of Small Towns in Danyang City of Zhenjiang in Jiangsu Province” (Project No. 12120114023101), and a project tilted “Comprehensive Geological Environmental Survey of Towns in Danyang City” cooperatively initiated by the People’s Government of Danyang City and Nanjing Center, China Geological Survey
Language	Chinese
Database(dataset) composition	The dataset consists of maps and data tables, mainly including one borehole distribution map, 18 data tables and 6 676 record entries. The names of the data tables are: basic information of survey points, field comprehensive geological survey, pumping & domestic well survey, records of field water sampling, comprehensive analytical results of water samples, analytical results of groundwater organic pollution, Quaternary geological boreholes, engineering geological boreholes, records of geotechnical sample testing, records of pumping tests, Quaternary organisms, Quaternary dating results, Quaternary grain-size parameters, records of in-situ tests, standard penetration test records of geotechnical engineering, basic information of groundwater observational borehole wells, and records of simultaneous measurement of groundwater levels.

hydrogeology and engineering geology at a scale of 1∶50 000, thematic research was conducted targeting the demand for urbanism. The comprehensive geological environmental survey was designed and deployed in accordance with the *Technical Requirement for Environmental Geological Survey* (1∶50 000), and all operations and tests during the survey were carried out strictly in accordance with applicable specifications or technical instructions on drilling, sampling and testing. The workload of the comprehensive survey involves the interpretation of remote sensing images covering an area of 1 047 km^2 (including data from three phases), 767 survey points, 115 boreholes, accumulated footage of 8 720 m (including 915 m for the Quaternary boreholes, 2 366 m for hydrological boreholes, and 5 439 m for engineering geological boreholes), 2 904 Quaternary geological samples, 240 groundwater samples, 1 108 undisturbed earth samples, 2 482 groups of soil samples, 70 points for simultaneous measurement of groundwater levels and 18 pumping tests.

2.1.1 Data Acquisition for the Regional Environmental Geological Survey

The environmental geological survey was carried out by the comprehensive application of remote sensing, ground investigation, geophysical prospecting and drilling. The methods of data acquisition for these survey processes are as follows.

(1) Remote sensing

The interpretation of the remote sensing images were carried out in accordance with *Specifications for Remote Sensing Image Plan Making* and *Technical Guidance on Geological Interpretation of Remote Sensing Images*. The remote sensing data primarily include data collected by satellite SPOT (The full name is Systeme Probatoire d'Observation de la Terre) which was purchased from China Aero Geophysical Survey & Remote Sensing Center for Land and Resources, CGS. Meanwhile, the data collected by satellites Landsat 7 and 8 were used as auxiliary data, with the orbit No. of 11 938 and time phases of 13-7-2002, 18-9-2006 and 11-8-2013.

(2) Ground investigation

For the ground investigation, the lithology of the subsurface at a depth of 2–5 m was revealed with slot drills. To reveal the lithology of deep strata, a portable GPS device was used for positioning; drilling was deployed as per geological units, and in-situ tests and indoor tests of samples were adopted for further assistance. High-precision real-time kinematic (RTK) was adopted to determine the position and elevation of boreholes.

(3) Geophysical prospecting

Geophysical prospecting was mainly conducted by the mehods of high-density resistivity exploration, high-frequency magnetotelluric survey and resistivity sounding. Meanwhile, the data were collected in strict accordance with *Technical Specifications for Resistivity Sounding*, the *Technical Specifications for Resistivity Profiling Method* and *Technical Specifications for Magnetotelluric Sounding*.

(4) Drilling

The drilling includes Quaternary geological drilling, hydrogeological drilling and engineering geological drilling. The boreholes were deployed in accordance with basic requirements stipulated in CJJ 57−2012 *Code for Geo-engineering Site Investigation and Evaluation of Urban and Rural Planning* and were drilled according to DZ/T 0017−1991 *Specifications for Engineering Geological Drilling* and GB 50021−2001 *Code for Investigation of Geotechnical Engineering* (Version 2009). The data were acquired as per GB/T 14158−93 *Synthetic Survey Code for Regional Hydrogeology, Engineering Geology and Environmental Geology* (*on a scale of* 1∶50 000). High-precision RTK was adopted to determine the position and elevation of boreholes. The distribution map of the boreholes was prepared with MapGIS.

2.1.2 Data Acquisition for the Quaternary Strata and Paleo-environment

Drilling was the main method to reveal the structure and lithology of the Quaternary strata. The samples of geochronology, paleobiology and environmental magnetism were collected and tested to determine the strata and reversely deduce the paleogeography and paleoclimate. The samples for analysis and testing were mainly distributed in cores of boreholes. They were acquired, selected and tested in accordance with applicable technical requirements. Furthermore, they were all tested and analyzed in nationally certified national or ministry-level open labs. The details are as follows: the samples for grain size analysis and paleomagnetism testing were tested in the East China Supervision and Inspection Center of Mineral Resources, Ministry of Land and Resources (Experiment and Testing Center of Nanjing Center, CGS). The samples of sporopollen, foraminifer and ostracoda were infused and verified in the South China Sea Institute of Oceanology, Chinese Academy of Sciences. Isotopic dating (^{14}C) was completed in the Xi' an Accelerator Mass Spectrometry Center, Institute of Earth Environment, Chinese Academy of Sciences. The samples for the ESR (Electron Paramagnetic Resonance) dating were tested in the China Institute of Atomic Energy.

2.1.3 Hydrochemical Data Acquisition for the Groundwater

Samples for total chemical analysis, organic pollution and isotopic dating were acquired in accordance with the *Specifications for Hydrogeological Survey* and the *Specifications for Groundwater Pollution Survey*. Samples for isotopic dating were tested in the Experiment & Testing Centre of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences and other groundwater samples were tested in the East China Supervision and Inspection Center of Mineral Resources, Ministry of Land and Resources (Experiment & Testing Center of Nanjing Institute of Geology and Mineral Resources). As required by the comprehensive geological environmental survey, technical parameters specified in applicable national/industrial standards were adopted in all analysis methods of the groundwater samples. Therefore, all the technical parameters meet or exceed the requirements specified in the standards. Additionally, the detection limits of analysis methods selected meet or exceed the requirements stipulated in the comprehensive geological environmental survey and applicable specifications.

2.1.4 Geochemical Data Acquisition for the Soil

Based on the full utilization of existing survey results and materials, the area-based geochemical samples of soil were mainly taken and processed by field survey according to the applicable technical specifications such as DZ/T 0258–2014 *Specification of Multi-purpose Regional Geochemical Survey* (1：250 000) and DZ/T 0295–2016 *Specification of Land Quality Geochemical Assessment*. During the data acquisition, field surveys including geochemical surveys of soil and environment quality surveys of irrigation water were completed successively. Following this, samples of soil and irrigation water were collected and processed, and parts of the samples were tested and analyzed. The chemical analysis of soil samples was completed in the Hefei Supervision and Inspection Center of Mineral Resources, Ministry of Land and Resources. The irrigation water samples were tested and analyzed in the East China Supervision and Inspection Center of Mineral Resources, Ministry of Land and Resources.

2.1.5 Data Acquisition for Shallow Geothermal Energy

The occurrence features of shallow geothermal energy in the riverside area and the central urban area of Danyang City were investigated. The thermal conductivity and diffusivity of the strata were determined by thermal response tests in boreholes and thermophysical property testing of undisturbed earth samples. Based on this, the physical models and mathematical models of heat conduction of the strata were built. The rate of natural heat recharge was determined by pumping tests and recharge tests in existing hydrogeological boreholes. Related in-situ tests and indoor tests were carried out in Hohai University and Nanjing University.

2.1.6 Data Acquisition for Groundwater Aquifers and Water Resources

The basic characteristics of aquifers such as thickness, structure, distribution and core were obtained by drilling. The permeability, water-yield property and water source features of different aquifers were determined by a pumping test in accordance with the applicable technical requirements. During pumping tests, groundwater samples were collected and relevant indices were determined by testing.

2.1.7 Data Acquisition for the Engineering Geological Characteristics of Rock and Soil Masses

The engineering geological parameters of rock and soil masses were mainly determined by in-situ tests and physical and mechanical tests of rock and soil mass samples. The in-situ tests predominantly included standard penetration, vane shear, cone penetration and wave velocity tests, which were carried out during drilling. The rock and soil mass samples were mostly taken during engineering geological drilling. The main tests of rock and soil mass samples and regular geotechnical tests were conducted in the Jiangsu Nanjing Geo-Engineering Survey Institute in strict accordance with GB/T 50123 *Standard for Soil Test Method*.

2.2 Method for Data Processing

2.2.1 Paleo-geography of Quaternary Structure and Lithofacies

Paleo-geographical research of Quaternary structures and lithofacies in Danyan City was carried out in order to ascertain the features of the 3D geological structure, build a 3D geological structure model and develop a series of geological popularization products of Danyang City.

The stratigraphic units and sedimentary sequences of the Quaternary in Danyang City were again determined by multiple stratigraphic division and comparison methods such as chronostratigraphy, lithostratigraphy, sequence stratigraphy, biostratigraphy, magnetostratigraphy and climatostratigraphy. Additionally, the mapping units of the ground surface were determined by genetic types and lithologic association and the temporal and spatial distribution laws, lithologic association features and sedimentary environment of the Quaternary were identified. The Quaternary sedimentary structure model of Danyang City was then built. Meanwhile, three sedimentary units that have developed since the Quaternary were delineated, i.e., the piedmont downland, the alluvial-lacustrine plain of the Taihu Lake basin and the alluvial plain of the Yangtze River Delta. Furthermore, sedimentary structures and the evolution of paleo-geography, paleo-climate and sedimentary environment of different sedimentary units were analyzed based on the test results of micro-paleo-organisms, sporopollen, etc.

2.2.2 Calculation of Groundwater Resources

The assessment of the groundwater resources of Danyang City was determined to be the primary objective of the hydrogeological survey according to in-deep communication with Danyang Water Group Co., Ltd.

The hydraulic connections among different water bodies such as atmospheric precipitation, surface water and groundwater including shallow and deep groundwater were ascertained. Meanwhile, the transformational relations among the three kinds of water bodies were studied based on the hydrogeological parameters obtained and the data observed. Moreover, the genetic conditions and circulation process of the groundwater were revealed. The hydrogeological conditions of different regions in Danyang City were identified, and then the hydrogeological zones were delineated. The shallow groundwater (including phreatic water and feebly confined water), the groundwater in confined aquifer II in the southern plain and the groundwater in the northern riverside area were mainly assessed under different precision levels with different methods.

(1) Resources calculation of shallow groundwater and confined aquifer II in the southern plain.

Water balance approach was mainly adopted in the calculation. In view of weak recharge and discharge of the groundwater in the southern plain, the resource reserve of the groundwater was calculated.

① Calculation of recoverable resource of shallow groundwater with the water balance approach

The basic principle of the water balance approach is that, for any aquifer system within a balanced area during any time Δt, the difference between the recharge and the discharge is always equal to the change of the water volume within the aquifer system. Based on this, the following water balance equations can be set up:

$$Q_{recharge} - Q_{discharge} = \pm \mu F \frac{\Delta h}{\Delta t} (phreatic \text{ water}) \tag{1}$$

$$Q_{recharge} - Q_{discharge} = \pm \mu^{*} F \frac{\Delta h}{\Delta t} (confined\ water) \tag{2}$$

$$Q_{\text{recharge}} = Q_{\text{runoff inflow}} + Q_{\text{leakage recharge}} + Q_{\text{river infiltration}} + Q_{\text{rainfall infiltration}} + Q_{\text{artificial recharge}} \left(\text{m}^3/\text{d}\right); \tag{3}$$

$$Q_{\text{discharge}} = Q_{\text{runoff outflow}} + Q_{\text{leakage discharge}} + Q_{\text{overflow}} + Q_{\text{evaporation}} + Q_{\text{practical exploitation}} \left(\text{m}^3/\text{d}\right) \tag{4}$$

Where $\Delta Q_{\text{discharge}}$ refers to reduced discharge, $\Delta Q_{\text{recharge}}$ refers to increased recharge during groundwater exploitation, $S_{\max}$ refers to allowable maximum drawdown and T refers to the production life.

② Resources calculation of groundwater in confined aquifer II in the southern plain

In view of weak recharge, runoff and discharge of the groundwater in confined aquifer II in the southern plain; the groundwater reserve was mainly calculated with the water balance approach. For the calculation, the recharge and discharge were ignored, and therefore, elastic groundwater reserve in the confined aquifer II was calculated.

In the confined aquifer II, the change in pressure head mainly reflects the release of elastic water, and thus is called elastic reserve. It can be calculated with the equation below:

$$W_{\text{elastict}} = \mu^* \cdot F \cdot h \qquad (5)$$

Where W_{elastic} refers to the elastic reserve of confined water (m^3);

*M*** refers to the coefficient of water storage (or release);

F refers to the area of confined aquifer (m^2);

h refers to the height calculated from roof of pressure head of the confined aquifer (m)

(2) Calculation of groundwater resources in the northern riverside area

The northern riverside area boasts comparatively abundant groundwater resources and, therefore, can be selected as a site for the construction of groundwater sources. A Conceptual model of the groundwater was established with a numerical simulation method and a numerical model of the groundwater was built with computer software. Moreover, the resources and allowable withdrawal of the groundwater were calculated and the dynamic change trend of the groundwater, subject to exploitation, was anticipated.

Groundwater quality (Table 2) was assessed based on the water chemical analysis and groundwater resources were assessed by zones. The groundwater exploitation potential was assessed by combining current groundwater withdrawal with allowable withdrawal. The balance between the supply and demand of water resources was analyzed based on the information collected on it. Any geological environmental problems that will possibly take place during groundwater exploitation were predicted. Strategic plans and protective measures for sustainable development and utilization of groundwater resource were put forward.

2.2.3 Assessment of Groundwater Quality

The assessment of the groundwater quality of Danyang City was determined to be the primary objective of the hydrogeochemical survey according to in-deep communication with the Danyang Water Resources Bureau.

As required, the groundwater quality assessment focused on the changes in water quality and the environmental geology of groundwater and was conducted in combination with the analysis of the hydrogeological conditions. The water quality, pollution degree and pollution trend of the groundwater were primarily assessed.

Table 2 Statistics of Groundwater Hydrochemical Types in Danyang City (Schukarev classification, unit: number)

equivalent>25%	HCO_3	HCO_3+SO_4	HCO_3 +SO_4 +Cl	HCO_3+Cl	SO_4	SO_4+Cl	Cl
Ca	17	3	0	0	0	0	0
Ca+Mg	29	3	1	1	0	0	0
Mg	0	0	0	0	0	0	0
Na+Ca	43	10	3	10	0	0	0
Na+Ca+Mg	37	8	1	8	0	0	0
Na+ Mg	0	0	0	1	0	0	0
Na	0	0	0	0	0	0	0

According to the *Standard for Groundwater Quality* (2007), *Specifications for Survey and Assessment of Groundwater Pollution* and also the applicable technical standards issued by the CGS in a united manner; 56 basic indices in total, consisting of 25 regular ones and 31 non-regular ones, were determined to be assessed.

Groundwater quality was divided into five categories as follows according to the status quo of groundwater quality and reference values of human health in China that are stated in GB/T 14848−2007 *Standard for Groundwater Quality* (version for Approval) and by referencing requirements of quality water for living, agricultural, and industrial uses. Such categorization is suitable for the groundwater except for geothermal water, mineral water and brine.

Category I: featuring a low content of chemical components that is suitable for various purposes. Category II: featuring a comparatively lower content of chemical components that is suitable for various purposes. Category III: consistent with GB5749 *Standards for Drinking Water Quality*, mainly suitable for use as concentrated sources of drinking water, agricultural and industrial uses. Category IV: meeting requirements of water quality for agricultural and industrial uses and carrying risks damaging human health to a certain degree, suitable for agricultural and some industrial uses; and can be used as drinking water after being properly treated. Category V: unsuitable for use as drinking water and can be used for other purposes if appropriate.

Method for the assessment of groundwater quality: Single-index-based, index-category-based, and comprehensive assessments were adopted. The principle that a qualified value prevails was held in the single-index-based assessment. However, the principle that an unqualified value prevails was held in the index-category-based assessment and comprehensive assessment (i.e., a category of indices or comprehensive quality was unqualified once an unqualified index value occurs).

2.2.4 Determination of Engineering Geology Layers and Zones

The determination of the engineering geological layers and zones of Danyang City was decided to be the primary objective of the engineering geological survey according to in-deep communication with the Danyang Commission of Housing and Urban-rural Development.

The engineering geology layers were determined according to the lithology, the properties and occurrence of rock and soil masses; as well as the parameters of geotechnical tests in accordance with GB 50021−2001 *Code for Investigation of Geotechnical Engineering* (version 2009). Furthermore, the layers were identified by different sedimentary units horizontally and by geological ages vertically in view of the specific situations of Danyang City. In consideration of the continuity and universality of a group of the layers within the same landform unit, some of the soil masses in each subgroup of the layers were further divided and merged according to the division means of segments within various formations of lithological strata.

The engineering geological zones were largely determined by genetic types of landform in consideration of the factors dominating the engineering geological conditions. Based on this, Danyang City was divided into four engineering geological zones, i.e., the alluvial-lacustrine plain zone of the Taihu Lake basin (Zone Ⅰ), the alluvial plain zone of the Yangtze River Delta (Zone Ⅱ), the piedmont downland zone (Zone Ⅲ) and the denudation monadnock zone (Zone IV).

The engineering geological subzones were determined as follows: (1) The denudation monadnock zone (Zone IV) is divided into three engineering geological subzones based on the types and features of geological formations of geotechnical engineering. (2) The alluvial-lacustrine plain zone of the Taihu Lake basin (Zone Ⅰ), the alluvial plain zone of the Yangtze River Delta (Zone Ⅱ) and the piedmont downland zone (Zone Ⅲ) were mainly divided into corresponding subzones according to the distribution of the engineering geological layers (hardpans of Gehu Formation, hardpans of Xiashu Formation and soft layers affecting project construction) that heavily affect engineering and construction (engineering geological conditions of natural shallow foundations and short-pile bearing strata).

2.2.5 Assessment of the Environmental Quality of Soils

The assessment of the environmental quality of the soils in Danyang City was determined to be the primary objective of the geochemical survey of land quality according to in-deep communication with the agricultural authorities of Danyang City.

The environmental quality and functions of soils were assessed according to GB 15618−1995 *Environmental Quality Standard for Soils,* in which the elements such as Cd, Hg, As, Pb, Ni, Cr, Cu and Zn are determined to be current well-founded indices for the assessment of the environmental quality of soils.

As for single element assessment, pH is mainly taken into consideration (Table 3) according to GB 15618−1995 *Environmental Quality Standard for Soils* and the quality indices were determined according to Table 3.

Table 3 Standard Values for Environmental Quality of Soils (mg/kg)

Grade	Grade I	Grade II			Grade III
pH value of soil	Natural background	<6.5	6.5–7.5	>7.5	>6.5
Item	Value				
Cd ≤	0.20	0.30	0.30	0.6	1.0
Hg ≤	0.15	0.30	0.50	1.0	1.5
As Paddy field ≤ Dry land ≤	1 515	3 040	2 530	2 025	3 040
Cu Farmland etc. ≤ Orchard ≤	35—	50 150	100 200	100 200	400 400
Pb ≤	35	250	300	350	500
Cr Paddy field ≤ Dry land ≤	9 090	250 150	300 200	350 250	400 300
Zn ≤	100	200	250	300	500
Ni ≤	40	40	50	60	200

Notes: ① Heavy metals (Cr mainly refers to Cr^{3+}) and As are calculated according to their element contents, suitable for the soils where cation exchange capacity > 5cmol (+)/kg. For the soils where cation exchange capacity ≤ 5cmol(+)/kg, the standard values shall be half of the values in the table. ② As for the environmental quality standard of the soils of land for the purpose of wet and dry crop rotation, the value for paddy fields and the value for dry land shall be respectively adopted for As and Cr.

The single-element-based environmental quality grade of the soil in each assessment unit was determined by directly comparing the measured values of pH, Cd, Hg, Cu, As, Pb, Cr, Zn and Ni in the soil with their standard values specified in GB 15618−1995. Building on this, the soil categories determined by the indices mentioned above were summarized and the environmental quality grade of the soil in each unit was determined by the method that the highest value prevails ("one-vote veto"). In this way, the soils of Category Ⅰ, Ⅱ, Ⅲ and super Ⅲ were delineated.

2.2.6 Determination of the Suitability-based Zones for Shallow Geothermal Energy

The determination of the suitability-based zones for shallow geothermal energy in Danyang City was decided to be the primary objective of the shallow geothermal-energy survey according to the in-deep communication with the government and relevant enterprises of Danyang City.

The suitability-based zones of shallow geothermal energy were determined with the Analytic Hierarchy Process (AHP) based on full data collection as well as the field tests results (Xu X et al., 2017; Yu DD and Luo ZJ, 2015; Luo ZJ and Du JJ , 2018). The suitability based zones of ground-source heat pump were determined as follows: first, divide Danyang City into typical units based on the formation mechanism of geological units and sediments; second, assign values for the typical units by combining thermophysical property parameters determined by field thermal response tests and indoor thermophysical property testing. As for the typical units for which the thermal response tests were not available, assign values by analogy with the units sharing the same stratigraphic lithology and by combining the data obtained from indoor thermophysical tests; third, vectorize each single-element map and then assign attribute values to the single-element maps with MapGIS; lastly, overlap various elements with ArcGIS, and then determine suitability-based zones of the ground-source heat pump in accordance with the area-specific zoning criteria. The suitability based zones of groundwater-source heat pump were determined as follows: first, divide Danyang City into typical units based on the data of the aquifers of hydrogeological units including the property, water-yield property, allowable withdrawal and the data obtained from pumping tests and recharge tests; second, also assign values for single elements that correspond to different typical units; third, also vectorize single-element maps and then assign attribute values to the single-element map with MapGIS; lastly, overlap various elements with MapGIS and then determine the suitability-based zones of groundwater-source heat pump in accordance with the area-specific zoning criteria.

Suitability-based zones consist of suitable zones, less suitable zones and unsuitable zones.

3 Description of Data Samples

As the main data type of the survey results, the dataset consists of one borehole distribution map in a.JPG format and 18 data tables. The names of the data tables are shown in Table 4, and some of them could not be public at present, including data tables of comprehensive results of water quality analysis, analytical results of groundwater organic pollution, Quaternary geological boreholes, hydrogeological boreholes, engineering geological

Table 4 Original Data

No.	Data table name	Number of record entries
1	Basic information of survey points	1 449
2	Field comprehensive geological survey	436
3	Pumping and domestic well survey	397
4	Records of field water sampling	251
5	Comprehensive results of water quality analysis	204
6	Analytical results of groundwater organic pollution	37
7	Quaternary geological boreholes	11
8	Hydrogeological boreholes	19
9	Engineering geological boreholes	89
10	Records of geotechnical sample testing	1 396
11	Records of pumping tests	11
12	Quaternary organisms	819
13	Quaternary dating results	19
14	Quaternary grain-size parameters	311
15	Records of in-situ tests	65
16	Standard penetration test record of geotechnical engineering	810
17	Basic information of groundwater observational borehole wells	31
18	Records of simultaneous measurement of groundwater levels	321

boreholes, records of geotechnical sample testing, records of pumping tests, Quaternary organisms, Quaternary dating results, Quaternary grain-size parameters, records of in-situ tests, standard penetration test record of geotechnical engineering.

4 Data Quality Control and Assessment

The field survey, drilling, sampling, analysis and testing in the comprehensive geological environmental survey in Danyang City were all conducted based on the work plan and design documents for single work that were approved by the CGS. The workload quota was made in accordance with the *Technical Requirement for Environmental Geological Survey* (1：50 000) and the precision of the hydrogeological and engineering geological surveys on a scale of 1：50 000 were satisfied.

Applicable national and industrial standards and codes were strictly followed. The Quaternary structure and lithofacies were identified based on the results of dating and paleo-organism testing; the water-yield property degree of aquifers was mainly determined by pumping tests and the engineering geological layers were determined based on the lithology and mechanical properties of rock and earth masses under the chronostratigraphic framework. According to corresponding test specifications and requirements, all tests were achieved with the appropriate methods that were selected based on the test items in suitably qualified labs. The sample analysis was qualified and the data obtained were credible due to a series of quality monitoring and control measures having been adopted during sample tests, including comparison with National Primary Certified Reference Materials as well as the adoption of laboratory blank samples, laboratory duplicate samples, quality control samples from the sender and quality monitoring samples.

A three-level quality inspection system was implemented, in accordance with the *Management Program of Geological Survey Projects* issued by the CGS, to ensure the quality of the data acquisition. It consisted of a self-check and a mutual-check, a check by project leaders and a check by the quality check team. The inspection rates of the three-level checks are 100%, greater than 30% and greater than 10% respectively. All original data were rated as excellent during all spot checks, quality inspections and quality acceptance. Meanwhile, the technical staff were trained in technical expertise during the comprehensive geological environmental survey in order to ensure that they were technically qualified and can operate the equipment properly.

With all the measures and methods described above, it is guaranteed that all original materials obtained are true and credible and meet the requirements stated in the applicable codes and specifications, thus ensuring that the results are accurate.

5 Conclusion

The comprehensive geological survey; consisting of a Quaternary geological survey, a hydrogeological survey, an engineering geological survey and an environmental quality survey of water and soil; was systematically carried out in Danyang City. It was jointly funded by central and local governments, aiming to serve the national urbanism strategy. The results of this comprehensive geological survey are as follows. Firstly, the Quaternary geological, hydrogeological and engineering geological conditions in Danyang City were ascertained. Next, 3D models of the geological structure and models of the hydrogeological structure and engineering geological structure of Danyang City were established, thus increasing the division precision of the Quaternary rock and soil mass structures. Secondly, the endowments of geological resources such as groundwater, shallow geothermal energy, underground space resources and Se-rich land resources were identified; emergency groundwater sources and concentrated areas of Se-rich land were delineated and the environmental quality of the groundwater and the land was determined. Lastly, the geological dataset of Danyang City was established based on the aforementioned information obtained from surveys and assessments. With this dataset, the service scale of geological survey results has been effectively expanded. The application efficiency of geological data in society has been improved, thus providing references; a scientific basis for the planning and construction, land resource utilization, underground space development, geological resource utilization and geological environmental protection in Danyang City and providing basic data for research in the relevant fields.

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