

申 报	系列：教师
	专业：城乡规划
	职称：副教授

业绩成果材料

（申报人的业绩成果材料包括论文、科研项目、获奖以及其他成果等）

单 位(二级单位) 林学与风景园林学院

姓 名 林蔚

材料核对人：

单位盖章：

核对时间：

华南农业大学制

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广东省教育厅

粤教高函〔2018〕180号

广东省教育厅关于公布 2018 年广东省 高等教育教学改革项目立项名单的通知

各本科高校：

按照《广东省教育厅关于开展 2018 年度省高等教育教学改革项目推荐工作的通知》（粤教高函〔2018〕132 号）安排，省教育厅组织各本科高校开展了 2018 年度省高等教育教学改革项目（以下简称“教改项目”）遴选推荐工作。现将本年度省教改项目立项名单予以公布，并就有关事项通知如下：

一、立项情况

根据文件要求，省教育厅对学校推荐的材料进行了形式审查，确定 2018 年度省高等教育教学改革项目共立项 767 项（详细名单见附件）。

二、项目经费

项目由各校统筹省“创新强校工程”专项资金及自有资金等，根据立项项目研究内容、性质和特点，综合确定资助额度，保障项目顺利开展研究和实践。

省教改项目的立项建设是申报省高等教育教学成果奖的重要基础，项目建设成效同时列入学校“创新强校工程”绩效考核因素，并直接影响下一年度学校教改项目立项限额。

三、项目管理

（一）日常管理

省高等教育教学改革项目要求立足学校教学改革实际，突出问题导向、实践导向和应用导向，项目最终要为推动学校教学改革服务。项目所在高校要加强对项目的日常管理、指导和检查，为项目研究并切实应用于教学实践提供必要条件。

（二）中期检查和结题验收

项目建设周期一般不超过3年，请学校管理部门按期做好项目中期检查和校内结题验收等工作。校内结题时，邀请校外评审专家人数不得少于专家总人数的三分之二。

满足以下条件的项目，经学校正式申请，可以参与省教育厅统一组织的项目验收：

- 1.项目已完成立项时设定的主要建设目标，且项目建设成果已在教学实践中有效应用；
- 2.已按照要求完成项目校内结题；
- 3.符合当年度省统一验收规定的其他条件。

（三）项目变更和调整

为保证项目建设的延续性和成果的一致性，原则上，项目研究过程中不得更换项目负责人；不得大幅变更研究内容或研究方

向；不得拖延项目建设进程。

如遇特殊情况需要进行项目变更或延期的，须由项目负责人在项目结题前至少 6 个月向学校提出书面申请，学校审核同意后，以正式函件形式（并附相关材料）报省教育厅。

对擅自做出变更决定或临时延长建设期限的项目，将视情予以撤销或终止项目研究，取消相应负责人 3 年内省教改项目的申报资格，并核减项目所在学校下一轮次教改项目推荐数额。

四、其他事项

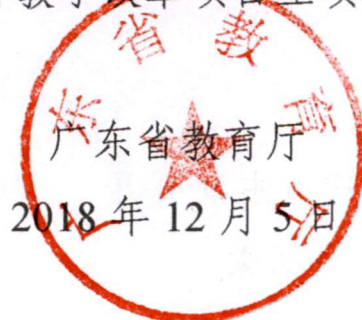
（一）2018 年度各校向省教育厅推荐并获得立项的项目，学校须将相关项目校内评审推荐及立项材料妥善保存，留底备查。

（二）项目立项后，学校应组织专家对项目进行开题论证，进一步优化项目建设目标和实施计划。

（三）省高等教育教学改革项目优秀成果将以适当方式在省级平台上向广大高校推介。

联系人：刘雨濛、李成军， 联系电话：020-37626882、37629463；传真：020-37627963。

附件：2018 年度广东省高等教育教学改革项目立项名单



公开方式：主动公开

校对入：刘雨濛

2018年度广东省高等教育教学改革项目立项名单			
序号	单位名称	项目名称	项目负责人
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城市建筑

URBANISM AND ARCHITECTURE

3.2021 No.385

URBANISM AND ARCHITECTURE

城市建筑

TOD模式下城市土地利用发展策略研究

平流古寨建筑文化特点及其保护形式研究

江西省红色工业遗产的现状调查与特征分析

综合管廊电力舱最佳换气次数的研究

基于使用需求的德国养老机构空间与部品设计探究

开封山陕甘会馆中的砖石雕艺术模式解析

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课程思政视角下的景观设计教学改革实践

林蔚, 刘维东, 余美莹

(华南农业大学林学与风景园林学院, 广东广州 510642)

摘要: 将生态文明价值观融入专业培养体系中, 发挥协同育人效应, 是课程思政的重要实践方向。本文依托农林院校城乡规划专业景观设计II课程, 探讨课程蕴含的生态理念及技术分析内容的切入点, 开展融合式教学改革实践, 通过构建基于GIS的场地定量分析评价、道路系统设计优化和雨水花园区域设计模式, 初步实现了生态文明理念结合专业教育实践的改革目标, 对于生态文明教育与专业课程有机融合做出了有益探索。

关键词: 课程思政; 生态文明; 融合途径; 规划设计; 技术分析

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Practice of Landscape Design Teaching Reform from the Perspective of Curriculum Ideology and Politics

Lin Wei, Liu Weidong, She Meixuan

(College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou Guangdong 510642, China)

Abstract: Integrating the values of ecological civilization into the professional training system and exerting the effect of collaborative education is an important practical direction of curriculum ideology. Based on the landscape design II course of urban and rural planning major in agricultural and forestry colleges, this paper discusses the ecological concept and the breakthrough point of technical analysis content contained in the course, which carries out the practice of integrated teaching reform. The GIS-based site quantitative analysis and evaluation, road system design optimization, as well as rain garden area design model has been constructed, which initially realizes the reform goal of combining the concept of ecological civilization with professional education practice. It makes a useful exploration for the organic integration of ecological civilization education and professional courses.

Key words: curriculum ideology and politics; ecological civilization; integration way; planning and design; technical analysis

1 背景

教育部印发《高等学校课程思政建设指导纲要》, 明确指出全面推进课程思政建设是落实立德树人根本任务的战略。高校要深化教育教学改革, 充分挖掘各类课程思想政治资源, 发挥好每门课程的育人作用, 全面提高人才培养质量。生态文明建设作为新时代中国特色社会主义思想和基本方略的组成部分被提到了新高度。生态文明教育作为生态文明建设的重要环节, 在思政课中有独特而重要的使命^[1]。如何使专业课程和思想政治教育有机结合起来, 形成协同效应, 构建全方位育人大格局, 是亟须开展实践探索的重要课题。

近两年来, 不同专业根据学科特点, 在教学内容设计与教学方法改革等方面做出了有益的探索^[2, 3]。风景园林学科在新时代生态文明建设、贯彻新发展理念的工作中肩负着极为重大的责任^[4]。从生态文明角度出发, 在规划设计课程中融入可持续发展观、自然资源保护等多学科知识内容^[5], 是风景园林教育事业发展的必然, 探索符合生态

文明内涵的学科创新是专业延续发展的必经之路^[6]。

风景园林学科以协调人与自然之间的关系为宗旨, 在学术和教学资源上独具特色, 理应在专业课程思政方面有所探索。华南农业大学风景园林学科包括风景园林、园林、城乡规划等专业, 城乡规划专业依托风景园林学科开设, 逐渐形成了与理工科院校相关专业不同的培养模式; 风景园林学科天然的多学科交叉优势, 为城乡规划专业建立特色知识体系奠定坚实的基础。本文以城乡规划专业景观设计II课程为例, 分析生态文明思想和专业课程思政的融合途径和教学方案。

2 风景园林学科下城乡规划专业课程思政改革思路

2.1 城乡规划专业发展现状及景观设计课程思政改革方向

受到学制及学分要求的限制, 城乡规划专业课程体系进行了调整, 如城乡生态与环境规划仍然处于“缺位”状态, 生态环境规划类知识传授和能力培养匮乏的现状与国土空间规划体系下强调生态优先的导向尚不匹配; 专业

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特色不够突出,未有效结合学校学科在自然生态领域的特色,特色课程(如园林植物学)与核心课程联动效果有限,不能发挥学科资源互补优势。因此,风景园林学科应响应时代号召,将生态文明教育充分融入城乡规划专业教学全过程,形成协同效应,凸显专业特色。

较大尺度场地的景观设计应避免或减少设计对生态环境的不利影响^[7]。从成果导向和技术手段层面看,以往景观设计课程偏重于微观尺度的设计实践,由于场地较小(空间异质性单一)和分析技术手段匮乏,学生对场地环境尤其是生态基底了解并不深入,开展相关生态分析与规划更无从谈起。

作为风景园林学理论知识的主要载体,景观设计I和II贯穿城乡规划专业大二学年,在微观设计向中宏观规划转换的关键时期,将生态文明思想和专业课程进行融合,挖掘理论价值和课程培养目标的衔接模式。改革后的教学实践实现了生态优先理念的多尺度渗透,引入场地规划设计的各个层面,重点增加了大尺度场的生态因子认知和生态专题规划分析内容,提高了学生应用生态理念进行规划设计的能力,促进了与相关专业知识的有机融合。

2.2 数字技术为教学实践和课程思政提供契机

定量分析、模拟和表达在规划设计过程中应用广泛。风景园林学界以定量辅助定性来推动学科和人居环境的持续发展^[8]。为适应国土空间规划转型期与其他自然资源整合和行业技术流程更新的需要,规划设计专业应借力GIS等优势,创建生态多元的人居环境。

在此背景下,利用信息技术拓展思政元素与专业知识相结合的领域,丰富教育路径和方式,GIS技术工具可成为课程思政隐性渗透的途径。改革后的课程教学采用数字技术支持规划设计过程,在实践教学环节重点讲授生态评价与分析方法,巩固学生对生态相关知识点的理解,提高学生的理论水平和分析能力,为后续专业课程奠定基础。

3 教学改革实践具体内容

3.1 场地概况和课程要求

景观设计II课程以华南农业大学树木园为例,场地面积极约为17.5 hm²。树木园创建于1972年,是广东省高校中面积最大、引进植物种类最多的林木种植资源圃。园内亚热带常绿阔叶次生林发育良好,植被群落结构多样,是广州市绿地生态系统的重要组成部分。

针对本次教学改革的目标,在前期调研、小组讨论和方案推演的过程中突出生态优先理念,探讨场地生态系统“山、水、林”等系统要素的相互关系,实施GIS分析技术路线(见图1),开展生态敏感性分析、道路交通系统优化和水文分析专题实践,以支持场地规划设计过程。

3.2 基于GIS技术开展教学改革,践行生态优先理念

3.2.1 场地定量分析与评价

科学定量的场地分析与评价是“因地制宜”的前提,

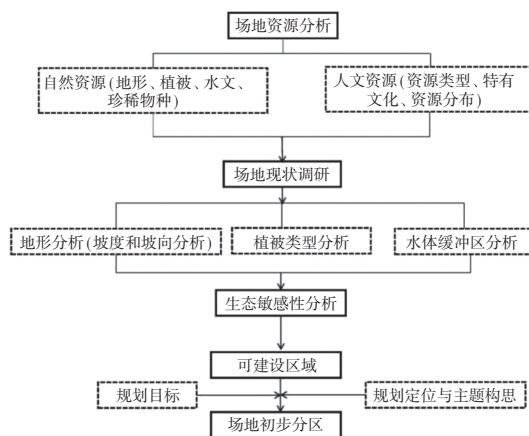


图1 基于GIS的前期分析技术路线(图片来源:作者自绘)

其中生态敏感性、建设适宜性是研究重点,体现了生态优先的原则^[9]。生态敏感性和建设适宜性分析的评价指标因子较多。本次设计针对场地地形地貌相对复杂、植被覆盖率高的特征选择评价因子,兼顾数据的可获取性,在生态敏感性分析中选取地形(坡度、坡向)、植物保护性、距水体的距离等开展单因子分析,进而执行多因子综合叠加分析。在生态敏感性分析结果的基础上,筛选出适宜建设区和不可建设区。

学生在场地踏勘的基础上,对场地自然资源展开分析。依托数字高程模型、无人机航拍影像、轨迹调研助手等技术资料,掌握了地形、地貌、植被、水体等单因子分析和多因子综合叠加方法,充分了解了场地环境和生态基底。通过小组讨论,设置影响因子的权重,作为分析阶段的可调整参数,直接代入设计过程。各组均遵循生态优先原则,根据生态敏感性分析和建设适宜性分析结果,结合不同的规划目标定位和主题构思形成场地初步分区。

3.2.2 道路交通系统设计优化

在园路选线的过程中,需要对整个场地景观资源和各项因子进行全面、准确的分析^[10]。风景环境道路的选线应与地形地貌相契合,线型灵活多变,避免过大的土方工程,减少对风景环境的人为扰动^[11]。

树木园的道路选线过程中,选择坡度因子作为成本—距离矩阵,执行成本—路径分析,串联入口与重要景点,减小对场地环境的干扰。选择坡度成本最低(坡度最缓)、生态敏感性等级较低的区域作为园路系统可选项。根据入口和对应区域景点、主要和次要节点间顺序,分批次独立运算,生成节点与出入口的交通逻辑关系,由此内部路网初具形态。

学生遵照园路系统对场地环境干扰最小化的原则,在场地初步分区基础上讨论景点分布位置,结合道路选线分析结果,比对场地现状路网,逐步推敲路网的线型和节点,景点位置和主次节点均可迭代。经过路径的筛选与优化,生成最终道路形态,用于推敲各功能分区布局(见图2)。相较于传统选线方法对经验和技术的较高要求,基于成本—路径分析的计算机选线方法避免了初学者因经验不足、水

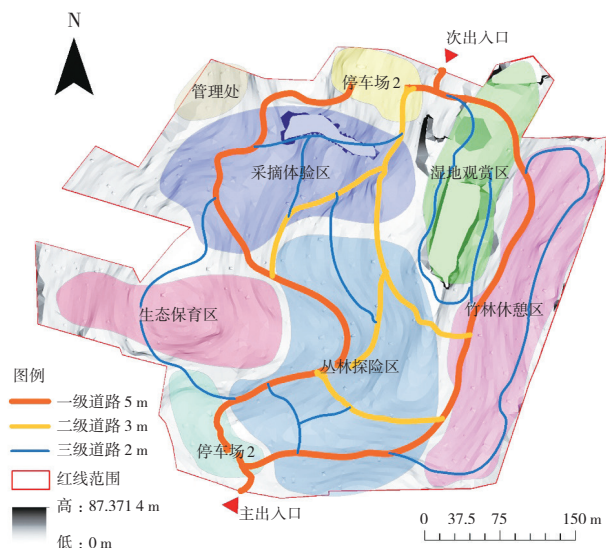


图2 道路选线结果支持场地功能分区(图片来源:作者自绘)

平与手法不同而导致方案的不确定性;能够有效地避开生态敏感区,减少对场地生态环境的影响。

3.2.3 雨水花园区域详细设计

雨水处理措施与景观规划设计相结合已成为城市生态建设的重要举措。场地中的水体与城市河涌段相连接,现状水量水质情况一般,因而是改造关注的焦点。本次改革实践旨在通过水文分析的结果支撑重点片区的设计。

水景营造需考虑利用现有低洼地,分析补给水源及场地汇水规律。方案拟在水体的东北侧修建雨水花园,基于不同暴雨强度情景的场地调研过程,判断现状水体的潜在径流位置。通过数字高程模型水文分析,确定雨水花园的径流补给位置和汇水路径,保证雨水花园在不同季节形成一定的水面景观。基于低影响开发原则,因势利导减少场地工程的土方量,通过生态种植池、透水铺装等措施达到恢复场地自然水文循环的效果。

水景观营造,除了关注传统美学价值,还应挖掘生态价值,该方案有效探索了水资源管理保护与景观营造之间的平衡。通过解读场地地形地貌和水循环特征,依托水文分析结果支持水景观选址。充分尊重场地的自然环境特征,不仅可以满足水景观营造的多目标,而且有助于实现可循环、减量化设计,进一步提升水资源的生态价值。

4 课程改革初步成效与思考

4.1 以技术融合途径为突破点,推动转型期课程思政教学改革

由微观设计向中宏观规划转变过程中,专业教师通过教学内容设计和方法优化,充分挖掘该课程所承载的思政教育功能,以场地分析评价和优化设计为抓手,将思政内容贯穿课程前期,重点引导学生通过GIS等技术手段了解场地概况,思考优势与不足,量化评价场地各因子及之间的联系,促进学生初步形成生态优先、综合分析的思维模式,以顺利衔接实施中宏观尺度规划类核心课程。

经过两个学年的磨合和尝试,课程反馈中普遍提及能

够更好领会本次教学改革的目的。学生重视场地资源的生态价值,以生态敏感性分析结果作为功能分区的依据;在方案的推导过程中,根据定量分析结果,减小对场地生态系统的扰动,因地制宜地采取资源认知、植被改造等相关措施,恢复场地生态系统服务功能。实践人与自然和谐统一,潜移默化地将生态文明理念融入学生的价值观。部分学生能够运用更复杂的GIS分析功能,开展雨水花园区域详细设计。学生因地制宜地开展分析并将结果辅助于方案的推演和设计,在专业能力得到提升的同时,加深了对生态文明建设的理解,初步达到了价值塑造、能力培养、知识传授“三位一体”的功能,取得了一定成效。

4.2 融合式课堂教学模式的探索与不足

任课教师的协作奠定了教学改革的基础,不同专业背景教师加强交流沟通,发挥教学团队各教师专长,推动了教学内容和课程知识结构的优化。在场地调研过程中,由植物分类方向的教师为学生介绍场地内的珍稀树种资源,由生态背景的教师分析场地内外的发展建设情况,追踪社会和学校时事热点,通过课堂讨论激发学生兴趣,引导学生树立正确的生态文明价值观。

教师的角色从传统讲授为主的教学者,朝着引导、咨询、合作等多角色定位转变。本次改革中,基于GIS的数字化技术引入,突破了设计对经验的单纯依赖,在设计成果科学性的同时,也易于学生掌握与应用;在教学过程中营造互动式教学环境,帮助学生理解不同专业知识融合的关键点,特别是生态背景知识与信息技术类内容的联动,从实践中促进学生生态文明观的建立;教师根据每个组方案的侧重点提供技术辅导(如雨水花园的水文分析),鼓励学生探索更多GIS技术融合生态要素分析的可能性。将价值引领贯穿到理论和实践环节讲授活动中,形成课程教学“大思政”的新格局^[12]。

学生对于融合式的教学模式接受程度较高,通过学习相关技术,针对性地解决场地现存问题,践行生态文明价值观,提高了对课程定位与教学内容的整体认知。受课时和其他条件的限制,本次教改尝试也存在一定的不足:教师首次开展专业课程和思政内容相结合的教学,对于教学内容的设计还有继续整合优化的空间,在教学形式上应加强分析内容和方案推演过程的互馈;个别学生对课程思政内容和专题分析融合的意义理解不深,导致参与度不高,仍须进一步改进。

5 结语

本文初步讨论了生态优先背景下景观设计类课程与技术内容的融合模式,在生态文明建设新时期风景园林学科城乡规划专业课程思政教学改革方面做出了有益探索。在专业培养方案和课程体系改革中,应融入生态观和系统观,牢固树立社会主义生态文明观,推动人与自然和谐发展。今后可进一步发挥技术类课程实践性强的优势,优化

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发展带中麻栗坡发展存在一定滞后,东西、南北向城镇发展主轴发展态势较好,西畴县经济发展较为缓慢;州域北部、东部、南部3个发展极核支点稳步发展。

4.2 思考

文山州应加快推进南北向快速路网建设,完善州域内综合交通体系,缩短城市之间经济距离。目前文山州仅有一条穿过北部的东西向高速铁路,应在下一步规划和实施中,重点推进落实南北向交通,构建合理有效的运输网络,串联区域内各个城市,避免较为突出的不平衡发展。尽快落实“沿边铁路”文山—富宁段的建设,弥补南部东西向交通运输的欠缺,同时促进沿边城镇群发展带的构建。

增强州府文山市的服务半径,构建有效的30 min内部经济圈,辐射周边城镇群;由于铁路欠缺,文山市2014—2018年已然呈现出发展疲软之势,区域核心性正在下降,增强其聚集效应,保障“文砚丘平”的核心性是下一步结构优化的重点;应该合理调控指标,充分发挥高铁沿线丘北、广南、富宁3个县的经济潜力。

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思政内容、核心课程与技术连接的实施模式,培养“复合型、跨学科”的专业人才,推动转型期城乡规划专业教学改革继续深化,发挥协同效应,落实立德树人的根本任务。

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新工科背景下城乡规划专业信息技术类课程思政探索实践*

林蔚 卢丹梅 余美萱

华南农业大学林学与风景园林学院 广州 510642

摘 要 推进专业课程思政建设是高校教学改革的发展趋势和有力抓手。信息技术类课程作为城乡规划专业教学核心内容，是专业课程思政体系中的重要组成部分。针对课程特点和核心能力培养要求，提出“交叉共融、知行合一”的课程思政建设理念，通过挖掘课程思政元素，探索课程思政教学方案，总结思政教学策略及方法，以期为新工科背景下城乡规划专业的人才培养模式更新和内涵建设提供有益参考。

关键词 新工科；课程思政；城乡规划专业；信息技术；教学改革；城市地理信息系统；GIS

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0 引言

习近平总书记在全国高校思想政治工作会议上强调，要坚持把立德树人作为中心环节，把思想政治工作贯穿教育教学全过程，实现全程育人、全方位育人，努力开创我国高等教育事业发展新局面^[1]。《高等学校课程思政建设指导纲要》明确提出要在所有高校、所有学科专业全面推进课程思政^[2]，这既是本科人才培养改革的创新实践，也是社会高质量高水平人才培养的现实响应^[3]。课程思政已成为高校开展学生思想政治教育的重要实践活动，将价值观引导寓于知识传授和能力培养之中，坚持育人与育才相统一，全面提高人才培养质量。

近年来，教育部一直积极推进新工科建设，全力探索形成领跑全球工程教育的中国模式、中国经验，助力高等教育强国建设^[4]。高校教育作为行业发展的人才培养摇篮，推动新工科建设势在必行。信息技术作为新工科建设的重要组成部分，是城乡规划编制、管理、研究的重要支撑^[5]。随着人工智能、智慧城市和大数据时代的来临，信息技术在城乡规划中的应用已经成为规划师核心技能，因此，本文以城乡规划专业信息技术类核心课程城市地理信息系统为例，总结课程思政实践的经验。地理信

息系统（Geographic Information System, GIS）作为新型空间信息技术，应用十分广泛。城市地理信息系统课程重点培养学生综合应用分析能力，解决城乡规划设计中遇到的问题。通过网络调研开设城市地理信息系统相关课程高校，课程思政教学实践已成为教学改革的热点趋势，传统测绘土建、地理科学院校以课程实践为载体，挖掘课程中的思政元素，积极探索有效教学引领方式，成效突出。

然而，以上均是基于地理信息科学^[6]或测绘工程本科专业^[7]开展课程思政教学改革的实践，关于城乡规划专业如何开展信息技术类课程思政探索尚未见报道，尤其是针对城乡规划专业综合性、跨学科的特点^[8]，进一步发挥城市地理信息系统课程在城乡规划专业知识体系中的核心作用和思政价值，亟待开展深入讨论。

基于此，突出GIS这一领域改进质量、提高效率的实用技术工具典型优势，结合城乡规划专业综合性、应用性强的特点，探讨课程思政建设目标和内容重点，科学设计课程思政教学体系，探索专业课程思政的教学改革与实践，为城乡规划专业内涵式发展提供支撑和借鉴，助力新工科建设。

1 课程特点与定位

城市地理信息系统授课对象为城乡规划专业三年级学生，课程性质为选修课。城乡规划作为新兴学科，在人才培养上紧跟新工科发展趋势。新工科背景下大数据、云计算、人工智能和本课程具有天然的结合条件。本课程以信息技术为主线，以技术专题形式开展教学，重点讲授GIS基本方法、主要功能和技术应用。学生已接触大部分专业核心课程，为课程开设创造了良好条件，渴望了解新技术并对如何解决复杂的问题具有较强的求知欲。但是，学生尚未形成软件学习方法，部分学生学习目标不够明确，如何在有限的32学时内完成规定教学内容是巨大的挑战。

本课程教学目标可以从知识传授、能力培养和

* 项目来源：2021年度华南农业大学校级教改重点项目“乡村振兴背景下农林院校城乡规划专业内涵建设研究”；2021年度华南农业大学校级教改一般项目“基于‘工农互促’理念的城乡规划专业乡村振兴高素质人才培养模式改革与创新”。

作者简介：林蔚，讲师，博士；卢丹梅，通信作者，教授；余美萱，华南农业大学林学与风景园林学院城乡规划专业主任，副教授。

价值引领三个方面展开：知识传授方面，培养学生基本掌握 GIS 理论、功能和应用，获得开展研究、创新活动必备的专业能力；能力培养方面，通过案例讲解与操作实践，使学生将所学理论融入规划实操中，重点培养学生发现问题、分析问题和解决问题的实践能力；价值引领方面，本课程将紧紧围绕立德树人根本任务，积极响应协同育人理念，引导学生树立正确的理想信念，形成正确的世界观、人生观和价值观，发挥育人作用，培养具有创新意识和专业素养的社会主义建设者，培养具有社会责任感和家国情怀的接班人。

2 课程思政建设理念

基于《高等学校课程思政建设指导纲要》，城乡规划专业开设城市地理信息系统课程应突出理工兼具、综合性强、应用性强的特点，结合课程教学目标，从家国情怀、专业素养、工匠精神、创新意识等方面确定课程思政元素（表 1），从知识传授、能力培养、价值塑造三个层次细化课程思政目标，充分体现专业教学目标和思政教学目标的有机融合。为落实专业思政要求，本课程以新工科背景下的“地理信息+”作为赋能要素，提出“交叉共融、知行合一”理念，以学生为中心，提升其在课程中的参与度和获得感，

通过丰富案例和多种教学手段实现专业性与思政性有机融合，让学生在知识、能力和价值三个层次目标上有所收获。本课程围绕“两性一度”进行专项设计，深入挖掘课程育人功能，充分体现专业教育与思政教育的有机融合，实现专业教学和思政育人协同发展。

3 课程思政实施路径

如图 1 所示，根据知识、能力和价值目标，首先对课程内容进行解构，将思政目标具象化为课程思政点，梳理重构课程知识体系，将课程目标由单一的知识传递转变为注重价值引领，在模块化知识单元的基础上融入。以课程思政教学目标为基本方向，在深入分析课程特点和知识体系的基础上，抓住能够渗透思政教育的课程内容作为融入点。本课程基于 GIS 主要功能和常见分析场景，同时体现城乡规划发展前沿动态，在专题教学中充分挖掘思政元素，充分体现“两性一度”的要求。

4 课程思政具体实践

通过充分梳理和深入挖掘课程知识点蕴含的思政元素，把立德树人与专业知识传授相融合，将思政教育贯穿课程教学全过程。以部分教学内容为例，阐述课程思政元素内涵及与教学知识点融合过程。

表 1 课程内容与思政元素对应关系

思政元素	核心要求	课程内容
工匠精神	精益求精	GIS 软件迭代更新；注重图纸成品质量
家国情怀	砥砺前行	国产核心 GIS 与遥感技术；出图环节注重国家主权意识；我国提出的空间参考基准
专业素养	多维统一	能够分析问题，提出解决问题的方法并展开实践；训练科学思维方法和科学伦理；塑造价值观
创新意识	知行合一	开展综合训练；自主选题开展研究

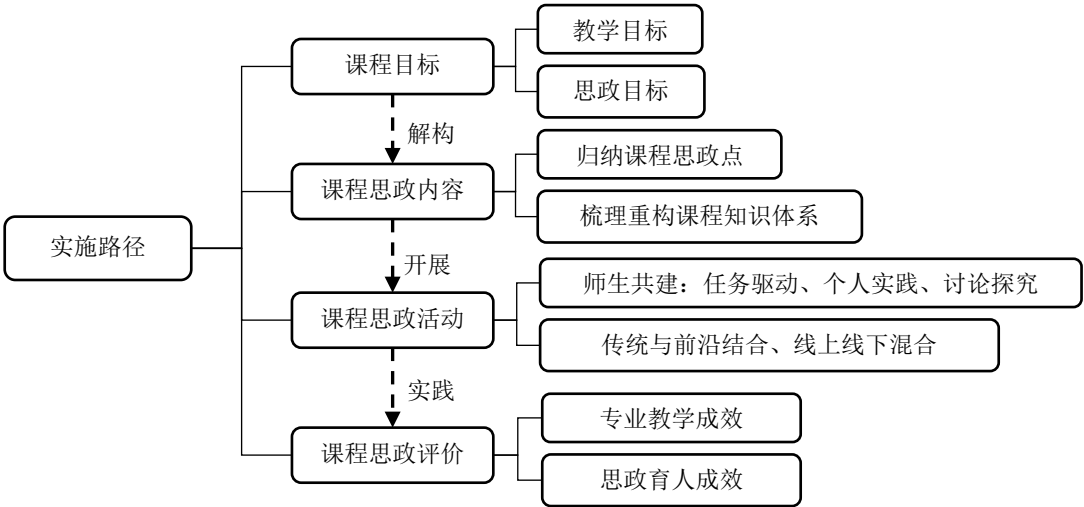


图 1 课程思政实施路径

4.1 GIS 应用发展和国产 GIS 软件：家国情怀、工匠精神

GIS 软件是开展教学的工作环境。长期以来，国外的专业软件吸引了大量用户资源，通过介绍国产 GIS 软件的瞩目成绩和发展历程，增强学生的民族自豪感，坚定文化自信，感受大国工匠精神。国产 GIS 软件在国土、测绘等多个领域得到广泛应用，国产 GIS 软件产业的发展壮大离不开从业人员的开拓创新，让学生受到大国工匠事迹的感染，培养精益求精的精神。在“互联网+”时代背景下，国产 GIS 软件引领技术潮流，与传感器、大数据、人工智能、区块链等技术融合，不断超越自我，具有巨大的发展空间。

信息安全事关国家安全和利益，必须从维护国家安全的战略高度确保国家地理信息安全。地理信息包含详细准确的位置，GIS 软件已成为多行业领域的核心支撑软件，管理着大量涉及国家地理安全的敏感信息，充分体现了 GIS 软件国产化的重要性。

GIS 技术在抗击新冠疫情的过程中发挥了重要作用：在疫情跟踪方面，通过对手机信令数据的分析，可以进行动态轨迹追踪，使疫情防控更为准确；针对疫情应对中暴露出的公共医疗资源短缺、结构不合理等城市问题，基于 GIS 软件分析指出主要优质医疗设施布局不合理，过度集中于中心城区，而基层卫生设施数量严重不足，未来亟须通过规划行动予以解决^[9]。GIS 服务于国家重大战略需求，服务于社会经济发展，给老百姓生活带来实实在在的价值，这是家国情怀的集中体现。

4.2 制作完整图纸：中国元素、工匠精神

制作完整图纸是 GIS 软件的核心功能，也是符号化表达的重要环节。完整图纸包括指北针、比例尺、图例、图框、图名等诸多要素，根据要求整饰出图是难点。规划设计图纸对出图环节有着严苛的要求，优秀的科研成果中必然有精美的图示支撑，通过展示科研文献的精美插图，让学生体会制图质量的重要性。学生应通过本节内容的学习，培养精益求精的工匠精神，意识到图纸表达的重要性。

从“问题地图”切入，吸引学生的注意力，让学生意识到图纸完整的重要意义。“问题地图”主要指存在危害国家主权统一、领土完整、安全和利益等严重问题的地图。“问题地图”的常见错误有漏绘钓鱼岛、赤尾屿、南海诸岛等重要岛屿，错误表示台湾省，错绘藏南地区和阿克赛钦地区国界线等。此处应强调地图是国家版图的表达形式，象征国家主权和领土完整，务必做到“一点都不能少，一点都不能错”。根据新版《地图审核管理规定》的要求：地图

不得含危害领土主权内容，本节内容以中国版图为底图开展操作示范和应用，可通过教学和练习强调地图要素的完整性，通过案例激发学生的家国情怀。

请学生浏览标准地图服务网站学习相关标准和规定，结合章节学习的要点，检查教师所提供地图案例的正确性。通过布置自选主题制图作业，要求学生寻找合适的数据库，确定恰当的符号化方式，完成图纸的制作，调动学生的主观能动性，在提升规范性的同时，进一步培养学生的创新能力，激发学生的专业思维。

4.3 现状容积率统计：专业素养、价值塑造

本节课内容覆盖了常用矢量数据空间分析功能，但能否将这些功能进行综合应用，解决行业实际问题，是高阶性的集中体现。由于本学时内容还涉及制作完整图纸等已学内容，对学生掌握情况是很好的检验；要求学生限时完成分析，也具备一定的挑战度。此外，本节教学内容还与其他专业课程打通，在融合的基础上进一步体现技术创新。

容积率是控制性详细规划中开发强度的重要指标之一，是国有土地使用权出让合同中必须规定的重要内容，也是进行城乡规划行政许可时必须严格控制的关键指标。从“容积率腐败案”说起，让学生意识到专业工作的严肃性，引起学生的重视。一些地方的城乡规划主管部门利用手中的权力擅自修改容积率等重要指标，对调整搞暗箱操作，甚至出现权钱交易谋取私利的违法行为。规划管理的违法违规行爲不但给国家造成巨大的经济损失，而且严重损害了政府部门和规划行业在公众中的形象，造成不良社会影响。

通过课堂讲授，要求学生理解容积率的定义、分解步骤和对应工具。容积率统计是矢量数据空间分析的组拳，重点讲解如何根据技术提要建立分析流程图，如何对分析功能“积木”进行“拼装”开展综合应用，解决行业实际问题，真正理解课程的出发点。通过 GIS 软件分析，在提升工作效率和精确度的基础上，进一步要求学生严肃认真，恪守职业道德。通过讨论激发学生学习兴趣，号召学生深刻认识维护人民利益、增进人民福祉是规划师重要职业信条。专业素养源自严谨清晰的思路和对细节的把控。

5 课程思政教学策略及方法

5.1 坚持传统与前沿、线上与线下相结合的教学策略

5.1.1 传统教学内容与前沿知识内容相结合

GIS 涉及千余种功能操作，难以面面俱到地进
(下转 P78)

[6] 虚拟现实技术 [DB/OL]. <https://baike.baidu.com>.
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(上接 P69)

行介绍。因此,本课程精选核心模块,重点突破极具代表性的功能,以点带面进行学习。同时,作为一门应用性极强的学科,如何利用 GIS 软件解决城乡规划领域实际问题是教学过程中的焦点,引入行业前沿的分析案例补充传统教学内容,有助于学生进一步领会课程的核心价值。

5.1.2 在教学过程中坚持线上和线下相结合

由于课程教学内容较多,同时涉及大量的软件操作环节,选课学生提问答疑的工作量大,难以全部在线下集中教学环节完成。因此,充分利用线上教学资源,通过提前布置任务、个人分散演练、搜集疑问答疑等形式,有效利用有限的课时,集中力量挑战综合性、高阶性任务。

5.2 形成任务驱动一个人实践一讨论探究的师生共建教学模式

5.2.1 转被动接受为主动探究

以往的软件实操型课程以教师课堂讲授示范为主,以“我教你学”为主要特征,难以保证每位学生都深度参与课堂。因此,通过提前布置课程任务、当堂组织考核等形式,促使学生提前接触当周教学内容并反馈学习情况,激发学生的学习兴趣 and 热情。

5.2.2 翻转课堂全面提升综合能力

在立足学生软件实操能力的基础上,注重学生口头表达能力、文字凝练能力的培养,提高学生正确认识问题、分析问题和解决问题的能力;通过师生间的交流讨论,可以进一步碰撞出思维的火花,同时增进师生间的互动,让课堂教学更有温度,更有感染力,更有创造力。

6 结束语

培养具有崇高道德水准的高素质人才是高等教育的中心任务^[10]。城乡规划专业在实施信息技术类教学过程中融入思政元素,有利于增强教学效果,促进学生全面发展。

当前,课程思政案例日益丰富,但信息技术类专业的课程设计与思政元素的结合还有待进一步提

高。通过充分梳理和深入挖掘城市地理信息系统课程所蕴含的思政元素和教育资源,以“地理信息+”作为赋能要素,提出“交叉共融、知行合一”的理念,落实立德树人的育人目标,提出实施路径与方法,将思政元素有机地融入专业知识技能教学,全面提升课程的育人成效,得到学生的普遍肯定,为在新工科背景下专业课教学中如何融入课程思政元素提供了一定的参考和借鉴。

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广州市社会科学规划领导小组办公室文件

穗社规办〔2023〕6号

关于广州市哲学社会科学发展“十四五”规划 2023年度课题立项的通知

各有关单位科研管理部门：

经专家评审、社会公示，报广州市社会科学规划领导小组审定，广州市哲学社会科学规划2023年度课题立项190项。其中，一般课题90项，羊城青年学人课题74项，广州大典课题22项，博士论文4项。现将有关事项通知如下：

1. 本年度课题立项时间为2023年5月15日，一般课题、羊城青年学人课题及广州大典课题结项时间为2025年5月15日前，博士论文的结项时间为2026年5月15日前。因故不能按期完成结项的，应在结项时间截止前10天提出延期申请。

2. 课题研究应按照《广州市哲学社会科学规划课题申请书》的设计进行。未经市社科规划办同意不得更改研究方向、内容、成果形式及变更管理单位。

3. 本年度广州市社科规划课题资助经费采取一次核定,分期拨款的方式,首期经费为总经费的 50%,课题立项后划拨;后期经费为总经费的 50%,课题结项后划拨。本年度一般课题、广州大典课题资助经费 5 万元/项,羊城青年学人课题、博士论文资助经费 3 万元/项。

4. 请各单位科研管理部门及时将本通知有关事项告知各课题负责人,并组织课题负责人签订《广州市哲学社会科学发展“十四五”规划 2023 年度课题立项协议》一式 3 份(模板下载请联系市社科规划办),于 2023 年 6 月 9 日前送达我办审定盖章。随协议同时报送《广州市哲学社会科学规划课题申请书》纸质版一式 1 份,课题题目以本通知附件的立项名单为准。以上材料签章均需规范齐全。

5. 未及时提交《广州市哲学社会科学发展“十四五”规划 2023 年度课题立项协议》和《广州市哲学社会科学规划课题申请书》的,视为课题负责人自动放弃课题立项。

附件:广州市哲学社会科学发展“十四五”规划 2023 年度
课题立项名单

广州市社科规划领导小组办公室

2023 年 5 月 15 日

(联系人：姬老师；联系电话：020-89815149)

附件

广州市哲学社会科学发展“十四五”规划 2023年度课题立项名单

序号	负责人	单位名称	课题名称	课题编号
一般课题90项（每项资助5万元）				
1	李珍	中山大学	数字时代马克思主义理论创新与传播研究——基于利用智能算法提升主流意识形态话语权的视角	2023GZYB01
2	梁增贤	中山大学	广州加快公园城市建设研究	2023GZYB02
3	蔡伟	中山大学	广州提升法律服务全球竞争力路径对策研究	2023GZYB03
4	徐健	中山大学	人才是第一资源的广州实践和对策研究——高校科技人才与企业技术需求对接问题与对策研究	2023GZYB04
5	李海涛	中山大学	新时代增强广州文明传播力影响力研究——广州侨批档案诚信文化价值开发推广研究	2023GZYB05
6	胡诗然	中山大学	中国式现代化建设中坚持改革开放的目标与重点任务研究——数字外交视角下的中美国际传播比较研究	2023GZYB06
7	王晓丽	华南理工大学	在高质量发展中促进共同富裕的制度设计研究——以实现机制为视角	2023GZYB07
8	张国启	华南理工大学	以党的自我革命引领社会革命研究——基于全面建设社会主义现代化国家新征程的实践效应维度	2023GZYB08
9	徐维军	华南理工大学	广州统筹推进碳达峰碳中和与经济社会协同发展研究	2023GZYB09
10	雷玉桃	华南理工大学	广州统筹推进碳达峰碳中和与经济社会协同发展研究：基于制造业碳减排与高质量发展的视角	2023GZYB10

序号	负责人	单位名称	课题名称	课题编号
			主体干预机制研究	
20	许清	暨南大学	广州构建具有全球竞争力的开放创新生态研究——以开放式创新背景下知识产权对技术创新的激励机制为视角	2023GZQN20
21	陈胜蓝	暨南大学	广州民营企业海外权益保护研究：以企业海外知识产权保护为例	2023GZQN21
22	李佳	暨南大学	广州加快岭南文化中心和文化强市建设研究——广州话的传统环境知识语汇整理	2023GZQN22
23	宋婉贞	暨南大学	“一带一路”视域下广州加快建设枢纽型侨都的路径对策研究	2023GZQN23
24	祝哲	暨南大学	新时代广州公共安全应急框架体系研究——政策信息学背景下风险政策叙事的效果评估和体系优化	2023GZQN24
25	周超	华南农业大学	实现第二个百年奋斗目标新的赶考之路上需防范的重大风险研究：开放经济条件下我国农业领域的外汇风险	2023GZQN25
26	刘树鑫	华南农业大学	广州公共文化服务高质量发展路径政策研究	2023GZQN26
27	张奕婧	华南农业大学	广州坚持制造业当家、构建现代化产业体系研究——双碳背景下企业开放性创新机理研究	2023GZQN27
28	朱庆莹	华南农业大学	广州超大城市治理体系和治理能力现代化研究——基于城市韧性建设视角	2023GZQN28
29	林蔚	华南农业大学	广州加快森林城市建设研究：供需视角的布局优化与增益路径	2023GZQN29
30	夏宇	华南农业大学	广州加快改善城乡人居环境的政策对策研究——健康老龄化视角下的乡村老年户外支持性环境整治设计研究	2023GZQN30
31	秦楠	华南师范大学	推进大中小学思想政治教育一体化建设研究——基于完整生活的立场	2023GZQN31
32	范云歌	华南师范大学	广州市人口老龄化的伦理问题与应对思路研究：基于家庭养老与社会养老中精神赡养问题的探讨	2023GZQN32
33	谢晓东	华南师范大学	人才是第一资源的广州实践和对策研究——“非升即走”高校青年教师负性情绪等对业	2023GZQN33

课题编号	2023GZQN29
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广州市哲学社会科学发展“十四五”规划

2023 年度课题立项协议

甲 方：广州市社会科学规划领导小组办公室/广州市社会科学界联合会

地 址：广州市天河区龙口东路 363 号宝供大厦二楼

联系电话：020 - 89815149

法定代表人：曾伟玉

乙 方：华南农业大学（单位） 林蔚（课题负责人）

地 址：（单位地址）广州市天河区五山路 483 号

课题负责人（签字）： 林蔚

课题负责人手机号码：18144869666

课题负责人邮箱：wlin@scau.edu.cn

二〇二三年五月

广东省哲学社会科学规划专项小组

粤社科规专通〔2024〕38号

广东省哲学社会科学规划 2024 年度 学科共建项目立项通知书

林蔚同志：

经省哲学社会科学工作领导小组审批，您申报的广东省哲学社会科学规划 2024 年度学科共建项目《供需视角下珠三角森林城市群建设空间优化路径研究》获准立项，批准号：

GD24XGL044。学科共建项目资助经费为 2 万元，由项目负责人所在单位自筹并分期划拨给项目负责人，第一次拨款 1.4 万元，预留经费 0.6 万元在项目鉴定结项后拨付。请尽快登录

- 1 -

广东省哲学社会科学规划项目管理平台上传签字盖章版申请书PDF扫描件并认真填报预算，预算个人填报截止时间为7月26日12点，单位审核截止时间为7月26日17点。逾时未填报立项预算视为放弃立项。

项目负责人填写预算后，本通知即成为具有约束效力的立项协议。项目负责人所在单位须承担保证责任。项目负责人及所在单位须了解和执行以下规定：

1.课题组须学习并遵守《广东省哲学社会科学规划项目管理办法》。对于出现违规行为的，省哲学社会科学规划专项小组依据《广东省哲学社会科学规划项目管理办法》的相关规定进行处理。

2.批准后的项目经费不再追加，课题组可以不接受。而一经接受，将不能以经费不足为由，擅自变更原设计的最终成果形式和内容。

3.项目立项后，课题组须按项目申请书所列计划开展研究。研究过程中，如有变更项目负责人、改变成果内容或形式、变更项目管理单位、变更或增补课题组成员、终止项目或撤消项目、延期等重要事项，项目负责人或所在单位必须及时填写《广东省哲学社会科学规划项目重要事项变更审批表》

（可在广东社科规划网“下载专区”下载），报省哲学社会科学

规划专项小组审批。

4.省社科规划项目成果为论文的，在公开发表时必须注明“广东省哲学社会科学规划项目（项目编号）”字样。成果（含阶段成果）为专著、研究报告的，未经规划专项小组组织专家鉴定或经鉴定但未获得通过，出版时不能标明“广东省哲学社会科学规划项目（项目编号）”字样；如成果确实有先出版后鉴定结项的需要，必须先向规划专项小组提出书面申请，经批准后才能出版并标明“广东省哲学社会科学规划项目（项目编号）”字样；如未经鉴定或未向规划专项小组申请，自行出版并标明“广东省哲学社会科学规划项目（项目编号）”字样，规划专项小组不接受项目结项申请，予以撤项处理。

5.项目成果的鉴定结项由省哲学社会科学规划专项小组组织，实行匿名鉴定制度。项目负责人及所在单位须在规定时间内向省哲学社会科学规划专项小组提交项目结项材料，在规定时间内不提交结项材料，将作撤项处理。结项所需材料、装印要求等具体事项，请登录广东社科规划网站“结项信息”栏目查看。

6.成果鉴定等级分为优秀、良好、合格和不合格四个等次。通过结项的，将拨付预留经费。不合格即未能通过结项，其预留经费不予拨付，课题组需修改后半年内重新申请结项鉴

定。仍不能通过的，将作撤项处理。

7.被撤项的项目负责人五年内不得申报国家社科基金项目和省哲学社会科学规划项目。

以上规定，项目负责人及所在单位应严格遵守。如有异议，可不接受资助，立项协议自行废止。

联系人：冯甜恬

地址：广州市天河北路 618 号广东社科中心 B 座 928 室

电话：(020)83825078

邮编：510635

广东省哲学社会科学规划专项小组

广东省哲学社会科学规划领导小组办公室（代章）

2024 年 7 月 11 日

广东省教育厅

粤教科函〔2022〕5号

广东省教育厅关于公布 2022 年度普通高校 认定类科研项目立项名单的通知

各有关高校：

为深入实施创新驱动发展战略，落实《广东省教育厅 广东省科学技术厅关于印发科教融合协同推进高校科技创新能力提升工作计划的通知》（粤教科函〔2019〕57号），省教育厅组织开展了 2022 年度普通高校科研项目认定工作。经学校推荐、省教育厅组织审核，现将批准立项的 2022 年度普通高校认定类科研项目立项名单（见附件）下达各高校。

请各高校按照国家和省相关科研平台项目管理办法，统筹安排项目资金，加强资金管理，督促项目承担人按照项目申请书开展建设工作，协助解决项目实施过程中遇到的困难和问题，确保研究项目如期完成目标任务。

附件：1.2022 年度广东省普通高校特色创新类项目立项名单

1	2022WTSCX001	岭南诗词在环境设计教学中的价值开发和传承创新	郑莉	华南理工大学
2	2022WTSCX002	面向GUI图形用户界面的专利规避设计研究	李森	华南理工大学
3	2022WTSCX003	纳税信用评级披露对税收遵从的外溢效应研究	杨玉萍	暨南大学
4	2022WTSCX004	基于“三生空间”功能协同的珠三角水网地区传统村落重构策略研究	林蔚	华南农业大学
5	2022WTSCX005	高校音乐教育中岭南传统音乐文化的创造性转化发展研究	石娟娟	华南农业大学
6	2022WTSCX006	新时代廉洁文化建设的VR动画传播与研究	李雷鸣	华南农业大学
7	2022WTSCX007	后疫情时代应急语言服务者胜任力模型及其评价体系的构建研究	李清华	南方医科大学
8	2022WTSCX008	“顶天立地”医疗卫生大格局高质量发展法治保障研究	刘昂	南方医科大学
9	2022WTSCX009	新医科语境下的生命健康叙事与健康管理研究	田峰	南方医科大学
10	2022WTSCX010	基于深度学习和知识图谱的中医古籍知识整理	刘秀峰	广州中医药大学
11	2022WTSCX011	全过程人民民主引领地方治理现代化研究——以广东省为例	董宏鹰	华南师范大学
12	2022WTSCX012	重大突发公共事件中慈善组织社会救助效能研究	彭灵灵	广东外语外贸大学
13	2022WTSCX013	中国“新电视”场域的结构变化、文化生产与边界策略	周娟	广东外语外贸大学
14	2022WTSCX014	商事制度改革与县域企业创新：基于全国实地调研的发现	马晶	广东外语外贸大学
15	2022WTSCX015	“意义”否定表征的实验语言哲学进路	朱晓真	广东外语外贸大学
16	2022WTSCX016	大卫·马梅特戏剧的伦理叙事研究	赖日升	广东外语外贸大学
17	2022WTSCX017	健康语境下负面情绪管理的人际语用学研究	雷容	广东外语外贸大学
18	2022WTSCX018	基于文化空间视角的潮州古城保护和发展实施路径探析	郑红彬	汕头大学
19	2022WTSCX019	粤东地区“文创+IP”产业的转型与创新成长路径研究	贺姿雅	汕头大学
20	2022WTSCX020	文学地图的理论建构和空间可视化创新研究	黄继刚	汕头大学
21	2022WTSCX021	珠江三角洲“白梳女”影像保护研究	孟祥斌	汕头大学
22	2022WTSCX022	清代甘青地区汉族与少数民族法律文化交融研究	李守良	汕头大学

检索证明

根据委托人提供的论文材料，委托人华南农业大学林学与风景园林学院 林蔚 2 篇论文收录情况如下表。

序号	论文名称	发表刊物及发表的年月卷期/页码等	作者排名	论文等级	作者文中单位	收录情况	影响因子	中科院大类分区
1	Integrating Ecosystems and Socioeconomic Systems to Identify Ecological Security Pattern and Restoration Strategy in a Rapidly Urbanizing Landscape	FRONTIERS IN ENVIRONMENTAL SCIENCE 出版年：2022 卷期：10 页码：- 文献号：862310 文献类型：Article	通讯作者	B 类	华南农业大学	SCI	IF2-year=4.6 IF5-year=5.3 (2022)	环境科学与生态学 3 区 Top 期刊：否 (2022)
2	Zoning strategies for ecological restoration in the karst region of Guangdong province, China: a perspective from the "social-ecological system"	FRONTIERS IN ENVIRONMENTAL SCIENCE 出版年：2024 卷期：12 页码：- 文献号：1369635 文献类型：Article	通讯作者	B 类	华南农业大学	SCI	IF2-year=4.6 IF5-year=5.3 (2022)	环境科学与生态学 3 区 Top 期刊：否 (2023)

说明：论文等级和中科院大类分区按《华南农业大学学位论文评价方案（试行）》划分。

报告免责声明：如未盖章，报告无效

检索员：张进
华南农业大学图书馆

华南农业大学图书馆SCAULIB202406212



检索证明

根据委托人提供的论文材料，委托人华南农业大学林学与风景园林学院 林蔚 7 篇论文收录情况如下表。

序号	论文名称	发表刊物及发表的年月卷期/页码等	作者排名	论文等级	作者文中单位	收录情况	影响因子	中科院大类分区
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WATER RESOURCES PROTECTION



WATER RESOURCES PROTECTION

构建黄河流域水网的思考◎

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气候变化诱导水体富营养化研究进展◎



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东江下游流域城水耦合协调关系评价及其影响因素

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摘要: 针对城镇化进程对水资源系统干扰逐步加强的问题, 基于水资源、水环境、水生态子系统构建水资源环境评价体系, 基于空间、人口、社会经济子系统构建城镇化质量评价体系, 测算东江下游流域14个区县单元的城水耦合协调度, 并运用灰色关联模型分析城水动态耦合关系的主要影响因素。结果表明, 2010—2020年大湾区东岸城镇化水平不断提高, 水资源环境水平波动上升, 城水耦合度提升显著, 由磨合阶段转变高水平耦合阶段; 耦合协调度在2010—2015年显著提升, 2016—2020年微弱下降, 其中黄埔、龙华等城市边缘区耦合协调度降幅较为明显, 空间分异显著; 高水平城水耦合关系下, 人口增长、建设用地扩张是胁迫水资源环境的主要因素, 水资源紧缺、用水效率低下以及水生态系统服务功能恶化是限制城镇化发展的主要原因。

关键词: 城镇化; 水资源环境; 耦合协调度; 灰色关联模型; 东江流域下游; 粤港澳大湾区

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Evaluation of urban-water coupling coordination relationship and its influencing factors in lower reaches of the Dongjiang River Basin // LIN Wei¹, CHEN Zilin², LI Hui¹ (1. College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou 510642, China; 2. School of Architecture & Urban Planning, Shenzhen University, Shenzhen 518060, China)

Abstract: In view of the increasing interference of urbanization on the water resources system, the evaluation system of water resources and environment was built based on water resources, water environment and water ecology subsystems, and the urbanization quality evaluation system was built based on space, population and socio-economic subsystems. The urban-water coupling coordinated degree of 14 districts and counties in the lower reaches of the Dongjiang River Basin was calculated, and the main influencing factors of the urban-water dynamic coupling relationship were analyzed by using the grey correlation model. The results showed that from 2010 to 2020, the urbanization level of the east bank of the Greater Bay Area continued to improve, and the level of water resources environment was fluctuating upward. The urban-water coupling degree had increased significantly, from running-in stage to high-level coupling stage. The coupling coordination degree increased significantly from 2010 to 2015, and declined slightly from 2016 to 2020. The coupling coordination degree of Huangpu District, Longhua District and other urban fringe areas decreased significantly, with significant spatial differentiation. Under the high-level urban-water coupling relationship, population growth and construction land expansion were the main factors that stress the water resources environment. The shortage of water resources, the low efficiency of water use and the deterioration of water ecosystem services are the main reasons that restrict the development of urbanization.

Key words: urbanization; water resources environment; coupling coordination degree; grey correlation model; lower reaches of the Dongjiang River Basin; Guangdong-Hong Kong-Macao Greater Bay Area

随着人类活动对自然水循环的影响逐渐加深, 自然生态系统和经济社会系统逐渐演变失衡, 产生了一系列城市水问题, 严重制约了社会经济持续健康发展^[1-2]。人水互动关系增强, 水文系统和人类

系统演变为一个耦合系统^[3]。粤港澳大湾区人口高密度聚集, 水资源与人类社会关系一直都是重要的研究课题, 大湾区水问题亟待思考及解决^[4-6], 已在水资源、水安全、水环境、洪涝灾害等

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方面开展了有益探索^[7-10]。通过构建评价指标体系,分析水资源脆弱性和生态敏感性及其演变特征^[11-12]。然而,以上成果多从单方面水问题开展研究,或侧重于生态系统方面的指标体系构建和评价分析,对“自然-社会”复合生态系统间复杂的相互作用考虑不足^[2],难以刻画水资源开发利用、经济社会发展及生态环境保护之间复杂、变化的互馈关系^[13]。

和谐的城水关系是科学配置城市水资源、改善人居环境、实现人与自然协调发展的前提和基础^[2]。随着水问题研究的推进,城镇化与水资源、生态环境的耦合关系分析和耦合协调研究成为热点^[14-16],很多研究通过收集统计数据构建指标体系,以省、市为单元测度耦合协调程度,然而这些研究并未采用生态系统服务表征水循环过程的状态,较少考虑城镇化影响生态系统服务及其时空变化过程,不利于生态文明背景下的城市群发展^[17],对城水耦合关系的支撑有待进一步探讨。

流域是典型的复合生态系统,探析城镇化建设对水资源系统的多维干扰是开展流域治理的重要前提^[18]。随着城镇化进程的推进,东江下游城市群面临着水资源短缺、水环境污染和水生态退化的严峻挑战^[19]。“十四五”时期,我国城镇化将向高质量发展全面转型,亟待通过城水耦合重塑城市建设与水环境之间良性友好的整体关系^[20]。因此,探究流域水资源保护、城市发展与水环境的内在关系,对促进粤港澳大湾区可持续发展具有重要实践价值。本文融合遥感、生态系统服务评估等多种技术方法,构建“水资源-水环境-水生态”的水资源环境系统评价体系,分析其与城镇化质量的耦合协调程度,以期为东江下游城市群提升发展提供参考。

1 研究区概况

东江是粤港澳大湾区东部重要水源地,具有突出的战略地位和生态价值。选取大湾区东部人口集聚、经济发达的下游流域(图1),行政范围包括广州、深圳、东莞、惠州等4市,涉及10个市辖区、3个县区以及1个地级市(无下辖区县)。下游流域整体地势较为平坦,平均高程低于100 m,多年平均温度约20℃,年均降水量为1200~2000 mm,水网密布。根据统计年鉴数据,2020年研究区城镇化水平达75%左右^[21]。

2 数据来源与研究方法

2.1 数据来源

研究数据包括 GlobleLand 30 土地覆被数据、

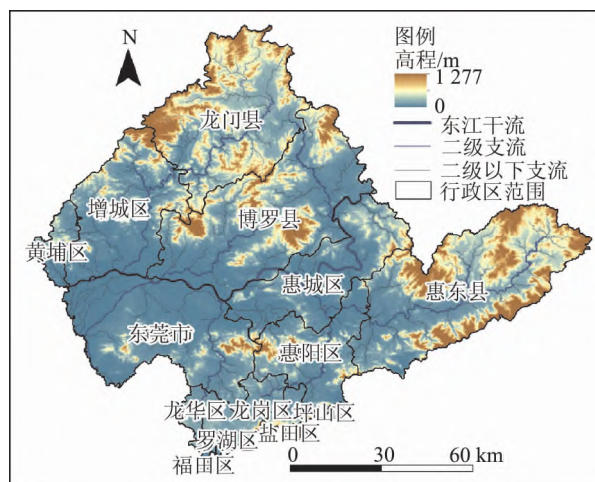


图1 东江下游流域概况

Fig.1 Overview of lower reaches of the Dongjiang River Basin

MODIS 全球蒸散发数据、植被指数数据、精细植被类型数据、气象数据、土壤质地数据、DEM 数据以及各地区社会经济、水资源等统计数据,各数据时间序列均选择2010年、2015年及2020年。其中蒸散发数据来源于MOD16A2 8d合成产品(<https://www.usgs.gov/>),空间分辨率为500 m,对数据进行拼接合成,提取实际总蒸散发波段;植被指数数据来源于MOD13Q1 16合成产品(<https://www.usgs.gov/>),空间分辨率为250 m,采用最大值合成法合成研究区逐月NDVI数据;土壤质地数据来源于寒区旱区科学数据中心(<http://westdc.westgis.ac.cn/>)中国土壤数据集,空间分辨率为1 km;数字高程DEM数据集源自地理空间数据云(<http://www.gscloud.cn/>),空间分辨率为30 m;社会经济、水资源及水环境等统计数据源于东江下游流域内广州、深圳、惠州、东莞等地级市统计年鉴、水资源公报等,其中坪山区(2016年新设)、龙华区(2016年新设)的2010年、2015年部分统计数据分别以龙岗区、宝安区代替。

2.2 指标体系构建

图2为东江下游流域城镇化质量与水资源环境评价指标体系,包括城镇化质量指标体系和水资源环境指标体系两部分(括号中数字为指标权重)。

2.2.1 城镇化质量指标体系

结合研究区城镇化发展情况,借鉴相关研究成果^[22-23],从空间、人口及社会经济发展3个子系统选取6个指标构建城镇化质量指标体系。选取建设用地率反映空间发展情况,人口发展用人口密度和常住人口城镇化率来反映,社会经济发展情况用人

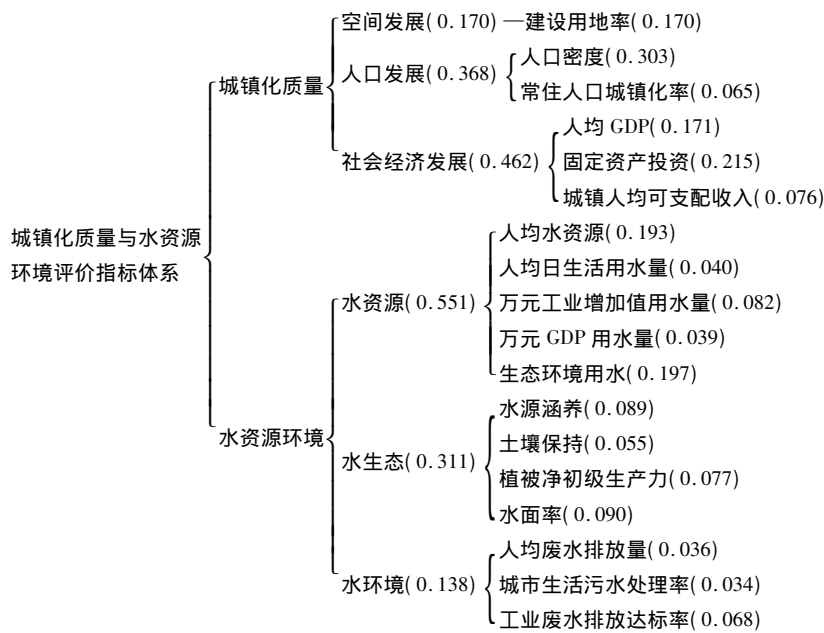


图2 城镇化质量与水资源环境评价指标体系

Fig.2 Evaluation index system of urbanization quality and water resources environment

均 GDP、固定资产投资、城镇人均可支配收入来反映。

2.2.2 水资源环境指标体系

流域水资源、水生态与水环境相辅相成 相互制约 水资源对维持城市社会经济发展具有重要意义 完善的水生态功能提供赖以生存的自然环境条件与效用 水环境是与水资源、水生物和污染密切相关的综合体^[18-19]。因此 从水资源、水生态和水环境 3 个子系统选取 12 个指标 构建水资源环境评价指标体系。

a. 水资源。研究区 2010 年以来水资源管理制度深化落实 结合已有评价成果 本文从水资源禀赋条件、用水效率及用水需求等方面选取人均水资源量、人均日生活用水量、万元工业增加值用水量以及万元 GDP 用水量、生态环境用水量等 5 个指标进行评价。

b. 水生态。传统的水生态功能评价多采用监测指标或统计数据 本文引入维持水生态系统服务的重要因子: 水源涵养、水土保持、植被净初级生产力以及水面率共同评价水生态功能。其中水源涵养利用 InVEST 模型产水模块中的水量平衡法的变形式进行计算^[24]; 水土保持通过修正水土流失方程计算年平均土壤流失量^[25] 数值越大 水土保持能力越差 为负向指标; 植被净初级生产力采用 CASA 模型进行计算^[26]; 水面率为河道面积与区域面积之比^[27]。

c. 水环境。良好的水环境质量是流域社会经济绿色协调、可持续发展的重要体现^[19]。结合当前研究区水环境治理政策实施情况 选取人均废水排

放量、城市生活污水处理率、工业废水排放达标率 3 个指标表征城市水环境状态。

2.2.3 数据标准化处理

由于评价指标存在量纲和属性差异 需引用极差标准化法对正、负向指标数据进行标准化处理^[22] 公式分别为

$$Z_{ij} = \frac{X_{ij} - X_{j\min}}{X_{j\max} - X_{j\min}} \quad (1)$$

$$Z_{ij} = \frac{X_{j\max} - X_{ij}}{X_{j\max} - X_{j\min}} \quad (2)$$

式中: Z_{ij} 为系统 i 指标 j 标准化后的指标值 其取值范围为 $[0, 1]$; X_{ij} 为原始值; $X_{j\max}$ 、 $X_{j\min}$ 分别为指标 j 的最大值和最小值。

2.2.4 指标权重确定及综合评价指数计算

熵权法通过计算指标信息熵确定权重系数 能有效消除主观因素影响^[28-29] 故采用熵权法计算指标权重 图2 括号中为权重值。依据指标标准化值与权重系数 加权计算城镇化质量与水资源环境综合评价指数 计算公式为

$$f(U) = \sum_{i=1}^a m_i U_i \quad (3)$$

$$g(E) = \sum_{i=1}^b n_i E_i \quad (4)$$

式中: $f(U)$ 为城镇化质量综合评价指数; $g(E)$ 为水资源环境综合评价指数; m_i 与 n_i 为评价指标权重; U_i 与 E_i 分别为城镇化质量和水资源环境标准化指标值; a 和 b 为各系统指标数量。

2.3 耦合协调度模型

耦合度模型能够探究城镇化与水资源环境相互

影响程度,反映城水系统无序和有序状态的转变过程,展现系统内部组成要素间的动态关联关系^[30],耦合度越高,表明系统间关联程度越强^[16]。结合相关研究及实际情况,将城镇化质量与水资源环境耦合度 C 划分为 4 个等级: $C \in (0, 0.3]$ 表示处于低水平耦合阶段, $C \in (0.3, 0.5]$ 表示拮抗阶段, $C \in (0.5, 0.8]$ 表示磨合阶段, $C \in (0.8, 1.0]$ 表示高水平耦合阶段。耦合度计算公式^[31]为

$$C = \left\{ \frac{f(U)g(E)}{[f(U) + g(E)]^2} \right\}^{\frac{1}{2}} \quad (5)$$

耦合度虽反映系统间相互作用程度,但无法表征各功能间是高水平的相互促进还是低水平相互制约^[31],因此进一步引入耦合协调度模型,量化城水系统在发展过程中的均衡状态和协调程度,着重分析系统之间的良性互动关系^[30]。结合相关研究及实际情况,将耦合协调度 D 划分为 6 个等级: $D \in (0, 0.2]$ 表示城水关系严重失调, $D \in (0.2, 0.4]$ 表示中度失调, $D \in (0.4, 0.5]$ 表示濒临失调, $D \in (0.5, 0.6]$ 表示勉强协调, $D \in (0.6, 0.8]$ 表示中度协调, $D \in (0.8, 1.0]$ 表示高度协调。耦合协调度计算公式^[31]为

$$D = \sqrt{CT} \quad (6)$$

其中 $T = \alpha f(U) + \beta g(E)$
式中: T 为城镇化质量与水资源环境综合发展指数; α 和 β 为系数,本研究认为两者同等重要,因此取 $\alpha = \beta = 0.5$ 。

2.4 灰色关联度模型

城镇化质量与水资源环境交互耦合关系复杂多样,因此引入灰色关联度模型定量分析城镇化质量与水资源环境系统间的动态耦合关系,揭示城水耦合关系的主要影响因素。灰色关联分析是依据各因素序列曲线几何形状的相似程度来判断其联系紧密程度的方法,通过计算要素间的关联系数,根据关联系数对于样本数的平均数计算评价要素间的关联度,对关联度进行排序得到对某一对象影响程度的大小,关联度越大,影响程度就越大。关联度计算公式为

$$\gamma_{ij} = \frac{1}{m} \sum_{t=1}^m \xi_{ijt} \quad t = 1, 2, \dots, m \quad (7)$$

其中

$$\xi_{ijt} = \frac{\min_i \min_j |Z_{Uit} - Z_{Ejt}| + \rho \max_i \max_j |Z_{Uit} - Z_{Ejt}|}{|Z_{Uit} - Z_{Ejt}| + \rho \max_i \max_j |Z_{Uit} - Z_{Ejt}|}$$

式中: γ_{ij} 为比较序列与参考序列整体关联度; m 为时刻数; ξ_{ijt} 为 t 时刻评价指标与参考序列对应元素的关联系数; Z_{Uit} 和 Z_{Ejt} 分别为各县(区) t 时刻的城镇

化质量与水资源环境指标标准化值; ρ 为分辨率系数,一般取值 0.5。

通过比较各个指标关联度 γ_{ij} 的大小,可以分析城镇化质量与水资源环境系统内部指标相互关联程度。 γ_{ij} 介于 0~1 区间,值越接近 1 代表系统间关联性越大。参考相关研究,关联度取值范围及其判断标准划分为 4 个等级: $\gamma_{ij} \in (0.00, 0.35]$ 表示二者为低水平关联状态, $\gamma_{ij} \in (0.35, 0.65]$ 表示中等关联, $\gamma_{ij} \in (0.65, 0.85]$ 表示高度关联, $\gamma_{ij} \in (0.85, 1.00]$ 表示极强关联。

3 结果与分析

3.1 城镇化质量与水资源环境综合评价

3.1.1 城镇化质量时空分异特征

自 2010 年以来,研究区城镇化质量各项指标均呈现稳步提升,常住人口城镇化率由 78% 提升至 85%,人均 GDP 上涨 1 倍,人口密度也大幅提高。2016—2020 年,固定资产投资及城镇居民人均可支配收入得到大幅提升。总体而言,2010—2020 年城镇化质量综合指数整体呈持续上升趋势,由 0.34 增加至 0.48,其中黄埔、增城、坪山、龙华以及惠城等区提升较为明显。研究区城镇化水平存在显著空间差异,城镇化质量指数高值区主要集中于大湾区腹地的东江下游河段及其左岸支流石马河流域,主要包括福田、罗湖、龙华、盐田、黄埔、东莞等市区。而低值区分布于靠近上游河段的右岸公庄水流域及左岸西枝江流域,包括龙门、惠东、惠阳、博罗等县,整体呈现上游河段至下游河段城镇化水平递增的空间格局特征(表 1)。

3.1.2 水资源环境水平时空分异特征

研究区水资源层面整体趋向良性发展,2010—2020 年人均日常生活用水量已下降 35 L/d,水资源利用效率也大幅提升,万元工业增加值用水量及万元 GDP 用水量逐渐降低,表明研究区用水结构逐步优化。人均水资源 2010—2020 年由 2 161.96 m³ 下降至 1 804.65 m³,低于全省平均水平。水生态层面的水土保持、水源涵养等水生态系统服务功能出现明显恶化趋势,主要原因是粗放的扩张建设导致植被覆盖度减少。数据分析显示,2010—2020 年植被净生产力呈现下降趋势,土壤流失量增加 16.54%,地表径流量由年均 3 933.78 m³/hm² 上升至 5 288.32 m³/hm²,水源涵养量下降 7.34%,表明研究区面临较为严峻的水土流失问题。同时,由于河流截弯取直等工程破坏水系结构,水面率也下降 6.43%。而水环境治理行动取得明显成效,污水排放处理各项指标均有所提升。

表 1 2010—2020 年各区县城镇化质量综合评价指数

Table 1 Comprehensive evaluation index of urbanization quality of each district and county from 2010 to 2020

年份	龙门县	博罗县	惠城区	惠东县	惠阳区	黄埔区	增城区
2010	0.011	0.068	0.183	0.065	0.142	0.330	0.162
2015	0.018	0.127	0.235	0.082	0.178	0.485	0.211
2020	0.037	0.179	0.286	0.125	0.192	0.538	0.315

年份	东莞市	龙华区	龙岗区	坪山区	福田区	罗湖区	盐田区
2010	0.519	0.493	0.492	0.399	0.783	0.543	0.508
2015	0.554	0.617	0.574	0.444	0.805	0.583	0.571
2020	0.593	0.673	0.646	0.516	0.849	0.629	0.651

水资源环境综合评价指数整体呈现波动变化趋势,2010—2015 年水资源环境水平稳步提升,由 0.38 提升至 0.42,2016—2020 年则下降至 0.40,呈微弱下降趋势。2010—2015 年,提升较为明显的包括龙门县、博罗县、惠城区、增城区及东莞市等干流沿岸地区(表 2),其主要原因是研究区流域重要河段的水环境治理与修复取得成效;而这些地区在 2015—2020 年水资源环境水平整体有所下降,初步判断为城镇化进程加快导致水资源过度消耗和水生态空间遭受严重挤占。而下游河段发达城区如福田区、龙华区、东莞市、坪山区等水资源环境水平在 2015 年后有所回升,该片区生态环境投入大幅增加,水污染排放有效控制与治理修复促使水资源环境得到明显改善,加之水资源利用效率有所提升,使得水资源环境逐渐恢复。研究区水资源环境水平空间差异较小,下游河段整体水平略优于上游河段,东莞市、石马河流域的盐田区及增江流域的龙门县处于较高水平。

表 2 2010—2020 年各区县水资源环境综合评价指数

Table 2 Comprehensive evaluation index of water resources environment of each district and county from 2010 to 2020

年份	龙门县	博罗县	惠城区	惠东县	惠阳区	黄埔区	增城区
2010	0.443	0.321	0.364	0.344	0.305	0.394	0.432
2015	0.490	0.385	0.392	0.373	0.331	0.394	0.452
2020	0.464	0.358	0.401	0.318	0.317	0.346	0.424

年份	东莞市	龙华区	龙岗区	坪山区	福田区	罗湖区	盐田区
2010	0.471	0.375	0.344	0.361	0.401	0.423	0.526
2015	0.491	0.373	0.335	0.378	0.364	0.420	0.492
2020	0.521	0.377	0.365	0.404	0.402	0.433	0.529

3.2 城镇化质量与水资源环境耦合协调时空分异特征

3.2.1 耦合度时空分异特征

2010—2020 年,研究区城镇化质量与水资源环境耦合度整体呈现逐步上升趋势,自 0.702 提升至 0.813,由磨合阶段转变为高水平耦合阶段,反映了城镇化发展水平与水资源环境高度关联,相互作用程度逐渐提升。表 3 为各区县城镇化质量与水资源

环境耦合度情况,可见耦合度持续上升且涨幅较大地区包括坪山、增城、东莞、博罗、惠城等区县。耦合度出现波动变化的主要有黄埔区与龙岗区,在 2010—2015 年呈现下降趋势,水资源环境水平提升速度难以匹配城镇化发展进程。其中,龙岗区由 0.837 降至 0.695,高水平耦合阶段退化为磨合阶段;黄埔区仍大于 0.8,处于高水平耦合阶段,而随着下游河段地区城镇化进程进入高质量发展阶段,龙岗区、黄埔区在 2016—2020 年阶段耦合度回升至高水平耦合阶段,水资源环境与城镇化发展相互适应。东江下游左岸石马河流域包括福田区、盐田区、罗湖区等城区。耦合度变化幅度较小,始终处于高水平耦合阶段,城镇化质量与水资源环境同步发展。2010—2020 年,各区县耦合度差异逐步缩小,但仍然存在明显的空间分异特征,高值区主要分布在东江干流沿岸及其左岸支流石马河流域,包括东莞市、深圳市各区及博罗县等地区,占研究区面积的 78.3%;而低值区主要分布在龙门县、惠东县、惠阳区。

表 3 2010—2020 年各区县城镇化质量与水资源环境耦合度

Table 3 Coupling degree of urbanization quality and water resources environment in each district and county from 2010 to 2020

年份	龙门县	博罗县	惠城区	惠东县	惠阳区	黄埔区	增城区
2010	0.250	0.426	0.546	0.345	0.439	0.923	0.808
2015	0.325	0.689	0.702	0.518	0.593	0.862	0.893
2020	0.404	0.721	0.792	0.540	0.642	0.978	0.954

年份	东莞市	龙华区	龙岗区	坪山区	福田区	罗湖区	盐田区
2010	0.898	0.815	0.837	0.845	0.821	0.802	0.878
2015	0.982	0.837	0.695	0.930	0.909	0.981	0.993
2020	0.998	0.892	0.847	0.984	0.906	0.990	0.991

3.2.2 耦合协调度时空分异特征

表 4 为各区县城镇化质量与水资源环境耦合协调度情况。2010—2020 年,研究区城镇化质量与水资源环境耦合协调度整体呈波动上升趋势,其中 2010—2015 年阶段由 0.557 提升至 0.612,由勉强协调状态转变为中度协调状态,提升较为明显地区主要为东江干流沿岸博罗、惠城、东莞、增城等区县,得益于这期间东江下游开展专项治水行动,以水生态修复为抓手,以水污染治理为重点,提升整体水环境质量,城镇化发展进程也持续推进,城水关系趋向协调共生。2016—2020 年阶段耦合协调度下降至 0.584,呈微弱下降趋势,整体状态仍为中度协调。降幅较大的区县包括黄埔、龙华、增城、惠阳,其中黄埔区由中度协调退化为失调状态,增城区与龙华区由中度协调状态转变为濒临失调状态。近年来,粤港澳大湾区边缘区优化增长和核心区有机更新成为新的发展趋势,如黄埔、龙华、增城等城市边缘区逐

渐成为发展重心。然而,人口快速聚集,人均生活用水和水资源开发压力急剧上升,生活、生产废水排放量持续提升,粗放的建设用地扩张造成水生态系统服务功能逐渐退化,水资源环境质量呈明显下降趋势,难以匹配城镇化快速发展进程,城水关系出现恶化。相较于城市边缘区的粗放扩张,下游河段福田区、罗湖区、盐田区、东莞市等城市核心区近年来进入高质量发展阶段,城镇化与水资源环境基本达到高度协调状态。这些片区随着环保投入的增加、水环境治理能力的强化、水资源利用效率提升、生态滨水空间修复改造等举措逐步落实,水资源环境整体水平得到有效改善,并促进城镇化可持续发展,推动城水关系呈现高水平相互促进,达到协调共生。2010—2020年,各区县耦合协调度差距有所缩小,但仍然存在显著差异,下游河段整体优于上游河段,其主要原因是区域城镇化发展不平衡以及面临水资源环境压力不一致。上游河段地区包括龙门、博罗、惠东等区县城镇化水平较低,但水资源本底条件较好。2010—2015年,上游河段地区耦合协调度整体提升显著;随着城镇化对水资源环境的胁迫增强,2016—2020年耦合协调度出现下降,部分地区回落至失调状态。而下游河段地区耦合协调度虽有波动变化,但整体仍维持在中度协调状态。

表 4 2010—2020 年各区县城镇化质量与
水资源环境耦合协调度

Table 4 Coupling coordination degree of urbanization
quality and water resources environment in each district
and county from 2010 to 2020

年份	龙门县	博罗县	惠城区	惠东县	惠阳区	黄埔区	增城区
2010	0.281	0.295	0.454	0.358	0.208	0.543	0.590
2015	0.406	0.510	0.506	0.416	0.486	0.669	0.638
2020	0.373	0.478	0.592	0.385	0.373	0.442	0.586
年份	东莞市	龙华区	龙岗区	坪山区	福田区	罗湖区	盐田区
2010	0.837	0.571	0.582	0.602	0.810	0.779	0.894
2015	0.905	0.641	0.489	0.606	0.642	0.766	0.887
2020	0.950	0.593	0.642	0.801	0.833	0.812	0.929

3.3 高水平耦合状态下城水关系影响因素

城镇化质量与水资源环境的耦合关系可从城镇化发展对水资源环境的胁迫和水资源环境对城镇化的制约两个方面进行分析^[30]。城镇化发展需要从水资源环境获取大量能量和物质,而该进程可能会对水资源环境产生胁迫作用,导致水资源环境恶化,各种水问题频发;另一方面,水资源环境是城镇化发展的重要承载条件,将对城镇化发展产生约束作用,当通过有效措施(如控制城镇人口、加大环保投入、提升水资源利用效率)改善水资源环境时,可促进城镇化发展质量提升(图 3)。高水平耦合阶段下,

城镇化质量与水资源环境系统内部组成要素交互耦合将推动城水系统走向良性或恶性的互动关系。为进一步厘清城水耦合关系的影响因素,以达到高水平耦合状态的 2020 年城镇化质量综合指数与水资源环境综合指数为参考序列,计算系统指标要素间的灰色关联度并排序,进一步揭示城水系统内部各要素交互耦合特征。

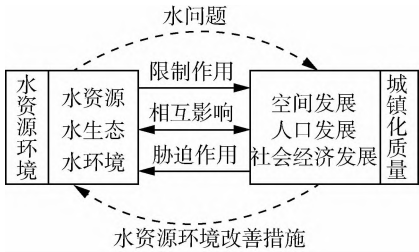


图 3 城水耦合机制

Fig. 3 Urban-water coupling mechanism

3.3.1 城镇化发展对水资源环境的主要胁迫因素

城镇化质量对水资源环境的综合关联度为 0.676,表明城镇化发展对水资源环境胁迫作用显著,主要胁迫因素为:人口密度(与水资源环境关联度最高,为 0.861)、建设用地率(关联度为 0.776)、人口城镇化率(关联度为 0.738)。人口要素是衡量城镇化水平的基础指标,也是地区水资源环境承载力剧增的重要原因。2010—2020 年,研究区人口快速增长,人均水资源持续下降,用水需求也急速上升,对水资源环境系统产生胁迫影响最大,这也促使下游河段发达城区不断提升水资源利用效率,并实施城镇人口、产业用水限制等相关政策保护水资源环境。建设用地扩张是城镇化进程的主要体现,但同时也挤占水生态空间并导致巨大的水资源消耗和水污染排放。2010—2020 年,研究区建设用地率增加 6.34%,2010—2015 年建设用地增加集中在研究区下游河段地区,2016—2020 年上游河段建设用地扩张明显,造成区域植被覆盖锐减,水生态系统服务功能逐渐退化,水资源环境面临严峻挑战。人均 GDP(关联度为 0.636)提升对水资源环境也有一定影响,经济产业快速发展可能导致水环境污染、水资源浪费以及治水成本提升。城镇人均可支配收入(关联度为 0.582)、固定资产投资(关联度为 0.464)对水资源环境的胁迫程度较小。

3.3.2 水资源环境对城镇化发展主要制约因素

水资源环境对城镇化质量的综合关联度为 0.642,表明水资源环境系统对城镇化发展具有较大的约束作用。其中,水资源环境系统与城镇化发展的关联度由大到小排序为:水资源层面(0.713)、水生态层面(0.621)、水环境层面(0.614)。制约城镇

化发展的主要水资源环境因素包括: 人均水资源(与城镇化质量关联度最高, 为 0.858)、水源涵养功能(关联度为 0.810)、单位 GDP 用水量(关联度为 0.738)、工业废水排放达标率(关联度为 0.672)、万元工业增加值用水量(关联度为 0.656)等, 表明水资源禀赋条件及用水效率对城镇化发展极为重要。研究区当前用水规模偏大, 水资源本底条件及用水效率区域差异明显, 制约了城镇化高质量发展。同时, 水生态系统服务功能同样影响城镇化质量提升。近年来, 龙门、惠东、博罗等山区县由于建设用地扩张、农田开垦导致植被覆盖度降低、土壤侵蚀性增强, 河道硬化、截弯取直工程破坏河流自然形态, 严重影响河网调蓄功能; 水污染日趋严重, 水环境治理较为滞后, 也成为城镇化质量提升的阻碍之一。生活污水处理率(关联度为 0.646)、人均日生活用水量(关联度为 0.640)、固碳功能(关联度为 0.624)、人均废水排放量(关联度为 0.608)、水土保持功能(关联度为 0.566)、河网调蓄功能(关联度为 0.509)、生态环境用水量(关联度为 0.482)等其他水资源环境因素对城镇化发展制约程度较小。

4 结 论

a. 城镇化质量综合评价指数呈现持续上升趋势, 但区域间发展极不均衡, 下游河段城镇化发展水平远超上游河段; 水资源环境综合水平呈现波动变化趋势, 2010—2015 年稳步提升, 2016—2020 年出现微弱下降趋势, 区域差异较小, 下游河段整体水资源环境略优于上游河段。

b. 城镇化质量与水资源环境耦合度逐步上升, 由磨合阶段转变至高水平耦合阶段, 不同地区耦合度差异逐渐缩小, 但仍存在明显的空间分异特征; 城镇化质量与水资源环境耦合协调度时序变化出现波动, 2010—2015 年耦合协调度显著提升, 由勉强协调状态转变为中度协调状态, 2016—2020 年微弱下降, 但仍为中度协调状态。耦合协调度空间差异同样显著, 下游河段优于上游河段, 这与区域城镇化发展不平衡以及面临水资源环境压力不一致有关。

c. 高水平耦合状态下, 城镇人口快速增长及建设用地的粗放扩张是城镇化发展胁迫水资源环境的主要因素; 水资源紧缺的本底条件、不合理的用水效率以及逐渐恶化的水生态系统服务功能是水资源环境限制城镇化发展的主要原因。

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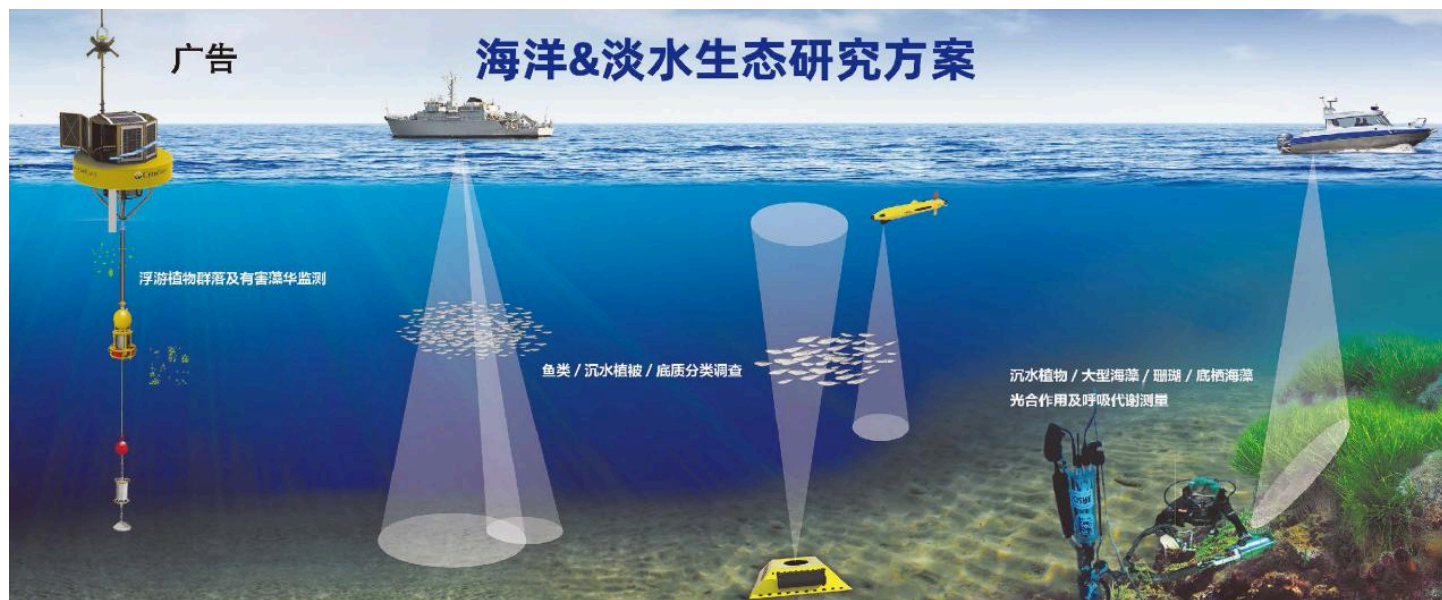
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汀江上游流域生态水文分区研究

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摘要:为反映生态水文系统的相似性和差异性规律,理解人类活动对生态水文系统的干扰规律,为流域资源开发、灾害预防和生态调控提供科学依据。以汀江上游流域为例,以地形、土壤、植被、水文、水资源与人口统计资料为基础,从生态现状、水文条件、生态背景和人类活动 4 个方面共 14 个指标统计各个子流域指标的特征值。采用主成分分析和聚类分析的方法将汀江上游流域内 35 个子流域划分为五类生态水文分区,并对每个分区的特征指标进行分析并命名,同时基于分区结果提出了相应的生态调控措施。分区结果能够揭示汀江上游流域生态水文特征空间上的差异性和相似性以及人类活动的影响,能够指导具有不同生态水文特征的区域进行因地制宜的发展。

关键词:生态水文分区; 主成分分析; 聚类分析; 生态调控; 汀江上游流域

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Research on Eco-hydrological Regions of Upper Reaches of the Tingjiang River

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Abstract: The similarities and differences of eco-hydrological system and the influences of anthropogenic activities on eco-hydrological system were investigated in order to provide scientific basis for resources development, disaster prevention and ecological regulation of basin. Taking the upper reach of the Tingjiang River (URTR) as the study area, based on the dataset of terrain, soils, vegetation, hydrology, water resources and population statistics, according to ecological status, hydrology condition, ecological background and anthropogenic activities of the URTR, we constructed the indicator system including 10 indexes of regionalization. Using principal component analysis and cluster analysis, 35 sub-catchments of the URTR were assigned to 5 eco-hydrological regions (EHR), the characteristics of each EHR were analyzed and corresponding ecological regulation measures were proposed. The similarities and differences as well as the influences of anthropogenic activities on the URTR were revealed by regionalization results, which could provide fundamental basis for sustainable development for different EHR.

Keywords: eco-hydrological regions; principal component analysis; cluster analysis; ecological regulation; upper reach of the Tingjiang River

作为反映自然条件及生态环境在空间上分异特征的空间单元,目前的水文区划^[1]、生态分区^[2]、水生生态分区^[3-5]和水生态功能分区^[6-7]等方面的研究已经比较成熟,在分区方法和指标体系上业已比较完善。但是针对流域尺度上生态系统和水文系统相互依赖和制约的特点,人类活动逐渐强化生态系统和水文系统的联系,如何协调二者日益成为流域管理的重要议

题^[8]。而现有的分区体系对于生态水文复合系统分异规律的研究还比较欠缺^[9],需要一个合适的空间单元进行流域生态水文进行综合管理。因此,流域生态水文分区应运而生,生态水文分区是指在对流域生态水文系统客观认识的基础上,以流域自然生态水文系统的相似性和差异性规律以及人类活动对流域生态水文系统干扰的规律作为划分生态水文空间单元的

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划分依据^[8-9]。进行流(区)域的生态水文综合区划是区域资源开发、灾害预防的重要依据,是对流域生态水文系统进行科学调控的基础。

生态水文分区研究最早应用于河流层面^[10],尹民等基于河流生态环境需水量研究的需要将全国河流划分为一级到三级的分区,揭示不同分区单元的生态、水文特征^[11],但侧重反映河流的形态结构、水体的水力联系和水利工程对生境的影响^[8];杨爱民等根据我国不同流域或区域的生态水文特征,将全国划分为 3 个生态水文大区 and 36 个生态水文区^[9],该研究可以较全面地反映生态和水文系统的空间特征,但用于指定流域内具体的管理目标时尺度偏大^[8]。蔡燕等以黄河流域行政区为基本单元划分生态水文分区,并依据分区的生态重要性识别需要优先保护的分区^[8];尹晔对长江上游的大渡河流域、云南省分别进行了生态水文区的划分^[12];张璐等根据南水北调受水区 89 个县(市、区)生态水文特征进行了相应区划^[13];王韶伟等以福建省泉州市为例进行了生态水文区划研究^[14]。综上所述,已有的生态水文分区研究主要侧重于大流域或省市尺度,缺少对我国大量山区范围内的中小河流开展类似分析,尤其缺少生态水文分区结果为山区流域中的城市与区域发展提供生态调控策略的应用。

分区指标是生态水文区划的基础,指标确定的是否合理,对于后续的分区分区工作有决定性的影响。一方面为准确揭示流域空间特征,指标应尽量全面。分区指标有影响因素和现状特征两种,前者包括影响背景的指标(如气候、地势等)和影响现状的指标(人类活动等),现状特征包括生态现状和水文现状^[8]。已有的大型河流流域尺度生态水文分区指标主要包含气候、地形、水文、植被和人类经济活动等方面^[9]。另一方面应立足于研究目的,指标需要着重反映研究区域的主要问题^[8]。选择指标后,针对仍然存在涉及因素过多,资料收取不易的问题,需要降维的方法来对过多的指标进行简化,遗传算法、多元统计等方法的大量研究为指标筛选提供了良好的基础;主成分分析、系统聚类分析、模糊聚类分析等方法为生态水文区划提供了有效的方法^[12]。

长汀县是福建省水土流失历史最久、面积最大、程度最严重的区域,2000 年以后开展的新一轮大规模水土流失治理初见成效,但治理任务还相当艰巨,应继续加大自然生态修复的力度^[15]。作为生态治理保育的重点,汀江上游流域属于低山轻度水土流失区,但是由于土壤多由风化发育而成,一旦植被遭到破坏,极易造成严重的水土流失。该区以水源涵养林

和商品用材林为主,维护着区域森林生态系统的水源涵养和调节功能,对全县水资源供给和水文状况的改善有着重要的意义。本研究以长汀古城上游的汀江流域为研究区域,通过 GIS 平台以子流域为划分单元,利用主成分分析及聚类分析方法,对汀江上游流域进行生态水文分区划分。根据生态水文分区结果为流域水生态环境保护、恢复和改善提供指导。

1 研究区概况

汀江上游流域(长汀古城上游)地处东经 116°15′—116°33′,北纬 25°45′—26°5′,位于福建省长汀县北部,覆盖大同镇、铁长乡、庵杰乡与新桥镇等行政区,东北部为宁化县治平畲族乡,西北部与江西省接壤。研究区面积为 472 km²,高程范围为 297 ~ 1 350 m,坡降为 5‰,主要支流包括七里河、郑坊河和铁长河。汀江上游流域多年平均降雨量超过 1 700 mm,其中 4—9 月是主要的降雨季节,约占全年降雨量的 70%。由于气候和地形等因素的影响,研究区极易受到锋面雨和台风雨的影响,最大日降雨量可达 200~400 mm,位于研究区下游的国家历史文化名城长汀古城已遭遇若干次流域性特大洪水,给当地的社会经济造成了毁灭性打击,文化遗产和生态建设项目损失巨大。

流域内主要的下垫面类型是林地,占总面积比例近 90%,其他的下垫面类型主要是建设用地(3.33%)和耕地(6.66%)。林地类型包括阔叶林、针叶林、毛竹和灌木,具体比例见表 1。研究区内的林地虽多为水源涵养林,但受人类活动的影响,现有林分以针叶林和毛竹为主,针叶林主要分布在海拔 400~800 m 范围内(随海拔高度上升而减少),毛竹则分布于 500~1 000 m 的海拔区间(随海拔高度上升而增多);幼、中林比重大,天然阔叶林、混交林比重小,水源涵养能力较差。汀江上游流域内主要的土壤类型包括红壤、黄壤和水稻土,其他土壤类型包括潮土、紫色土和石灰土,具体组成比例见表 2。

表 1 汀江上游流域林地类型组成

林地类型	面积/km ²	比例/%
灌木	18.39	3.9
针叶林	209.08	44.4
阔叶林	28.65	6.09
毛竹	164.06	34.84

2 数据与方法

2.1 基础数据及来源

研究所需的基础数据包括数字高程模型、遥感影

像、土地利用现状图、土壤类型图、植被统计资料以及水文水资源资料和人口统计数据。数字高程模型基于 1:50 000 数字地形图生成;遥感影像选择 2013 年 Landsat 8 遥感影像,用于研究区植被覆盖度的提取;林地类型分布图利用 2012 年福建省森林资源二类调查数据结合 2015 年福建省林地变更调查结果得到,根据《国家森林资源连续清查技术规定》将林班资料进行归纳整理;研究区土壤类型分布图通过长汀县土壤资源调查图数字化得到。人口数据来自于长汀县第六次人口普查,水文水资源资料均来源于 2013 年《长汀县水资源综合规划》。

表 2 汀江上游流域土壤类型组成

土壤类型	面积/km ²	比例/%
红壤	162.57	34.44
黄壤	199.92	42.36
水稻土	74.3	15.74
潮土	31.87	6.75
石灰土	3.18	0.67
紫色土	0.91	0.19

2.2 生态水文分区区划方法

为更好地认识流域生态水文特征及空间分布规律,为流域可持续发展提供必需的决策,根据汀江上游流域的地形、土壤、植被、水文、水资源与人口资料,采用主成分分析和聚类分析的方法将子流域划分为不同的生态水文分区。具体步骤为:

(1) 将汀江上游流域划分为 35 个子流域,子流域面积 7~23 km²,平均面积为 13.5 km²。

(2) 以汀江上游流域内的 35 个子流域作为生态水文分区的划分单元,选取能够反映流域生态系统和水文系统二者相互影响机制以及人类活动干扰规律的指标,统计各个子流域指标的特征值。

(3) 根据各子流域生态水文系统的相似性和差异性规律,利用主成分分析和聚类分析,对所有子流域进行分组,得到生态水文分区结果。

2.3 生态水文分区指标选择

汀江上游流域生态水文分区应遵循以下两个原则:(1) 生态系统和水文系统的整体性原则。二者不仅在地理位置上重叠,而且在结构和功能上不可分割。两种系统具有天然的联系,相互依存、相互制约,人类活动使二者的联系更加突出^[8]。(2) 生态水文系统的等级性原则。与生态系统分区的等级性原则不同^[2],该原则主要体现在生态系统重要性大小、水文系统水量丰枯和人类影响的强弱等^[8]。

生态水文分区涉及到生态系统和水文系统,在指标选择时还需要考虑到现状指标和影响因素指标。根据汀江上游流域生态区位的重要性,主要的下垫面

类型为林地,水资源量比较充沛但容易遭受洪涝灾害影响的特点,在选择指标时要突出重要的生态系统,造成洪涝灾害或水土流失的原因及问题的严重程度等。本研究所选的生态水文分区指标包含生态现状、水文特征、生态背景和人类活动 4 类指标,每类指标特征值获取方法及数据来源见表 3。

(1) 生态现状。选择林地类型组成、植被覆盖度和土壤可侵蚀性三个指标。林地类型组成能够直接说明流域的生态现状,原生阔叶林可有效增加土壤入渗、减少径流量与泥沙量,生态重要性最高,而次生的针叶林和毛竹生态价值和人文效应较差。植被覆盖度表明森林的生长状态,一定程度上能够表征生态功能和涵养水源能力。土壤可侵蚀性(K 值)是一项评价土壤被降雨侵蚀力分离、冲蚀和搬运难易程度的指标^[16]。K 值越大,在相同条件下,土壤受侵蚀的潜在危险就越大,反之越小^[17]。

(2) 水文条件。水文条件既是影响汀江上游流域生态系统的因素,也是造成洪涝灾害的直接原因。降雨量是直接的径流来源,蒸发是径流形成过程中的主要损失,由于汀江上游流域内只有一个水文站对蒸发量进行长期观测,因此选择年平均降雨量和年平均径流深度反映研究区的水文条件。根据福建省水文图集多年平均径流深等值线图查得长汀县年平均径流深为 900~1 100 mm,年平均降雨量同样来源于福建省多年平均降水量等值线图。

(3) 生态背景。生态系统主要由气候、地形、植被、土壤等因素决定。由于研究区内的气候变化较小,植被和土壤因素在生态现状中已有考虑,因此选择受人类活动影响较少的地形作为影响因素指标。

(4) 人类活动。人类对水资源的开发强度是生态水文系统空间差异的一个重要原因,由于人类过度开发导致生产和生活用水量大幅上升,从而造成生态系统可用水量减少。选择人口密度、人均生产用水和生活用水作为衡量开发强度的指标。同时选择建设用地比例和耕地比例作为反映人为作用影响的指标。

3 结果与分析

3.1 生态水文分区划分

采用主成分分析与 k-means 聚类分析方法,对汀江上游流域进行生态水文分区划分。为剔除原始因子间的相关性,得到不包含重合信息的新变量,将提取出的汀江上游流域的地形、土壤、植被、水文水资源与人口指标经过标准差标准化处理后,在 SPSS 平台上进行主成分分析。抽取特征值大于 1 的 3 个主成分来解释所有的原始变量,为使主成分便于解释各

原始变量,采用最大方差法实现正交旋转。由主成分分析结果(表 4)可见,第一主成了解释了人口密度、人均生产用水、毛竹比例、针叶林比例和建设用地比例五个变量,第二主成了解释了覆盖度、平均坡度、土壤可侵蚀性三个变量,第三主成了解释了径流深度、降雨量、两个变量。在主成分分析结果的基础上,针对 35 个子流域分别计算抽取出的三个主成分的得分,并根据各子流域各主成分的得分在 SPSS 平台上进行 k-means 聚类

分析。在聚类分析中以类中心点不再发生变化、或变化小于给定阈值作为收敛条件,由此得到每个子流域的聚类划分结果。经过 16 次迭代,聚类中心不再发生变化而达到收敛条件,通过上述聚类分析,根据各子流域的主成分得分,将 35 个子流域划分为五类生态水文分区,将聚类划分结果载入 ArcGIS 中生成生态水文分区分布图(图 1),并统计各生态水文分区的各项指标的均值(表 5)。

表 3 不同特征值获取方法及数据来源

子流域特征值	获取方法	数据来源
植被状况—林地类型(阔叶林、针叶林、毛竹、灌木)所占比例	GIS 叠置分析+统计分析	林地类型分布图
植被状况—覆盖度	波段计算+特征值统计	30 m 分辨率 Landsat 8 遥感影像
土壤可侵蚀性	已有研究 ^[18]	《长汀县土壤志》
年平均降雨量	GIS 插值分析	《长汀县水资源综合规划》
年平均径流深度	GIS 插值分析	《长汀县水资源综合规划》
地形—平均坡度	GIS 地表分析	25 m 分辨率数字高程模型
地形—最大高程差	GIS 地表分析+统计分析	25 m 分辨率数字高程模型
人口密度	GIS 统计分析	《长汀县第六次人口普查》
人均生产用水	GIS 统计分析	《长汀县水资源综合规划》
人均生活用水	GIS 统计分析	《长汀县水资源综合规划》
建设用地比例、耕地比例	GIS 统计分析	土地利用现状图

表 4 主成分载荷矩阵

项目	主成分 1	主成分 2	主成分 3
覆盖度(X_1)	0.295	0.834	-0.198
平均坡度(X_2)	0.344	0.725	0.028
高程差(X_3)	0.57	0.556	0.156
土壤可侵蚀性(X_4)	0.215	-0.89	0.069
径流深度(X_5)	0.047	-0.181	0.935
降雨量(X_6)	0.039	0.02	0.94
人口密度(X_7)	-0.751	-0.265	0.246
人均生活用水(X_8)	0.386	0.361	0.416
人均生产用水(X_9)	0.747	-0.064	0.254
阔叶林比例(X_{10})	0.482	0.303	0.342
毛竹比例(X_{11})	0.745	0.449	-0.294
针叶林比例(X_{12})	-0.744	-0.475	0.102
耕地比例(X_{13})	-0.342	-0.482	0.544
建设用地比例(X_{14})	-0.862	0.032	-0.094
方差/%	40.145	20.121	11.212
特征根	5.62	2.82	1.57

3.2 生态水文分区特征分析

分区一主要分布在七里河下游和郑坊河下游流域。该分区行政区划主要为大同镇,人口密度为五类分区之首。该分区人均生活用水和生产用水量为最低值。该分区有着最低的毛竹比例(3.3%)和最高的针叶林比例(73.64%),植被覆盖度属于中值。土壤可侵蚀性和最大高程差均为五类分区中的最低值。分区二主要包括铁长河中上游和郑坊河上游,在行政区划上包括铁长乡和庵杰乡西部区域及大同镇部分区域。由于铁长乡和庵杰乡是汀江上游流域主要的毛竹产区,林地结

构中毛竹超过 45%,该区域以毛竹的加工制造业为主,人口密度最小,人均生产用水量较大。地形方面,该分区的平均坡度和最大高程差均为五类分区中的最大值。分区二有着次高的平均径流深度和最高的降雨量,说明该分区位于汀江上游流域的多雨区。分区三包括大部分七里河流域。该分区的平均径流深和降雨量为五类分区中最低。分区三有着五类分区中最高的毛竹比例,同时植被覆盖度也是最高(约 70%),土壤可蚀性在五类分区中较小,说明良好的植被结构能够有效地降低土壤受侵蚀的风险(图 1,表 5)。

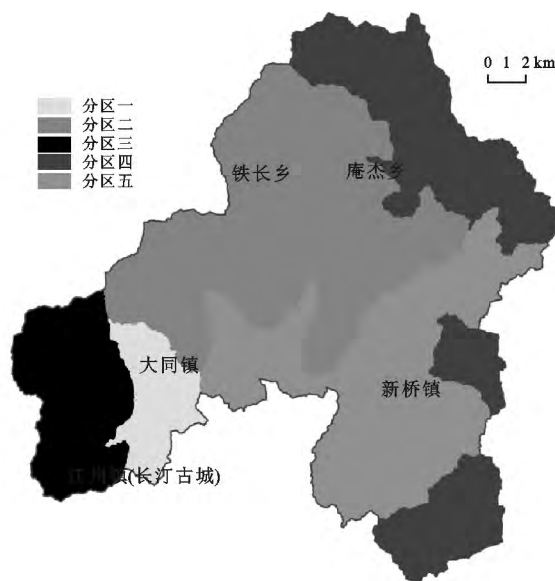


图 1 汀江上游流域生态水文分区

表 5 生态水文分区各项指标的平均特征值

指标	生态水文分区				
	一	二	三	四	五
覆盖度(X_1)/%	63.38	68.38	69.97	60.55	53.84
平均坡度(X_2)/(°)	20.61	23.26	21.38	20.39	18.28
高程差(X_3)/m	447.67	767.10	610.00	625.63	518.2
土壤可侵蚀性(X_4)/ ($t \cdot hm^2 \cdot hm^{-2} \cdot MJ^{-1} \cdot mm^{-1}$)	0.20	0.22	0.21	0.27	0.27
径流深度(X_5)/mm	988.65	1022.31	901.97	979.20	1029.76
降雨量(X_6)/mm	1698.73	1727.13	1608.43	1673.89	1716.43
人口密度(X_7)/(pop km ⁻²)	272.35	52.21	58.29	76.10	181.3
人均生活用水(X_8)/m ³	41.01	110.79	41.01	64.31	63.96
人均生产用水(X_9)/m ³	421.25	712.27	421.25	820.85	537.95
阔叶林比例(X_{10})/%	3.46	9.60	2.11	5.83	4.49
毛竹比例(X_{11})/%	3.30	45.79	49.16	45.95	7.36
针叶林比例(X_{12})/%	73.64	31.17	38.86	38.05	66.22
耕地比例(X_{13})/%	4.48	5.41	3.46	4.30	12.75
建设用地比例(X_{14})/%	6.97	1.87	5.38	1.13	3.96

此外,该分区人口密度、人均生产、生活用水量均比较低,说明该分区人类开发活动的强度较低。分区四行政区划上主要包括庵杰乡以东和新桥镇的东部、南部。该分区地处汀江干流上游区域。该区域的土壤可侵蚀性为五类分区之首,植被覆盖度较低。该分区的建设用地比例为五类分区中的最低值,毛竹与针叶林比例均比较大,人均生产用水量最高。分区五地处铁长河下游和汀江干流部分区域,行政区划主要包括大同镇东部和新桥镇西部。由于地处汀州镇(长汀古城)的外围,因此人口密度较大。分区五有着最高的平均径流深度和次高的降雨量,说明该分区位于汀江上游流域的多雨区。另一方面,该分区的林地比例是五类分区中最小的(78%),针叶林比重超过 66%,植被覆盖度也是最低值(54%),表明分区五的植被结构较差,同时该分区土壤可侵蚀性很大(0.27)。

表 6 汀江上游流域生态水文分区指标特征

分区	地理位置	水文条件	生态现状	开发程度
一	七里河和郑坊河下游	平水	中植被覆盖低土壤侵蚀	低
二	铁长河和郑坊河上游	多水	高植被覆盖低土壤侵蚀	高
三	七里河流域	少水	高植被覆盖低土壤侵蚀	低
四	汀江干流上游	平水	低植被覆盖高土壤侵蚀	高
五	汀江干流下游	多水	低植被覆盖高土壤侵蚀	高

根据各个分区的生态水文特征,采用具体地理位置+水文条件+生态现状+开发程度对生态水文分区进行命名,并提出相应的生态调控策略:分区五为汀江干流下游多水+低植被覆盖高土壤侵蚀+高开发强度区;分区四为汀江干流上游平水+低植被覆盖高土壤侵蚀+高开发强度区;分区三为七里河少水+高植被覆盖低土壤侵蚀+低开发强度区;分区二为铁

长河和郑坊河上游多水+高植被覆盖低土壤侵蚀+高开发强度区;分区一为七里河和郑坊河下游流域平水+中植被覆盖低土壤侵蚀+低开发强度区。

3.3 基于分区结果的生态调控策略

植被破坏是导致水土流失加剧的主要原因,同样也可能造成洪涝灾害风险提高。针对汀江上游流域的下垫面特征和分区结果,保护并进一步发挥森林的生态价值和生态效应是流域层面重要的生态调控措施,有助于流域生态系统的高效与优化。通过流域层面森林类型的逐步改造,发挥森林—土壤结构在一定降雨强度下对洪水的削减作用,不仅可以保持汀江上游流域生态系统的稳定,还可以减小流域内城市与区域遭受洪涝灾害的冲击。

汀江上游流域的林地由于长期受到人为影响,原有的基带性植被已大量破坏,林分质量较差,出现了严重的水土流失问题。近 20 a 来政府高度重视汀江上游流域的生态环境建设,持续进行有规模的造林并取得了一定的成果,但是补种的多为针叶林,分区一、五的针叶林比例分别达到 66%和 73%。由于次生的针叶林群落结构不稳定,水源涵养能力与天然阔叶林相差较大,对应的生态价值和防洪效应均较差^[19]。故有必要通过增加阔叶林的比例逐步改善林分结构,改善林地蓄水和保水能力,降低土壤受侵蚀的风险。分区五针叶林比例大,植被覆盖度也是五类分区中最低,作为汀州城区外围的屏障区,由于人口密度较高且开发强度大,在未来应该注意开发建设与生态调控相协调,大力推进林分改造的工作,将针叶林逐步改造为阔叶林或针叶阔叶混交林。

毛竹是研究区主要的经济作物,分区二、三、四的毛竹比例均超过 45%,以毛竹加工制造业为主的经济在带来一定经济效益的同时也提高了生产用水量,甚至可能会给下游地区带来水污染的问题。尤其是分区二和分区四位于汀江干、支流的上游,应该注意避免对毛竹加工制造业的依赖,减小对下游流域的影响。同时需要注意的是,毛竹为单一林分会造成林地多样性急剧下降、生态退化等负面效应^[20]。毛竹与阔叶林混交具备生态和经济的双重优势,因此可考虑将原有的毛竹纯林逐步改造为毛竹阔叶混交林,发挥混交林涵养水源的优势,提升汀江上游流域林地的生态价值。分区二虽然同时拥有五类分区中最高的阔叶林比例(9.6%),但由于较高的毛竹比例,仍建议将大量的毛竹进行改造。

五类分区中,分区五的土壤可蚀性最低,主要受益于相对较好的植被结构和最小的平均坡度。分区三的阔叶林比例在五类分区中最小,但植被覆盖度和

林地比例均是五类分区的最高值,在土壤可蚀性、水文条件和开发强度均较低背景下,建议通过提高阔叶林的比例增强生态价值和防洪效应。汀江上游流域虽然属于长汀县内水土流失轻度地区,但由于其生态区位重要性,除了林分改造,还需要其他辅助的水土保持措施来降低土壤遭受侵蚀的风险。分区一和四的土壤受侵蚀风险最高,主要受到植被结构的影响,应该在该分区实施生物措施和工程措施综合的生态调控策略^[21],降低土壤受侵蚀的风险。

4 结论

通过分析汀江上游流域生态水文系统的相似性和差异性规律,生态系统和水文系统二者之间相互影响机制以及人类活动干扰规律的指标,从生态现状、水文条件、生态背景和人类活动4个方面统计各个子流域指标的特征值;将以上具有一定相关关系的指标进行主成分分析得到3个相互独立且不含重叠信息的主成分,利用k-means聚类分析方法将汀江上游流域内35个子流域划分为五类生态水文分区,并对其空间分布规律及其生态水文特征进行描述和分析。

分区结果能够揭示流域生态水文特征空间上的差异性和相似性以及人类活动干扰程度,能够指导具有不同生态水文特征的区域进行因地制宜的发展,为汀江上游流域提升生态功能,保证城市与区域的防洪安全提供必需的决策依据。我国东南部大多数山地城市自然生态环境条件优越,林业资源和生物多样性丰富,但自然生态系统十分脆弱,容易发生水土流失和山洪灾害,本研究所用的生态水文分区方法及相应的生态调控措施可为类似区位的山地城市的生态建设与防洪减灾所借鉴。

虽然研究区范围属于较小的流域尺度,但由于分区特征指标和子流域单元的尺度较为匹配,因此生态水文分区结果较为连续。未来可考虑结合流域范围内长时间土地利用变化的情况对生态水文分区的结果进行比较,将能够更为深入探讨人类活动对流域生态水文特征的影响;同时可借鉴“景观安全格局”理论,寻找对于流域水文过程具有重要意义的生态要素,通过城市与区域规划落实为水生态基础设施,可持续地解决流域的生态与水文问题。

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Integrating Ecosystems and Socioeconomic Systems to Identify Ecological Security Pattern and Restoration Strategy in a Rapidly Urbanizing Landscape

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The rapid process of urbanization has been accompanied by a disordered expansion of construction land, which has resulted in the degradation of ecosystem services. The identification of ecological security patterns (ESPs) is an important means to coordinating human-land relationships and carrying out ecological restoration strategies, which are of great significance to protecting ecological sustainability. However, previous studies have ignored the mutual impact of urbanization and ecological protection, which leads to the contradiction between them and useless of ESPs. This paper takes a rapidly urbanizing metropolitan area as an example. Ecological sources were identified based on the integration of ecosystem services and socioeconomic indicators by the Ordered Weighted Averaging (OWA) method, which considers the trade-off between ecosystems and socioeconomic systems. The Linkage Mapper tool was used to extract ecological corridors, and thus ecological barrier points and pinch points were identified to implement ecological restoration. ESPs included 158 ecological sources according to the results. In more detail, the ecological sources and corridors were mainly distributed in the area dominated by ecosystem indicators, whereas the central urban area contributed less ecological sources, which indicates that the trade-off between ecosystems and socioeconomic systems has a significant impact on the construction of ESPs. Specifically, 406 ecological corridors were classified into different resistance levels to extract 433.26 km² barrier points and 458.51 km² pinch points. The study also proposed primary and secondary ecological restoration strategies for medium-, high- and low-resistance corridors based on the optimization of ESPs, which could not only improve ecosystem quality, but also fulfil the demands of human well-being. The integration of ecosystems and socioeconomic systems improves the existing methods for identifying ecological sources and restoration priority areas, and provides a scientific basis for balancing the development of urbanization and ecological protection in metropolitan regions.

Keywords: ecological security pattern, ecosystem services, socioeconomic system, trade-off, OWA method, Guangzhou

1 INTRODUCTION

Along with the continuous urbanization of recent decades, disorderly expansion of urban construction land and significant loss of ecological land have restricted the sustainability of urban development (Feist et al., 2017; Peng et al., 2018; Zhai and Huang, 2022). Within a coupled human and natural system, the quantity and quality of the ecosystem services are impacted by anthropogenic disturbances, which affects regional landscape patterns and ecological security (Peng et al., 2017b). As a result, how to ensure the structural stability and functional security of natural ecosystems for sustainable urban development is an urgent issue (Li et al., 2015; Cumming and Allen, 2017; Serra-Llobet and Hermida, 2017). The construction of ecological security patterns (ESPs) was proposed to develop a method for improving ecological security. The ESPs, an interconnected ecological network composed of different ecosystems, is an effective approach to support biological species, maintain natural ecological processes and promote ecosystem services, as well as to achieve regional ecological sustainability (Su et al., 2016; Peng et al., 2018; Fu et al., 2020). The concept of ESPs was derived from landscape ecological planning in the 1990s (Yu, 1996). Many scholars have studied ESPs on different scales from the perspective of landscape ecology and urban planning (Peng et al., 2017b; Peng et al., 2018).

Landscape elements of key significance for ensuring regional ecological processes and ecosystem services, such as ecological sources, ecological corridors and strategic points, are all focused on ESPs (Dong et al., 2021; Gao et al., 2021). Therefore, the basic research paradigm of “identification of ecological sources, construction of resistance surfaces, and extraction of ecological corridors” has been gradually formed (Zhang et al., 2017). The strategy for selecting ecological source areas is fundamental to the construction of an ESPs, which is mainly conducted through assessing the ecological sensitivity, ecological importance or connectivity (Su et al., 2016) (Zhang et al., 2017). The method of identification of ecological sources has changed from the direct selection of nature reserves to the evaluation of ecosystem services that affect regional ecological security (Peng et al., 2017a; Wu et al., 2018). The integration of multiple ecosystem services, such as water yield and biodiversity protection, has been applied to source identification (Peng et al., 2018; Fu et al., 2020).

Integrating various components of coupled human and natural systems is necessary to address complex interconnections and to identify effective solutions to sustainability challenges (Liu et al., 2015). However, ecosystem services and human activities are seldom considered jointly in the assessment of ESPs (Wang et al., 2019); most studies have not adequately considered the ability to fulfill people’s demand for ecosystem services when identifying sources of ESPs, which still focus on ecological patches as the supplier of ecosystem services, ignoring the interaction between ecosystems and human socioeconomic systems (Zhang et al., 2017). These ecological patches with the ability to fulfill human demand (e.g., cultural ecosystem services) is essential to consider when evaluating their capacity to form part of the source area.

It is worth noting that previous studies that considered an integrated valuation approach weighting various overlapping types of ecosystem services, may have overlooked the relationships (trade-offs or synergies) between these services. This may have either induced space competition among multiple ecosystem services or undermined the causal interrelationship among multiple ecosystem services (Dai et al., 2017; Zhao et al., 2020; Pan and Li, 2021). There is thus an urgent need to study and balance the trade-offs among multiple ecosystem services in decision-making processes (Zhang et al., 2015). One of the multicriteria evaluation methods, the ordered weighted averaging (OWA) operator, was first developed in the context of fuzzy set theory (Yager, 1988). The use of the OWA method has proven to be an effective approach in decision-making processes, and proposed a set of scientific and flexible planning methods to balance multiple conflicting ecosystem services in ESPs construction processes (Zhao et al., 2020; Pan and Li, 2021). Moreover, increasing economic development has led to urbanization in previous undeveloped areas (Deng et al., 2021), and caused many ecological and environmental problems in the meanwhile. The increasing ecosystem services may lead to the control of the development of urbanization (Li et al., 2022). These are issues needed to be discussed, the mutual impact of urbanization and ecological protection has not been considered and the trade-off between ecosystems and the socioeconomic system is still unclear. To address this gap, socioeconomic indicators should be considered to integrate with ecosystem services in order to construct the ESPs. Therefore, the OWA method was introduced to resolve the contradiction between ecological protection and urbanization decisions in this study. The optimization of ESPs in most of the current studies focused on the improvement of the evaluation process (Peng et al., 2018; Wang et al., 2019). However, there was little research on optimization after the establishment of ESPs (Fu et al., 2020). ESPs can provide a practicable way for ecological restoration to spatially identify key landscape elements; existing studies have identified key restoration areas in ecological corridors, pinch points, break and barrier points (Wang et al., 2018; Fang et al., 2020), and put forward zoning ecological restoration solutions (Ying et al., 2019; Ni et al., 2020). In addition, the ecological restoration of a coupled ecosystem and socioeconomic system based on ESPs is still in its infancy.

In recent years, Guangzhou has grown rapidly and has spread in a disorderly manner (Fan et al., 2018), and the ecological land has been seriously damaged, which seriously affects the welfare of the residents (Zhang et al., 2020). Hence, the Municipality government of Guangzhou proposed a framework of ecological networks and corridors in the metropolitan area and municipal administrative area according to ecological civilization construction planning (2016–2020). There have been similar approaches to constructing an ecological network of Guangzhou and to improving environmental protection under rapid urbanization (Zhao et al., 2017; Yang et al., 2018). However, previous approaches focused solely on ecological elements, such as forest land, natural reserves and the habitats of crucial species, without using an ecosystem service importance evaluation. The

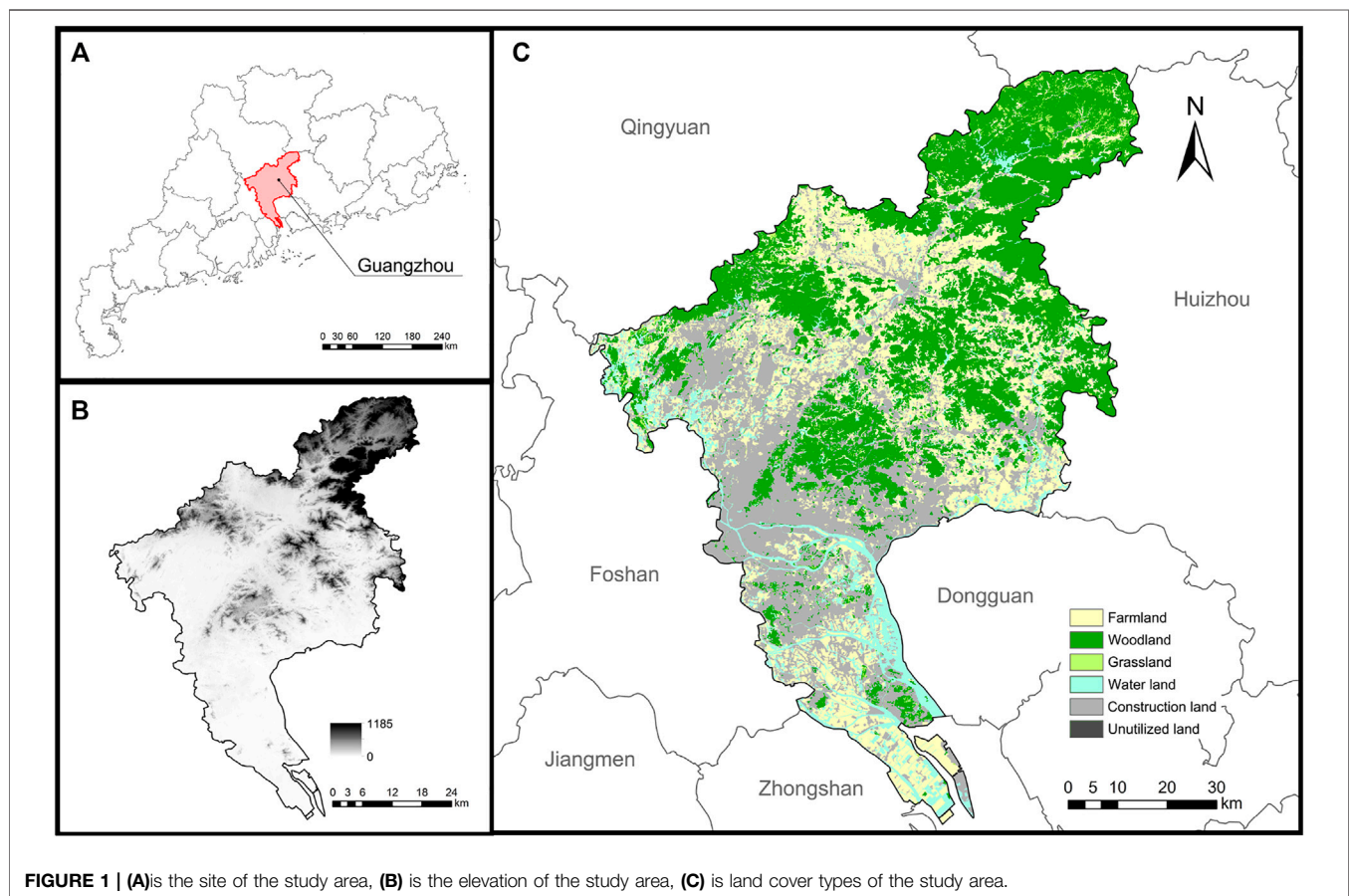


FIGURE 1 | (A) is the site of the study area, (B) is the elevation of the study area, (C) is land cover types of the study area.

studies mentioned above only assessed the landscape connectivity, failing to consider both the importance of ecosystem services and socioeconomic indicators, as well as restoration strategies. Therefore, it is urgent to move the process of ecological protection and restoration forward in order to identify key restoration regions for Guangzhou based on the optimization of the ESPs.

Based on the above considerations, the research objectives were to identify ecological sources by comprehensively evaluating the integration between ecosystem and socioeconomic indicators, to build ESPs based on the lowest cost path and identify the barrier point and pinch point for the corridors and to propose the optimization of the ecological restoration regions on the basis of ESPs.

2 MATERIALS AND METHODS

2.1 Study Area

Guangzhou is the central city in the Guangdong-Hong Kong-Macao Greater Bay Area, with a total area of 7434.4 km². There are eleven municipal districts in Guangzhou (**Figure 1**). Having a topographical structure of densely forested mountains, the northern area is the ecological supporting area of Guangzhou. The central area, with its topography of hilly and basins, is the location of the socioeconomic center. Besides, the southern area is

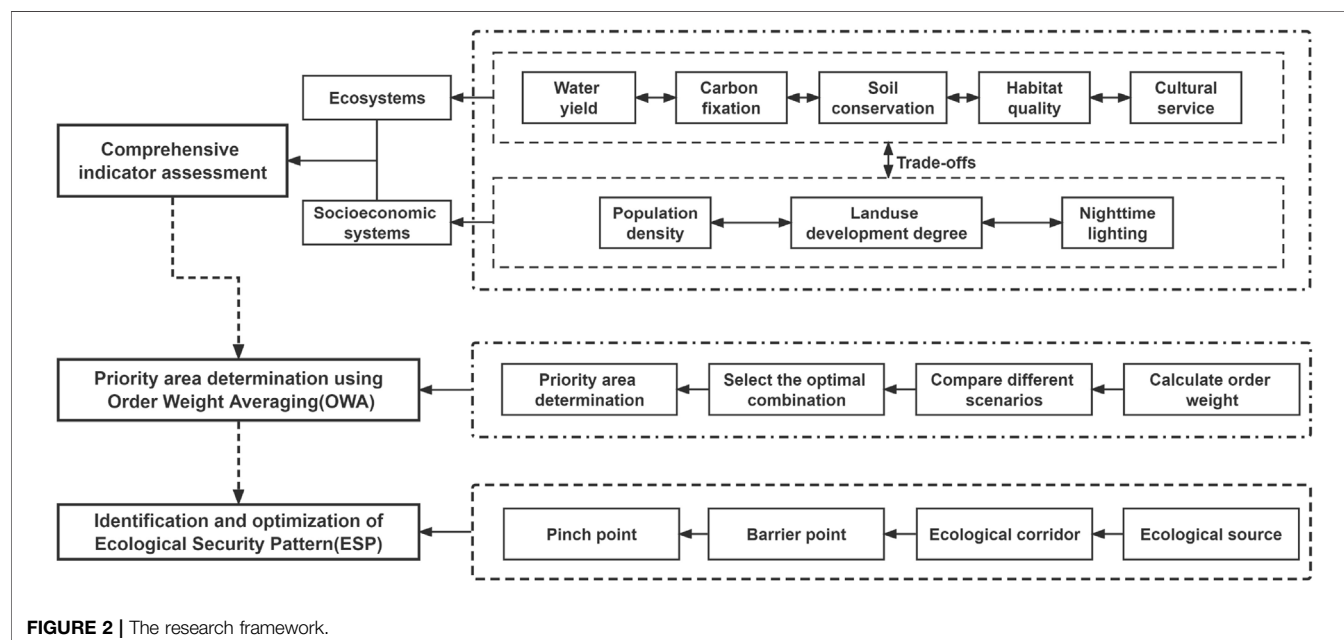
also a potential area for the future development of construction land due to the plain topography. With the rapid socioeconomic development of Guangzhou in the past decade, the construction land has expanded rapidly and the population has grown about 500,000 people per year. Therefore, Guangzhou has become one of the cities where the conflict between urban development and the ecological environment is most prominent in the Greater Bay Area (Li et al., 2021).

2.2 Data

The basic data in this study mainly include: 1) the 2020 Globe Land 30M surface coverage dataset from Globe Land <http://www.globallandcover.com/>; 2) the 2020 GDEM V2 30M resolution digital elevation data from NASA <https://search.earthdata.nasa.gov/search/>; 3) Guangdong Province 30M resolution soil erodibility factor dataset from National Science and Technology Infrastructure Platform - National Earth System Science Data Center <http://www.geodata.cn/>; 4) 2020 MODIS MOD13Q1 NDVI 16-days data from NASA <https://modis.gsfc.nasa.gov/data/>; 5) 2020 monthly values of basic elements of China's international exchange station for meteorological radiation and monthly values of China's ground climate data from the National Meteorological Science Data Center <http://data.cma.cn/>; 6) 2020 national urban road dataset from Gaode Map <https://www.amap.com/>; 7) 2020 Guangzhou city POI data from Gaode Map <https://www.amap.com/>; 8) NPP/VIIRS annual

TABLE 1 | Assessment methods.

Indicator	Method	Calculation
Carbon Fixation	To study the metabolic capacity of the ecosystem, the net primary productivity is used to characterize the Carbon fixation Yang et al. (2016). Carnegie Ames Stanford (CASA) model	$NPP(i,t) = APAR(i,t) \times \xi(i,t)$; $NPP(i,t)$ is the net primary productivity on-grid i in time period t ; $APAR(i,t)$ is the photosynthetically active radiation index on-grid i in time period t , and $\xi(i,t)$ is the light energy conversion rate on-grid i in time period t
Water Yield	The Water Balance Method Casagrande et al. (2021)	$WY = P - ET - D$; WY is the annual water yield; P is annual precipitation; ET indicates the annual evapotranspiration; D is the surface runoff, which is the product of surface runoff coefficient and precipitation Wang et al. (2020)
Soil Conservation	RUSLE Erosion Model Ye and Shi (2021)	$A = R \times K \times LS \times C \times P$; A is the erosion amount of soil; PA is the erosion amount of soil; R is the rainfall erosion factor; K is the soil erodibility factor; LS is the slope length slope factor; C is the vegetation cover and management factor, and P is the soil conservation measure factor. Among them, the rainfall erosion factor (R) is set as a constant due to the small difference of precipitation in the study area, and the P and C coefficients will refer to the research results of related literature
Habitat Quality Cultural Ecosystem Service	Habitat Quality module of the InVEST model Liu et al. (2021) Recreation services, accessibility, and historical heritage services Yu et al. (2018); Marina et al. (2020) demonstrate the level of cultural resources in the study area, so the study identifies the potential for sustainable cultural development through this index	$CS = 0.9L + 0.1CH$; $L = 0.2LU + 0.5P + 0.15RD + 0.15PT$; CS is the value of cultural services; L is the value of recreation and leisure; CH is the value of spiritual and cultural resources, calculated by estimation of historical and cultural facilities in the study area. LU is the type of land use coverage; P is the service of the parks in the study area, which is quantified with reference to the evaluation of Guangzhou city parks in "Guangzhou City Park Directory" "Guangzhou City Green Space System Plan (2020–2035)". RD is road density, and PT is public transport station distribution density, which is quantified by kernel density estimation to POI data of public transport stations Yang and Li (2021); Bing et al. (2021)
Landuse Development Degree		The ratio of construction land to the total land area in the study unit. This study quantifies the degree of land use development by the ratio of built-up land to total land area within a 100 m grid Peng et al. (2017a)
Population Density	Worldpop 100 m population density raster dataset	There are significant differences in population density and nighttime lighting index between different areas. Therefore, the study will take the logarithm of the two indicators PD and NL Gong et al. (2019)
Nighttime Lighting	NPP/VIIRS annual nighttime lighting index	



nighttime lighting index sourced from National Oceanic and Atmospheric Administration <https://ncc.nesdis.noaa.gov/VIIRS/>;
9) 100 m population density raster dataset for 2020 sourced from

worldpop <https://www.worldpop.org/>; (10) Guangzhou City Park Directory <http://lyylj.gz.gov.cn/attachment/6/6806/6806818/7295517.pdf>

3 METHODOLOGY

3.1 Indicator Assessment

As shown in **Table 1** and **Figure 2**, The assessment of the importance of ecosystem services is the basis for the construction of ESPs. In terms of the topography and land cover types of Guangzhou, the study area is facing some ecological problems of soil erosion, massive destruction of native vegetation, habitat fragmentation and the decline of water yield. Therefore, ecosystem services of Soil Conservation (SC), Habitat Quality (HQ) and Water Yield (WY) were selected as indicators and Carbon Fixation (CF) was also selected because it is a quantitative approach to the delineation of ecological redline for ecological protection in planning. In the meanwhile, due to the incomplete parks and recreation system and increasing demands of cultural ecosystem service in the study area, Cultural Service (CS) was also selected as ecosystem indicators. On the other hand, the degree of Land-use Development (LD), Population Density (PD) and Nighttime Data (NT) were selected to represent the socioeconomic system (Ding et al., 2019).

3.2 Correlation Analysis

According to the previous study, ecosystem and socioeconomic indicator trade-offs and synergies were based on linear data fitting, which can show the direction and intensity of interactions between each of the two indicators (Li et al., 2020). In this study, we first used Pearson correlation analysis to form a correlation matrix by using the GGally package in R, version 4.1.1. The values of eight types of indicators were randomly extracted from a total of 50,000 locations at the scale of the study area. The Pearson correlation coefficients between two indicators were calculated and tested for significance. When the correlation coefficient between two indicators is positive, there was synergy between them. When the correlation coefficient is negative, there were trade-offs between the indicators (Chen et al., 2021). The magnitude of its absolute value reflects the degree of trade-offs or synergy between the indicators. Complex trade-offs may exist among different indicators of the same factor, while specific trade-offs may exist between the ecosystem and socioeconomic system.

3.3 Multicriteria Evaluation

Multicriteria evaluation (MCE) can measure and evaluate regional suitability by weighing multiple relationships (Valente and Vettorazzi, 2008). The OWA method can weigh different decision objectives to determine the optimal decision by performing spatial operations on each evaluation metric. OWA method presents different decision sets by considering the trade-off relationships between different criteria (Chen et al., 2021). OWA method can weigh different decision objectives to determine the optimal decision by controlling each evaluation indicator for spatial operations and balance multiple conflicting indicators in the decision-making process. By considering the trade-offs between different criteria, different decision scenarios were

simulated and different decision sets were presented. The formula is as follows (Zhao et al., 2020):

$$OWA(x_{ij}) = \sum_{i=1}^n w_i s_{ij}, \left(w_i \in [0, 1], \sum_{i=1}^n w_i = 1, \text{ and } j = 1, 2, 3, \dots, n \right) \quad (1)$$

where x_{ij} is the standardized comprehensive evaluation index value; s_{ij} is the sequence value arranged in descending order by x_{ij} through the size of the attribute value; w_i is the order weight arranged in descending order by x_{ij} through the size of the attribute value; n is the number of indicators.

According to different decision risks, the bit-order weights generated and the trade-offs obtained based on the bit-order weights under various decision risks were calculated as follows:

$$w_i = Q_{RIM}\left(\frac{i}{n}\right) - Q_{RIM}\left(\frac{i-1}{n}\right), i = 1, 2, 3, \dots, n \quad (2)$$

$$Q_{RIM}(r) = r^\alpha, \alpha \in (0, \infty) \quad (3)$$

$$\text{trade-off} = 1 - \sqrt{\frac{n \sum_{i=1}^n \left(w_i - \frac{1}{n}\right)^2}{n-1}}, 0 \leq \text{trade-off} \leq 1 \quad (4)$$

In the formula, Q_{RIM} is the monotonical rule function; w_i is the number of the bit order; n is the number of indicators; α is the decision risk coefficient under different decisions.

In this study, seven decision scenarios (α of 0.001, 0.1, 0.5, 1, 2, 10, 1000) were presented. It shows that under the decision scenario of $\alpha < 1$, ecology space will be restricted protected or even reach the scenario of Complete Protection. On the other hand, changes in decision making from $\alpha = 1$ to $\alpha = 1,000$ gradually shows the scenario of developing with the risk of ecological destruction (Li et al., 2022). In the process of OWA method, eight evaluation indicators were min-max normalized from 0 to 1 and ranked in descending order by the mean size of the normalized values to obtain the rank order weights of each indicator. The decision risk level was ordered into seven types, and a total of eight decision scenarios were dynamically generated for different decision levels. By multiplying the rank order weights of each indicator with the weighted weight values of the eight assessment indicators and their indicator values, comprehensive ecosystem and socioeconomic evaluation maps can be obtained under different scenarios. The top 20% of each scenario were identified as ecological priority areas based on the comprehensive evaluation map (Chen et al., 2021). By comparing the degree of trade-off in different scenarios, the scenario with the highest degree of trade-off was selected as the optimal scenario. In this scenario, ecological conservation and socioeconomic development will be in dynamic balance, and the city will be in a state of effective conservation while developing (Li et al., 2022).

3.4 Building the Ecological Security Pattern

3.4.1 Ecological Source

In this study, ecological sources were identified by combining ecosystem and socioeconomic system. Ecological priority areas of a certain size are essential for the material and energy connection of the ecological network (Cui et al., 2020). Referring to previous studies and the actual situation of Guangzhou (Long et al., 2018),

our study integrated and screened all $\geq 1\text{km}^2$ areas from ecological priority areas as ecological sources (Mao et al., 2020).

3.4.2 Ecological Corridor

Urban ecological corridors connect ecological sources in the urban system network (Mao et al., 2020). The resistance surface is the key to influencing material and energy flow between ecological sources. Therefore, the resistance surface value was determined based on the comprehensive evaluation value of the ecosystem and socioeconomic system. In particular, we normalized the integrated assessment value raster to calculate the resistance of the raster with the following equation (Peng et al., 2018).

$$R_i = 1000 \times (1 - A_i) \quad (5)$$

where R_i is the surface value of resistance in grid i ; A_i is the comprehensive evaluation value in grid i .

In the next step, the least-cost path was calculated by the Linkage Mapper tool and set the maximum cost-weight distance as 20,000 (Xu et al., 2021a). Linkage Mapper filters the optimal corridors from the source to the neighboring source to map the optimal paths by simulating the minimum cost distance accumulated by ecosystem services (Song and Qin, 2016). This study identifies each ecological corridor's average resistance level by the ratio of the cost-weighted distance of each least-cost path to the Euclidean distance between sources. The corridor ratios were separated by the natural breakpoint method into extremely high resistance, high resistance, medium resistance, low resistance, and extremely low resistance (Su et al., 2021).

3.4.3 Barrier Point Analysis

Barrier points are high-resistance areas that prevent ecological corridors from connecting to the ecological source (Pan and Wang, 2021). In this study, the Barriers Mapper function in the Linkage Mapper tool was used to identify ecological barriers by setting 250, 500, 750 and 1000 m as the search radius. Five intervals were set based on the identification results by the natural breakpoint method, and the highest-value interval was selected as the barrier point (Wang et al., 2022).

3.4.4 Pinch Point Analysis

Ecological pinch point is a high-flow, key node in the ecological process, that should be protected as a priority. Pinch points play an important role in ecological connectivity, being in areas of high resistance and making a large contribution to connecting ecological corridors (Peng et al., 2018). Pinch points can be identified using the Pinch point Mapper function in the Linkage Mapper tool. In this study, the analysis results were divided by the natural breakpoint method. The category with the highest current values (which means the least average resistance distance) is extracted as the ecological pinch point (Zhu et al., 2020).

4 RESULTS

4.1 Indicator Assessment

The normalization result of each indicator value was shown in Figure 3. The high values of HQ and SC were located in the

northern area and river around the southern area, and therefore would be rich in biodiversity and high soil retention. Besides, the high value of CF was concentrated in the northern area due to the high vegetation cover and woodland there. What's more, there was a relatively low WY capacity due to the effects of high urbanization in the central area. By contrast WY was generally at high value in the northern and southern areas because of abundant precipitation and the impact of rivers in the study area. However, compared with other ecosystem indicators, the high value areas of the CS are situated sporadically in the large forest parks and landscape areas from northern and central area in hilly. In addition, the indicators from the socioeconomic system including LD, PD and NL were highly similar. Their high value was concentrated in the highly urbanized areas in the central area and the southern area under rapid development (Ding et al., 2019).

4.2 Correlation Analysis

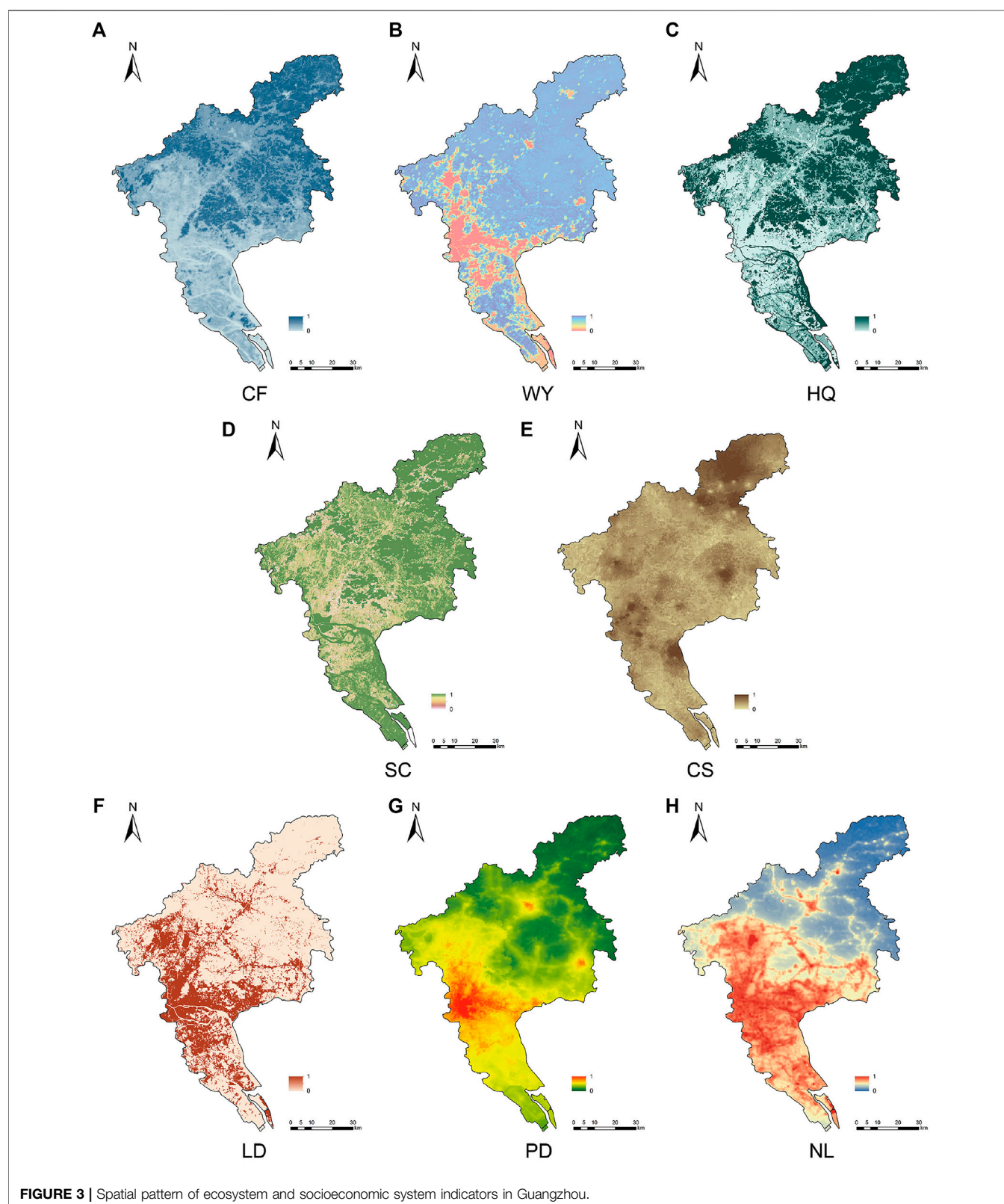
The study calculated the correlation coefficients among the comprehensive evaluation indicators (Figure 4). The correlation coefficients between ecosystem indicators generally showed a positive correlation. Most indicators' correlation indices were concentrated in the range of 0.1–0.5. The correlation between CF-WY (0.544) and CF-HQ (0.705) showed a significantly positive correlation, indicating synergies between these two relationships, while CS weakly correlated with WY and SC at 0.012 and 0.037, respectively. On the other hand, the data revealed significant positive correlations between the socioeconomic indicators.

Overall, all indicators show negative correlation between ecosystem and socioeconomic system, which indicates that there was an apparent trade-off relationship between them.

4.3 OWA Method for Different Scenarios

As shown from Table 2, with the increase in the decision risk coefficient, the rank order weight of high-level comprehensive evaluation indexes decreases continuously. In contrast, the rank order weight of low-level comprehensive evaluation indicators increases continuously.

Under different scenarios, the top 20% of the comprehensive evaluation value was selected as the ecological priority area. Consequently, the map of ecological priority areas under different scenarios was shown (Figure 5). From the seven different types of scenarios (Table 3), it can be seen that the decision result was optimistic at $\alpha = 0.001, 0.1, 0.5$. The high-value areas were mainly concentrated in the north and south of the study area, and most of the land types in the ecological priority protection areas were woodlands. Obviously, this type of scenario makes it difficult to develop construction land and maybe not easy to meet the growing population needs of megacities. Meanwhile, the criterion weights of all indicators in this study were 0.125 when $\alpha = 1$. The high-value areas were evenly distributed throughout the study area, and the ecological priority areas were mainly forest land at that time. Moreover, farmland, water area and construction area occupy part of the ecological priority area. The comprehensive evaluation weighting value was the



largest when $\alpha = 1$. However, when $\alpha = 2, 10, 1000$, the decision result was pessimistic. The high-value area was concentrated in the central area, and the ecological priority protection area was

mainly dominated by construction land. The indicator of the socioeconomic system currently dominates the comprehensive evaluation indicator, and the area was at a high-risk level. As

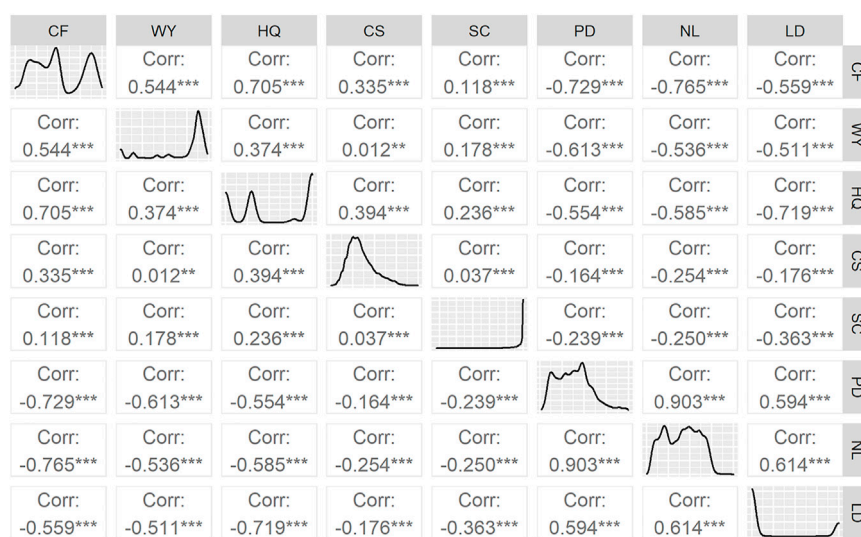


FIGURE 4 | Correlation matrix.

TABLE 2 | Bit order weight operators under different decision risk scenarios.

Scenario	1	2	3	4	5	6	7
α	0.0001	0.1	0.5	1	2	10	1,000
w_1	0.9998	0.8123	0.3536	0.1250	0.0156	0.0000	0.0000
w_2	0.0001	0.0583	0.1464	0.1250	0.0469	0.0000	0.0000
w_3	0.0000	0.0360	0.1124	0.1250	0.0781	0.0001	0.0000
w_4	0.0000	0.0265	0.0947	0.1250	0.1094	0.0009	0.0000
w_5	0.0000	0.0211	0.0835	0.1250	0.1406	0.0081	0.0000
w_6	0.0000	0.0176	0.0755	0.1250	0.1719	0.0472	0.0000
w_7	0.0000	0.0151	0.0694	0.1250	0.2031	0.2068	0.0000
w_8	0.0000	0.0133	0.0646	0.1250	0.2344	0.7369	1.0000
trade-off	0.0002	0.2134	0.7280	1.0000	0.7835	0.2723	0.0000

the ecological risk gradually increases, the ecological priority area changes from green space, woodland and grassland, to farmland and construction areas.

4.4 The Ecological Security Pattern of Guangzhou

4.4.1 Ecological Source

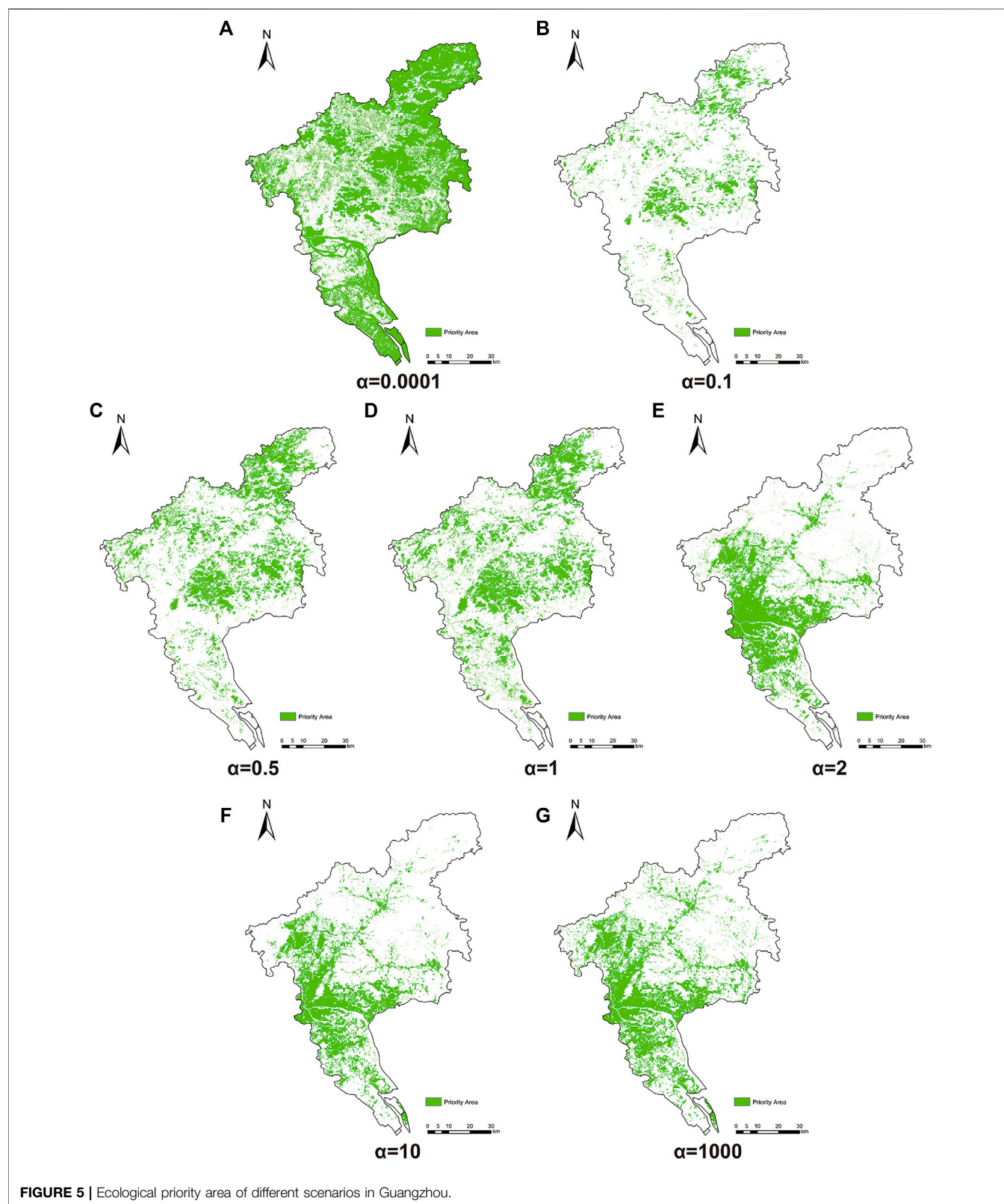
By simulating the decision risk of each scenario in the OWA method, the result ($\alpha = 1$), with the highest trade-off was selected as the final scenario. Therefore, the comprehensive evaluation was shown in **Figure 6A** and resistance surface was shown in **Figure 6B** based on the final scenario. In this study, spots of more than 1 km^2 were selected as ecological sources of the study area.

According to **Figure 7**, the number of ecological sources was 158 and the total area of ecological sources was $1,085.34 \text{ km}^2$, accounting for 15.03% of the total area of Guangzhou.

From the spatial layout, most ecological sources were distributed in the northern area, accounting for 84.91% of the total area of ecological sources.

The ecological sources in the central area account for 8.88% of the total area of ecological sources. This revealed the fragmentation of green space caused by the expansion of urban construction areas in the central area of Guangzhou, as there were relatively few ecological sources with eligible area and high comprehensive evaluation values.

Moreover, the area of ecological sources in the southern part accounts for 6.21% of the total area of ecological sources. The ecosystem values were much lower than those of the northern part of the study area, where woodland was the main land cover type. The socioeconomic system indicators were lower than those of the central area due to the lack of urbanization activities and population density, which results in a low overall evaluation value. Ecological sources were spatially scattered, and the area of individual sources was small.

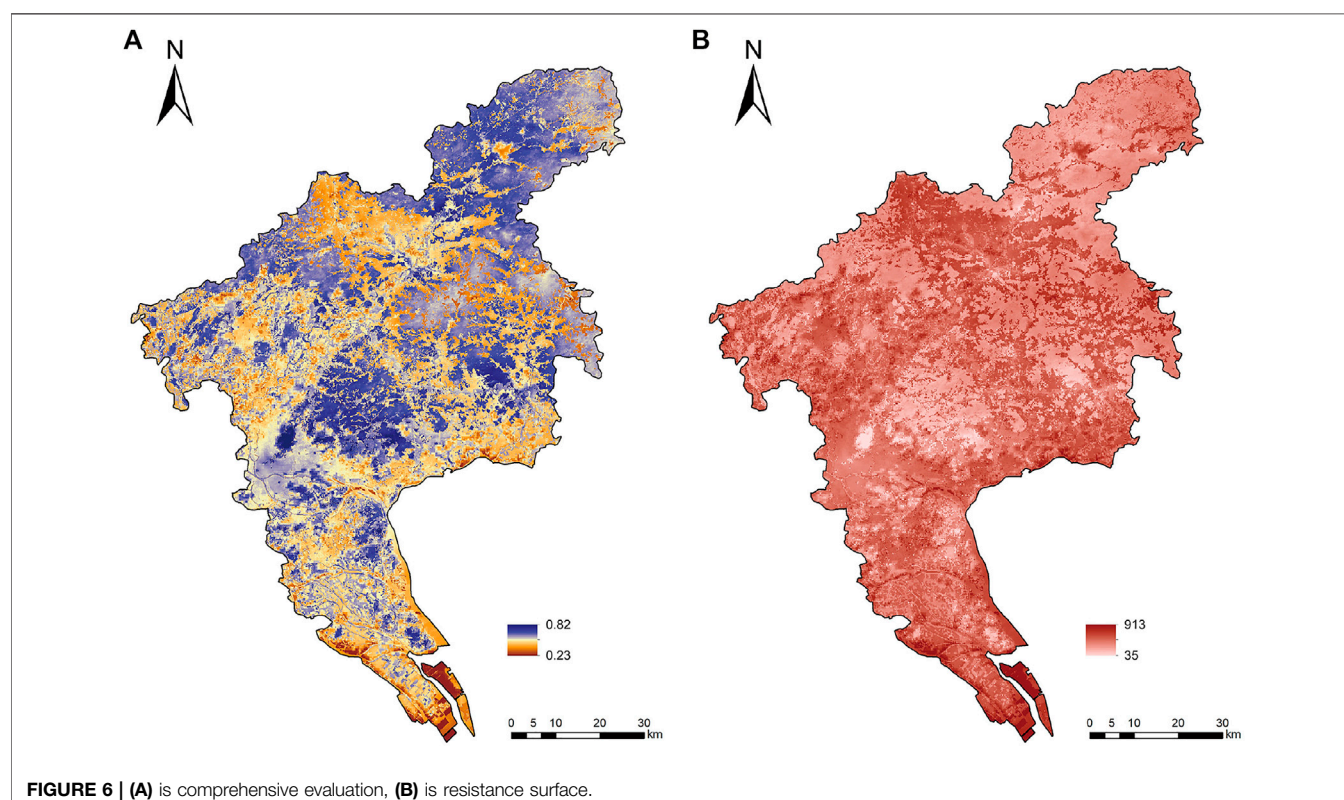


Most of the ecological sources were woodland, accounting for 85.58% of the total area of ecological sources, with a small proportion of water land and construction land. Due to the

trade-offs between ecosystem and socioeconomic system, the sources in the northern and southern area were mostly dominated by ecosystem indicators. Moreover, the

TABLE 3 | Changes in the proportion of land use in ecological priority areas under different scenarios.

α	Farmland (%)	Woodland (%)	Grassland (%)	Waterland (%)	Constructionland (%)
0.0001	21.73	52.90	3.29	17.24	4.85
0.1	0.00	93.36	0.15	6.49	0.00
0.5	0.05	93.05	0.70	6.20	0.00
1	1.23	85.58	1.16	6.29	5.73
2	2.00	5.76	0.48	1.52	90.25
10	0.33	0.22	0.05	0.10	99.30
1,000	0.77	0.30	0.08	0.13	98.71



ecological sources in the central urban area were generally dominated by economic indicators.

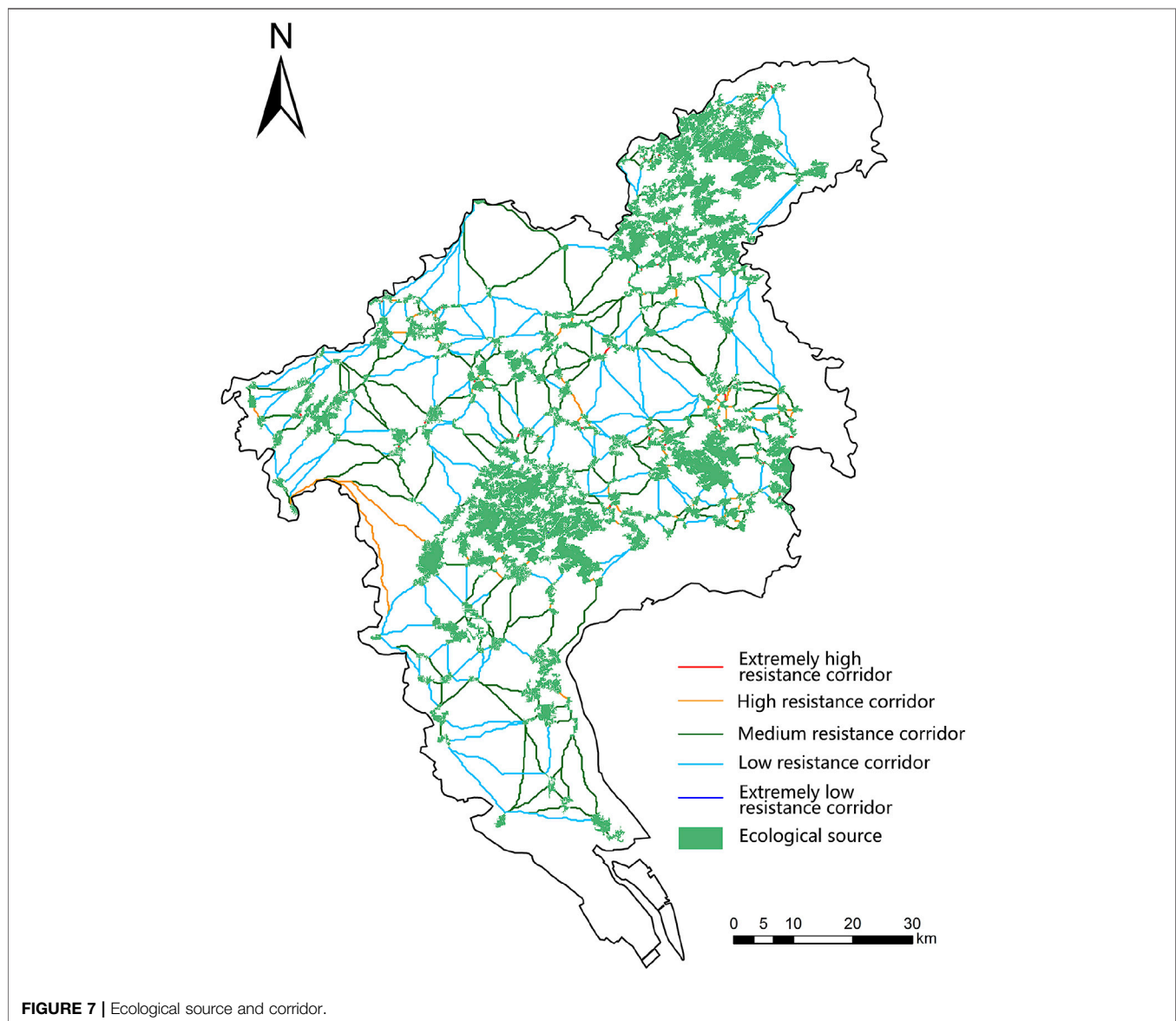
4.4.2 Ecological Corridor

In total, 406 major ecological corridors with a total length of 1520 km and an average length of 3.3 km were identified in Guangzhou. As shown in **Figure 7**, the ecological corridor in Guangzhou was uniformly distributed, changing from dense in the northern area to sparse in the southern area.

The northern area in Guangzhou has the largest number of ecological corridors, with 334 in total. There was a short average corridor length due to the dense and continuous distribution of ecological sources. Some of the smaller ecological sources connect the northern area through dense, low-cost-distance corridors, occupying most of the area. Therefore, most of the northern corridor could maintain the connectedness of the whole area. There was the lowest number of ecological corridors in the central

area, at 30. The spatial layout of corridors in this area was in a circular radial shape. The socioeconomic system index-driven ecological sources link the northern and southern parts, increasing ecological space connectedness in the central zone. However, the average cost distance of corridors in the region was much higher. There were 41 ecological corridors in the southern area. Due to the remote distance between ecological sources, the average distance of corridors was relatively long, and they have a higher cost distance. The southern area was in its initial development stage, and the socioeconomic conditions were far lower than the central area.

Overall, 30 extremely high-, 65 high-, 161 medium-, 147 low- and 2 extremely low-resistance corridors were identified. Extremely high- and high-resistance corridors were normally distributed in the north area, at extremely close distances among the ecological sources. However, the intervening patches of extremely low ecological value significantly reduce



the connectedness of the corridor between two sources. Furthermore, medium-resistance corridors were generally located in two ecological sources with longer cost-weighted distances. The complex and various land-use types have an impact on the overall resistance of the corridor.

4.4.3 Barrier Point Analysis

Comparing the results of the different radii, the four different radii have a similar range of barriers. The search results from a smaller radius can accurately search for a higher barrier score in the fine area in the corridor. Therefore, a 250 m radius was selected to identify ecological barrier point and the total area was 433.26 km^2 (Figure 8A).

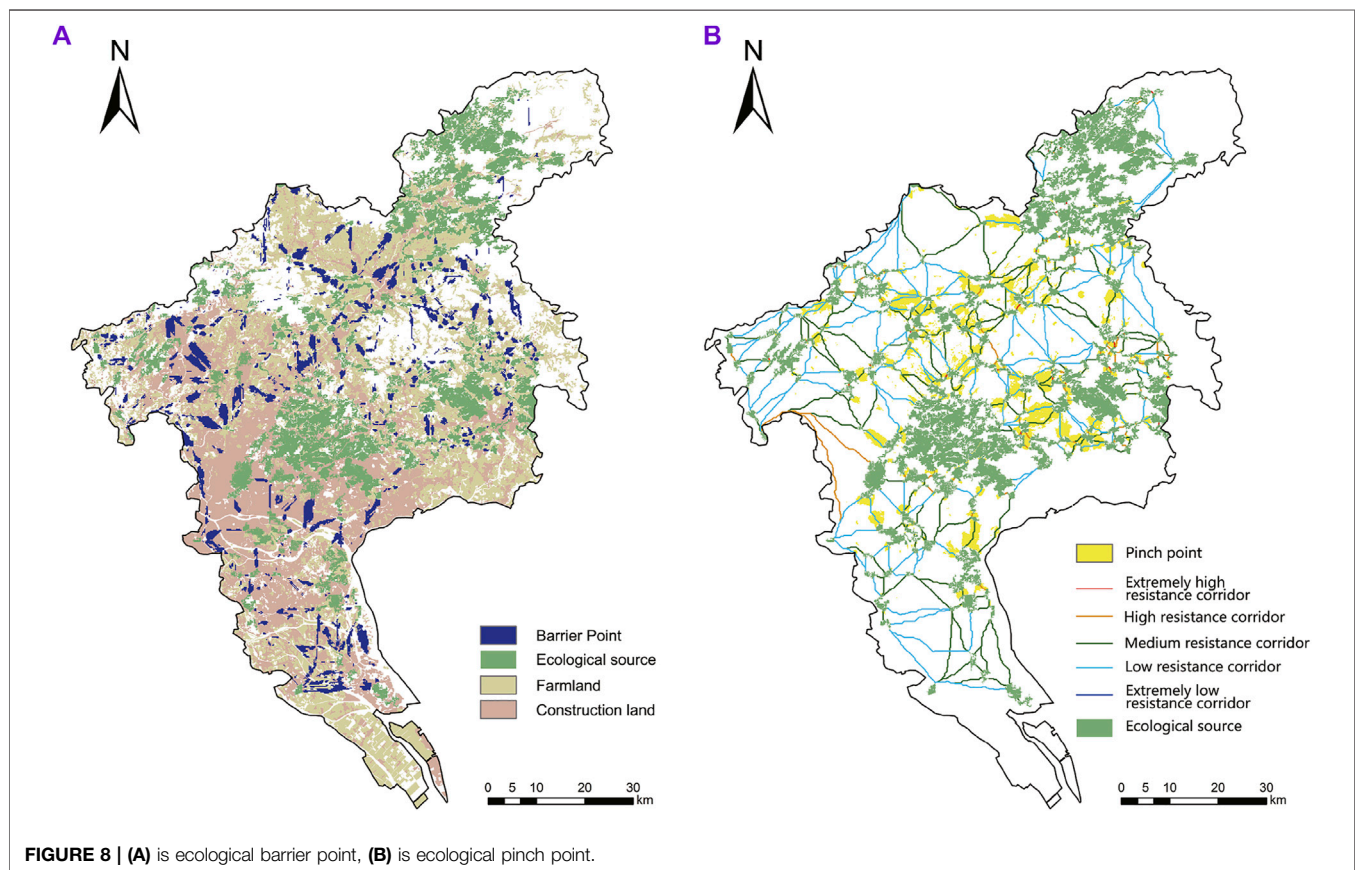
Most of the ecological barrier points were located in the farmland and construction land. When it comes to the spatial layout, there were a large number of scattered barrier points in the northern part of the study area, and it would be very difficult to

completely remove them in the future. In the central and southern areas, there were large-scale barrier points. Corridor connectivity can be significantly improved by removing barrier points in this area. Ecological restoration measures should be recommended for optimization.

4.4.4 Pinch Point Analysis

The results (Figure 8B) show that the ecological pinch points were mainly located in the northern area. Pinch points were mostly situated in woodland, with a small amount in farmland and construction land. On the other hand, in the southern area, the proportion of pinch points in farmland and construction land was significantly higher.

The narrow pinch point area acts as a catalyst for corridor connectivity when the relatively high-resistance patches spread around the area. However, the analysis of ecological corridors with different resistance types shows that although the study



identifies high-value pinch points, they were mostly in low-resistance corridors. Medium- and high-resistance corridors were impeded by the disorderly encroachment of construction land in the northern and southern areas, resulting in the fragmentation of green space and farmland patches. The fragmented areas were highly mixed with various land-use types, and therefore contribute less to connectivity.

5 DISCUSSION

5.1 Significance for Integration of Ecosystem and Socioeconomic System

Previous studies directly select forest patches or habitat areas of wild animals as source areas, but the subjective interference in this selection method was large. Although good accessibility was considered in this selection method, the results only identified ecological patches as the sources of Guangzhou (Yang et al., 2018). Therefore, the high comprehensive value areas in other land-use types tend to be ignored. Furthermore, by changing the selection criteria of sources, the importance of core patches could also be quantitatively evaluated based on the structure of ecosystem and ecological sensitivity (Peng et al., 2017a; Su et al., 2022). The ecosystem services-based ESPs were regarded as an effective method for strengthening the integrity of ecosystems and socioeconomic systems (Fan et al., 2021). It is reasonable to rank patches based on their multifunction of

providing key ecosystem services, however, the interaction between the ecosystem and human socioeconomic system cannot be neglected due to the role of ESPs in figuring out the contradiction between ecological land protection and urban development.

We proposed a comprehensive selection method containing five crucial ecosystem services in Guangzhou; aside from regulation and provision ecosystem services, cultural services were also included to quantify the importance of ecological areas. To understand the relationship between ecosystem and socioeconomic system, several scenarios based on the OWA method were compared to identify the ecological sources. Our approach identified the demand for human well-being and the ability to provide effective services (Peng et al., 2017a). Green space and parks in the central part of Guangzhou were also extracted, although the patches were fragmented due to the expansion of construction land. Specifically, a small proportion of construction land also extracted due to the trade-offs between ecosystem and socioeconomic system, which can be identified as the strategic points in the ESPs. Our selection method, therefore, is more conducive to the identification of ecological sources.

In the context of global climate change and anthropogenic disturbances, socioeconomic development will lead to more prominent eco-environmental problems (Liu, 2016). Aiming to solve problems of ecological security, the Guangzhou government has carried out a series of projects and plans such as ecological protection redline, however, these “bottom-line” policies mainly

concerned ecological space while neglected the human-land contradiction in metropolitan area (Xu et al., 2021b), or neglect the potential crucial patches outside the ecological protection redline (Ye et al., 2018). To address this gap, this study considered both the ecosystem and socioeconomic system to construct the ESPs. It is worth noting that the most ecological sources were distributed in the hilly area with woodland, which tend to be threatened by unforeseeable human activities. It should be of great concern to integrate ecosystem and socioeconomic system to deal with future climate changes and sustainable development.

5.2 Limitations and Challenges

Previous studies mostly used the artificial discrimination method to eliminate results directly, but it was not easy to determine the ecological sources (Fu et al., 2020). In this study, the ecological sources were selected under the specified threshold, and as a result, ecological sources in the southern and central areas of Guangzhou were much less abundant than in the northern area. Several important “green core” areas such as Dafu Mountain, Seagull Island, and Huang Shan lu forest park were identified. Some important patches such as Nansha wetland in the southern area were eliminated due to their small area, though they may have potential value in other ecosystem services. Future study is still needed to determine the rationality of the threshold, and the assessment indexes need to be enhanced to make sure that the ecological sources are in their best state.

Referring to related studies, the selection of ecosystem indicators is mainly based on support, cultural and regulating services. However, the farmland is usually contributed to the provision of ecosystem services and may be underestimated when the study does not select food production as an indicator (Xu et al., 2014). As a result, high-quality farmland in the southern area may not be highly valued, leading to a reduction in ecological sources in the south. Therefore, the range of evaluation indicators could be expanded in future studies, which could add into the integration of ecosystem and socioeconomic system relationships in comparison with the results of current studies.

The connectivity of heterogeneous landscapes can be effectively identified by the least-cost path. However, the identification of corridor importance merits further discussion (Song and Qin, 2016). Circuit theory can provide multiple potential corridors and contribute to identifying corridors of priority importance (Liu et al., 2021; Pan and Wang, 2021), but it is not possible to intuitively investigate corridor movement pathways and connectivity because of random-walk (LaPoint et al., 2013). Therefore, we use the intuitive least-cost path to describe the priority of each corridor and ratio of cost-weighted distance to length to determine the relative resistance. This could be more flexible in researching corridor connectivity. However, compared with circuit theory it is still insufficient in identifying the importance of multiple pathways (McRae et al., 2008).

Different ecological corridor widths have an impact on the identification of ecological barrier points and pinch points. Consequently, they can provide the scientific basis for the definition of ecological restoration and protection areas in

ecological corridors (Hou et al., 2021). An agreement regarding the widths of different ecological corridors has not yet been reached (Peng et al., 2017c). Therefore, determining the widths of corridors is an essential point in the implementation of ESPs (Zhai and Huang, 2022). However, this has not been discussed due to the constraints of the study, but should be considered in future research.

5.3 Optimization and Restoration

Different strategies should be proposed depending on the land-use types of different areas. For the northern areas dominated by the ecosystems, it is necessary to consider this area as the role of the ecological supporting area and focus on ecological conservation strategy. Ecological protection areas such as forest parks should be strictly protected, while appropriate recreational services should be provided as rationally direct ecological resources. For the central area, which is dominated by socioeconomic systems, small green spaces should be constructed and distributed throughout the area. Moreover, green spaces should be designed to deliver recreational and cultural characteristics, balancing ecosystem values with socioeconomic system values. In addition, in the southern area, which is a potential area for urban construction in Guangzhou according to Territorial Spatial Planning, the expansion of construction land should be rationally restricted to prevent the shrinkage of ecological space. Strategies such as exposure to green space and ecological greenways (Zhang et al., 2021), which can deliver different kinds of ecosystem services and enhance the multifunctionality of corridors, are recommended to integrate complementary ecosystem connectivity (Carlier and Moran, 2019).

Corridors play an important role in the maintenance of ecological processes (Peng et al., 2018). Furthermore, in order to implement ecological restoration in ecological corridors, the areas of barriers points and pinch points should be given more priority (Peng et al., 2018). Medium-to-high-resistance ecological corridors should be set as priority areas for future ecological restoration. Ecological restoration should start by prioritizing the removal of ecological barriers. In urban spaces, corridors should be connected by road green belts and greenways. It is possible to improve the corridor barrier points by enriching the green space with various types, vegetation species and vertical structures. Furthermore, the barrier point can be also improved by combining green and blue spaces to form an ecological network and green infrastructure (Yu et al., 2020), which simultaneously contribute to human well-being and sustainable climate adaption planning (Ignatieva et al., 2011; Monteiro et al., 2020; Yang et al., 2020; Yu et al., 2021). When it comes to the connectedness of farmland, high-standard farmland should be interpenetrated by building connecting channels within the space which could interfere with the corridor's connectivity.

Ecological pinch points should be a conservation priority, including strategies to maintain and recover the areas (Castilho et al., 2015). It is necessary to integrate the fragmented patches through land consolidation, which can integrate different spaces with various land-use types in a unified way and carry out spatial reconfiguration. Low-resistance ecological corridors should

be flexibly maintained. These scattered barrier points can be set as secondary areas for ecological restoration and can be gradually improved by nature-based solutions (Bush and Doyon, 2019). In the future, the area needs to avoid being divided into fragmented spaces. Throughout the stages of development, these areas should be centrally classified by a unified authority, which will also facilitate maintenance at a later stage.

6 CONCLUSION

Although previous studies have identified ecological security patterns based on multiple ecosystem services, traditional methods only identified what were considered “ecological patches” as the suppliers, and lacked integration between ecosystems and the socioeconomic systems. This study selected comprehensive evaluation indicators including ecosystems and socioeconomic systems to identify ecological sources, introducing the OWA method from the perspective of trade-off. The highest trade-off scenario was selected and, finally, the ecological sources and resistance surfaces were identified.

There were 158 ecological sources with an area of 1,085.34 km^2 and 406 ecological corridors with a total length of 1506 km in Guangzhou. The pattern of ecological sources and corridors from various areas were influenced by the dominant ecosystem or socioeconomic system, which indicates that the trade-off between ecosystem and socioeconomic system has a significant impact on the construction of ESPs. Moreover, ecological barrier points and pinch points with total areas of 433.26 and 458.51 km^2 , respectively, were recognized to implement ecological restoration. This study also proposed primary ecological restoration strategies for medium- and high-resistance corridors. A large number of scattered barrier points were located in the northern area and large-scale barrier points were generally situated in the central and southern areas. Therefore, restoration strategies including enriching vegetation types and vertical structures and building green belts and greenways should be proposed to restore large-scale barriers points. When it comes to pinch points, land consolidation strategies such as construction land reclamation and farmland preservation should be implemented in medium- and high-resistance corridors, while buffer zones should be constructed

to enhance the resilience of low-resistance corridors. This could achieve the win-win scenario of preserving ecological space while furthering urban development.

The integration of ecosystems and the socioeconomic systems was used as a fundamental basis to improve the existing methods of constructing ecological security patterns. The proposed ecological restoration solutions based on this method contribute to the overall improvement of the connectivity of the ESPs, offering a reference for balancing the development of urbanization and ecological protection in other metropolitan areas.

DATA AVAILABILITY STATEMENT

Information about the existing publicly accessible datasets is contained within the article, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, WL JT, and HL; methodology, WL and JT; data analysis, JT; validation, WL and JT; investigation, WL; resources, WL; writing—original draft preparation, JT and WL; writing—review and editing, WL and HL; visualization, JT; supervision, WL and HL; project administration, HL; funding acquisition, HL. All authors have read and agreed to the published version of the manuscript.

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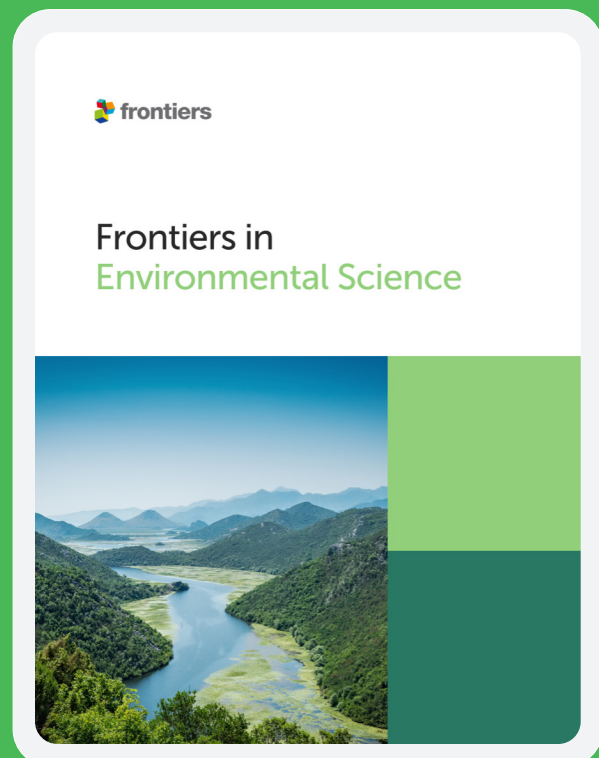
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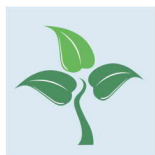
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Article

Spatial and Temporal Evolution of Ecosystem Service Values and Topography-Driven Effects Based on Land Use Change: A Case Study of the Guangdong–Hong Kong–Macao Greater Bay Area

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Article

Spatial and Temporal Evolution of Ecosystem Service Values and Topography-Driven Effects Based on Land Use Change: A Case Study of the Guangdong–Hong Kong–Macao Greater Bay Area

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Abstract: The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) is rich in natural and marine resources, and it is scientifically valuable to study the evolution patterns and driving mechanisms of the ecosystem service values (ESVs) of the GBA for the governance and conservation of its ecosystems. Based on the land use changes in the GBA from 2000 to 2020, the ESVs in the GBA were measured at the grid scale, and the Markov model was used to predict the ESVs in 2030; the calculated results were used to analyze the spatial and temporal variation characteristics of the ESVs during the 30-year period, while the driving role of the topographic factors on the ESVs is revealed through the construction of the geographically weighted regression model (GWR). The results show the following: (1) During the 20-year period, the area of arable land and water in the GBA fluctuated greatly, with the area decreasing year by year and shifting mainly into construction land; in terms of shifting the center of gravity of the land, and the center of gravity of the grassland and unused land shifted the greatest distance due to the expansion of construction land, with the center of gravity shifting westward as a whole. (2) The ecosystem services (ESs) in the GBA show obvious aggregation in the spatial distribution, with the total ESVs decreasing year by year. Among them, the areas with an increasing total value are mainly located in the cities of Zhaoqing and Huizhou in the GBA, accounting for 27%, and the areas with a decreasing total value year by year are mainly located in the dense urban areas in the central part of the GBA, accounting for 35%, and the area is increasing, indicating that the habitat quality is deteriorating, and the model prediction shows that the value of ecosystem services in 2030 have a decreasing trend under the development of the natural state. (3) Topographic factors have a significant influence on the ESVs, and in terms of spatial distribution, the areas with the strongest effect are distributed in the northwestern and northeastern parts of the GBA, and the main uses for the land are wood land, arable land, water and the area of the water–land intersection near the sea.

Keywords: The Guangdong–Hong Kong–Macao Greater Bay Area; ecosystem service value; temporal and spatial evolution; topographic factors; geographically weighted regression model



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1. Introduction

As a strategic national development region, the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) has a key geographical location and a wealth of natural resources. The sustainable development of the GBA plays a crucial role in the enhancement of regional ESVs as well as the construction and optimization of ecological patterns [1]. For the coastal areas with complex and fragile environments, impaired habitat quality will lead

to a decline in the ESVs and negatively affect environmental security and socioeconomic development [2]. Therefore, strengthening the accounting of the ESVs and analyzing the influencing factors that affect the evolution of the ESVs will help with the governance and protection of ecosystems in the GBA [3].

The concept of ecosystems was first proposed by Tasley in the 1930s, marking the gradual refinement of the study of ecosystems; on this basis, SCEP first proposed the concept of ESs in the 1970s [4], and listed a number of ESs provided by the natural environment. Subsequently, Costanza deepened his research on ESVs and classified them into 17 categories, including gas regulation, climate regulation, water regulation, soil formation, nutrient cycling and recreation, based on four dimensions including production, basic functions, environmental benefits and recreation, which became the basis for the classification of subsequent scholars and greatly enriched the research results in this field. At the beginning of the 21st century, the UN Millennium Ecosystem Assessment redefined the concept of ESs and classified them as provisioning, regulating, cultural and supporting services in relation to human benefits, leading to a boom in research on the value of ecosystem services. In China, the study of ESs began in the 1990s when Liu Xiaodi introduced the concept of ESs to the country based on the research results of Daily [5]; subsequently, Ouyang Zhiyun conducted in-depth research on this concept, continuously enriching the theoretical findings on ecosystem services [6]. In the same era, Xie Gaoqi defined ES functions as products and services obtained directly or indirectly through ecosystem functions and classified them into three major categories, namely, production functions, ecological functions and recreational and leisure functions [7]; since then, domestic research on ES functions has been gradually enriched and diversified [8,9].

Early research on ESs at home and abroad focused on the valuation of ecosystem services. There are two main approaches to accounting; the first is the physical quality assessment method, which, in turn, includes the functional volume assessment method and the energy value assessment method. The material quality refers to the value of the final products or services obtained by humans directly or indirectly from the ecosystem [10]. Its principle is to obtain the total value of an ecosystem service from its functional volume and the unit price of that volume [11,12]; the functional volume of the relevant indicator is usually calculated using models such as InVEST and ARIES, which are commonly used. The advantages of the physical quality assessment method are that the results can objectively reflect the structural functions and ecological processes of the ecosystem, but the limitations are that there are uncertainties in the data acquisition and the calculation process is cumbersome, and there are differences in the units of measurement for the individual functional indicators, which makes it difficult to measure the value of ecosystem services with multiple functions. The second approach is the value–volume approach, which includes the monetary and value-equivalent approaches. The principle of this approach is to quantify ecosystem services using economic algorithms, including the direct market approach, the substitution market approach and the simulated market approach [13]. The analysis of the different ecosystem service valuation methods shows that each method has its own advantages and limitations, so the appropriate method can be weighed according to the purpose and focus of the study [1]. Based on changes in the social environment and the different methods of accounting for value, scholars measured the ESVs at different environmental scales and gradually built up a systematic research method for quantifying ESs [14–17], of which a highly representative research result was the principle and method of valuing ESs proposed by Costanza et al. in 1997 [18]; Costanza first accounted the ESVs at the global scale using this method. Subsequently, Chinese scholars such as Xie Gaodi combined the actual situation of ESs in China and, after a series of revisions, developed a table of value equivalent factors applicable to terrestrial ecosystems in China [19]. Later research directions integrate spatial techniques in value assessment to explore the coupling between the land use types and the ESVs. The number and rate of land type changes can directly reflect the intensity of the land type conversion [20–22], thus exploring the temporal and spatial evolution and variation of ESVs in the region from multiple dimensions.

At present, research on the factors influencing the evolution of ESVs has made great progress, mainly focusing on the relevance of physical geographic factors to ESVs [23–26], while regional topography, as one of the determinants of landscape patterns, has an important influence on the evolution of ESVs [27,28]. There are two main methods for coupling ESVs with topographic factors. The first is the direct coupling method, which is mainly calculated through the topographic position index; this index is a composite analysis of the elevation and slope, and is often used to quantify the spatial effects of land use on topographic gradients. The second is the model coupling method, which is mainly carried out through a spatial autocorrelation analysis, such as the Moran index and the geographically weighted models, among which the GWR is more advantageous in the analysis of coupling relationships, because it can express the data characteristics of spatial data at different locations and can reflect the weight size of local areas in the data [29,30]. Therefore, it is important to use spatial autocorrelation analysis to study the driving effect of ESVs in order to optimize the regional ESVs and build an ecological security pattern [31,32].

From the current research results, it can be seen that studies on ESVs in the GBA mostly focus on the relationship between urbanization and ESVs, but the depth of the studies are still insufficient [33–35], mainly in two aspects. Firstly, current studies on the spatial and temporal variation of regional ESVs seldom involve future-year scenarios, and at the same time, when analyzing the spatial and temporal variation of ESVs in regions with rapid urbanization, the coupling study of ESVs and land use changes is seldom involved; secondly, studies of the driving effects of ESVs within the GBA are less likely to involve topographic factors. Therefore, based on the remote sensing image interpretation maps of the GBA from 2000 to 2020, this study measures and predicts ESVs in the GBA in 2030 at the grid scale, analyzes its spatial and temporal variation characteristics, and introduces a model called GWR to reveal the driving effect of topographic factors on ESVs. The aim is to explore the following issues: (1) the spatial and temporal evolutionary characteristics of ESVs in the GBA; (2) the impact of land use on changes in the ESVs; and (3) the relationship between topographic factors and ESVs. These issues are explored to deepen the content of the study and to provide theoretical guidance for the GBA ecosystem to achieve regional ecological governance and integrated urban development.

2. Materials and Methods

2.1. Study Area Overview

The GBA belongs to one of the four major bay areas in the world, with a total surface area of about 56,000 square kilometers. In terms of administrative area, it mainly consists of the nine cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, Zhongshan, Jiangmen and Zhaoqing in the Guangdong Province and the special administrative regions of Hong Kong and Macau (Figure 1). The study area has a mild and humid climate, with a dense network of rivers and water, and is distributed in the mountainous forests of Mafeng Mountain–Baiyun Mountain, Gudou Mountain–Wuguishan Mountain–Phoenix Mountain, Daling Mountain–Yangtai Mountain–Tanglang Mountain, etc., which form an inter-urban ecological transition zone. The study area also has a wide distribution of forests and agricultural land, with arable land scattered throughout the bay area; wetland resources are abundant, with water entering the rivers located in the four cities of Foshan, Zhuhai, Shenzhen and Zhongshan [36,37].

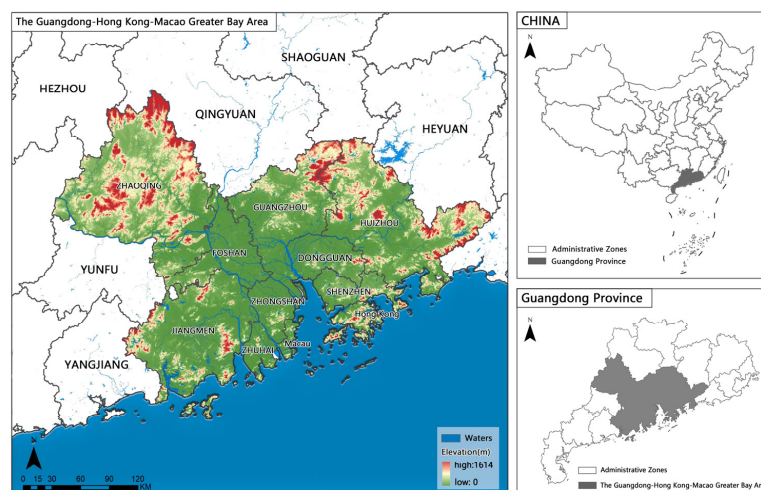


Figure 1. Map of the Guangdong–Hong Kong–Macao Greater Bay Area, China.

2.2. Data Sources and Initial Data Processing

The remote sensing image source data selected for this study were obtained from the Resource and Environment Science and Data Centre of the Chinese Academy of Sciences (<http://www.resdc.cn/>, accessed on 1 July 2021), with three periods including 2000, 2010 and 2020, and the spatial resolution of the data is 30 m. The topographic data were obtained from the geospatial data cloud database (<http://www.gscloud.cn/>, accessed on 1 July 2021), with the type ASTER GDEM. The relevant statistical data were mainly obtained from the Guangdong Statistical Yearbook, the Hong Kong Statistical Yearbook and the Macao Statistical Yearbook during the study period. The collected remote sensing data were corrected and classified using ArcGIS software, and according to the previous research results, the land types were classified into six categories, such as construction land, arable land, grassland, woodland, water and unused land [38]; the relevant yearbook data were collated, summarized and analyzed, and processed using SPSS software.

2.3. Research Methods

The research idea and process are shown in Figure 2.

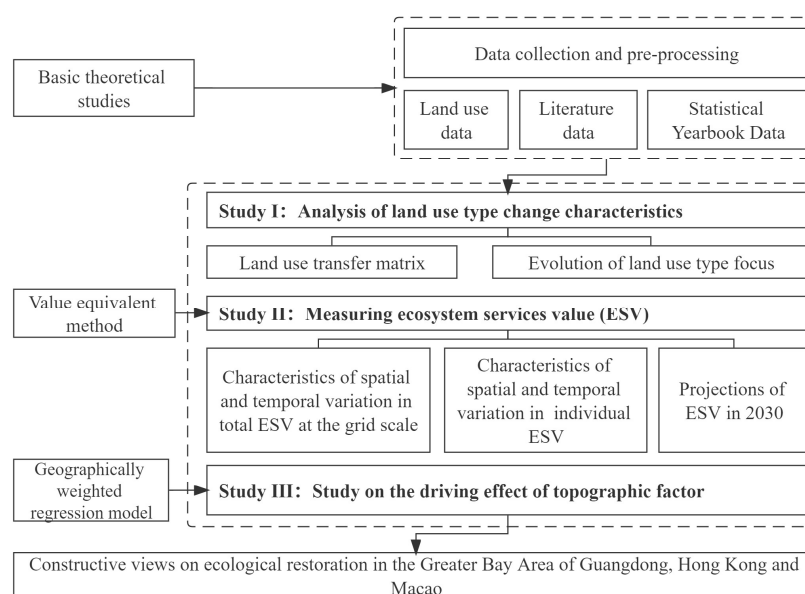


Figure 2. Article flow chart.

2.3.1. Analysis of Land Use Change

The land use transfer matrix can concretely reflect the characteristics of the land use structure. It reflects the transition relationship between a certain land type within a certain time interval, and calculates the transition process of land state from moment t to moment $t + 1$ using Equation (1) [39,40]; the direction and distance of the land center of gravity shift can reflect the natural economic conditions as well as the quality of land in the region [41,42], and the coordinate change of the land use type center of gravity can be calculated using Equation (2) as follows:

$$S_{ab} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix} \quad (1)$$

In the equation, S_{ab} represents the land use status at the beginning and end of the study, and n represents the number of land use types.

$$X_a = \frac{\sum_{i=1}^n (C_{ai} \times X_i)}{\sum_{i=1}^n C_{ai}} \quad Y_a = \frac{\sum_{i=1}^n (C_{ai} \times Y_i)}{\sum_{i=1}^n C_{ai}} \quad (2)$$

In the equation, X_a and Y_a represent the latitude and longitude coordinates of the center of gravity of a land type in year a , C_{ai} represents the area of the i patch in a land type in year a , and X_i and Y_i represent the latitude and longitude coordinates of the center of gravity of the i patch in a land type.

2.3.2. Ecosystem Service Value at the Grid Scale

The grid scale can quantify the spatial heterogeneity of the land use types in the study area and express their information adequately, which is an effective evaluation unit for quantifying the spatial and temporal evolution of the land use [43]. In this study, 1 km × 1 km, 3 km × 3 km, 5 km × 5 km, 10 km × 10 km, 15 km × 15 km and 20 km × 20 km grids were constructed as pre-selected evaluation units based on previous research results. Considering the scale and shape characteristics of the study area, in order to make the grid cells not only have certain regional characteristics, but also contain sufficient research information, and at the same time, be able to reflect the spatial variation of ESVs in the study area more freshly, we referred to a large amount of the literature relevant to our study and compared the spatial variation effect of different grid calculation results, and finally chose 3 km × 3 km as the base measurement cell (Figure 3). The calculation of ESVs referred to the equivalence factor table modified by Xie Gaodi according to the actual situation in China; in addition, considering the differences in grain prices in different regions, the average grain price of farmland in the Guangdong Province was chosen as the average grain price in this study, while the ESV coefficients for construction land referred to the coefficients proposed in the table for the value of each ecosystem service per unit area of the different types of terrestrial ecosystems in China to make corrections [44,45]. In terms of the value per unit area, ESVs at the grid scale were corrected using the coefficient proposed by Xie Gaodi (1.40 for Guangdong Province) and using the vegetation cover [46], resulting in ESVs per unit area in the GBA (Table 1), with the following revised equation:

$$\begin{aligned} FV &= \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \\ F_a &= f_{ai} / f \\ E &= E_a \times F_a \end{aligned} \quad (3)$$

In the equation, FV is the vegetation index, $NDVI$ is the standard value of vegetation cover, f_a denotes the sum of the FV values of the a th grid cell, f is the mean value of FV ,

E_a and E refer to ESVs before and after the revision and F_a denotes the vegetation cover revision factor of the a th grid cell.

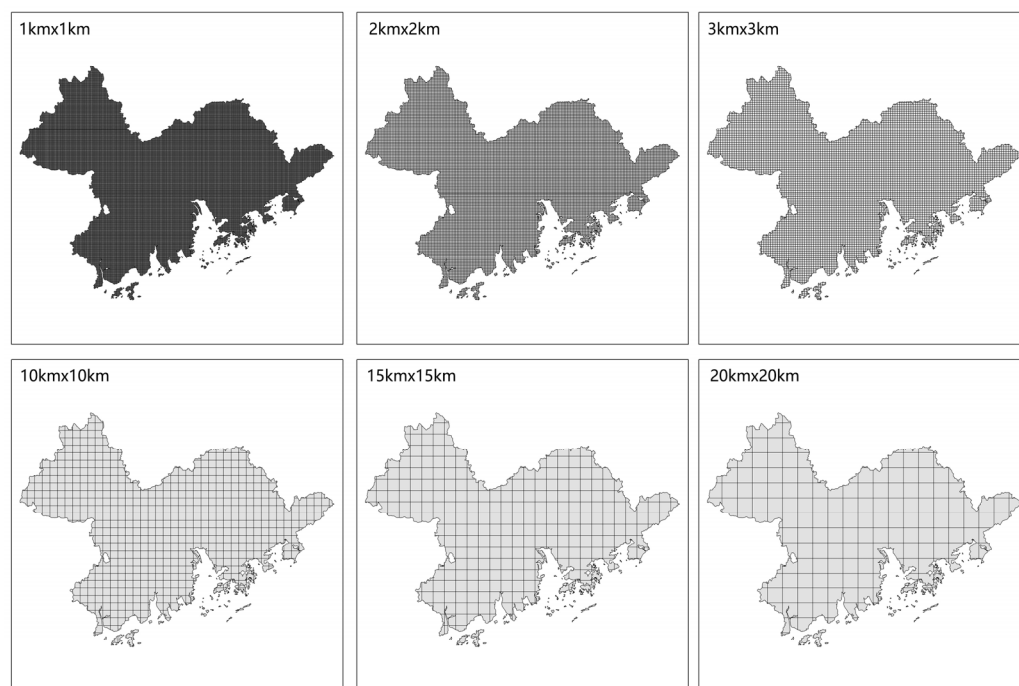


Figure 3. Schematic diagram of grid scale in the research area.

Table 1. Ecosystem service values (1×10^8 CNY) per unit area in the Guangdong–Hong Kong–Macao Greater Bay Area.

Ecosystem Services	Arable Land	Woodland	Grassland	Water	Unused Land	Construction Land
Food production	1833.63	605.10	788.46	971.82	36.67	-
Raw material production	715.12	5464.22	660.11	641.77	73.35	-
Atmospheric regulation	1320.21	7921.28	2750.44	935.15	110.02	-
Climate regulation	1778.62	7462.87	2860.46	3777.28	238.37	-
Hydrological regulation	1411.90	7499.55	2805.45	34,417.24	128.35	−6678.00
Waste disposal	2548.75	3153.84	2420.39	27,229.41	476.74	−2174.10
Soil maintenance	2695.44	7371.19	4107.33	751.79	311.72	3480.00
Biodiversity maintenance	1870.30	8269.67	3428.89	6289.35	733.45	-
Recreation	311.72	3813.95	1595.26	8141.32	440.07	-
Total	14,485.68	51,561.68	21,416.80	83,155.12	2548.75	−5372.10

2.3.3. Markov Model

Markov chain represents the sequential state of the development process of things, which is discrete in time and state, and the development process of things is only linked to adjacent things. Markov model can be used on this basis to predict the future state of things in the same time interval according to the development process and state of things [47–49]. In this study, the Markov model is used to predict and analyze the change in land use types in the GBA in 2030 and estimate the ESVs in the study area based on the prediction results. The relevant calculation equation is as follows:

$$S(a+1) = P_{ij} \times S(a) \quad (4)$$

In the equation, $S(a)$, $S(a+1)$ represent the states of the ground class at moments a , $a+1$; P_{ij} represents the state transfer matrix.

2.3.4. Geographically Weighted Regression Model

Geographically weighted regression model (GWR) is a local regression model that assists the original spatial data in determining the coordinate location parameters [50], which is based on the principle of independent linear regression calculations at all point locations, thereby allowing for the expression of data characteristics of spatial data at different locations, perfectly compensating for the shortcomings of the global regression model, while reflecting the magnitude of the weights of local areas in the data [51,52]. In this study, the relationship between topography and slope data and ESVs is analyzed comprehensively by constructing a GWR model, in which topography and slope data are used as independent variables, and the ESVs are used as dependent variables, from which the corresponding explanatory variable coefficients (predicted) and local R^2 data can be calculated. The Y value represents the predicted estimate of the dependent variable, and the closer the Y value is to the ESVs, the better the fit between the two; the local R^2 means the fit of the local regression model to the Y value, with larger values indicating a higher model accuracy [53]. The relevant calculation equation is as follows:

$$Y_i = \beta_0(\mu_a, \nu_a) + \sum_{a=1}^k \beta_k(\mu_a, \nu_a) X_{ak} + \varepsilon_a \quad (5)$$

In the equation, (μ_a, ν_a) represents the spatial coordinate point a ; Y_a and K_{ak} are the dependent variable Y and the set of sub variables X_k of the measured values of the spatial position; k is the number of independent variables; $\beta_0(\mu_a, \nu_a)$ is the spatial position of the constant term (μ_a, ν_a) ; $\beta_k(\mu_a, \nu_a)$ is the value of the continuous function $\beta_k(\mu_a, \nu_a)$ at point a and ε_a represents the random error term.

3. Results

3.1. Analysis of Spatial and Temporal Land Use Change Characteristics

3.1.1. Land Use Transfer Matrix

From the land use transfer matrix of the study area (Table 2), the urban boundaries within the GBA expanded continuously from 2000 to 2010, encroaching on the surrounding arable land, woodland and water. The areas of arable land, water and woodland transferred out of the GBA during the 10-year period were 2636 km², 1098 km² and 992 km², respectively, while the largest amount of construction land was transferred in, accounting for 43% of the original area, which is mainly due to the fact that the urban master plan expanded the use of reserve land resources such as mudflats and coastal zones, while the construction of infrastructure also accelerated the change in the construction land. From 2010 to 2020, arable land, waters and woodland remained the largest land types transferred out, with areas of 3459 km², 2141 km² and 1937 km², respectively, while construction land was transferred in at 4205 km². In general, the area of arable land in the GBA fluctuated due to the national policy of returning farmland to forests and the continuous reduction in the primary industry over the past 20 years; the area of woodland changed less, while the area of land transferred for construction reached 51% of the original area over the past 20 years, which shows that the rapid development of the GBA has put the ecological land under pressure (Figure 4).

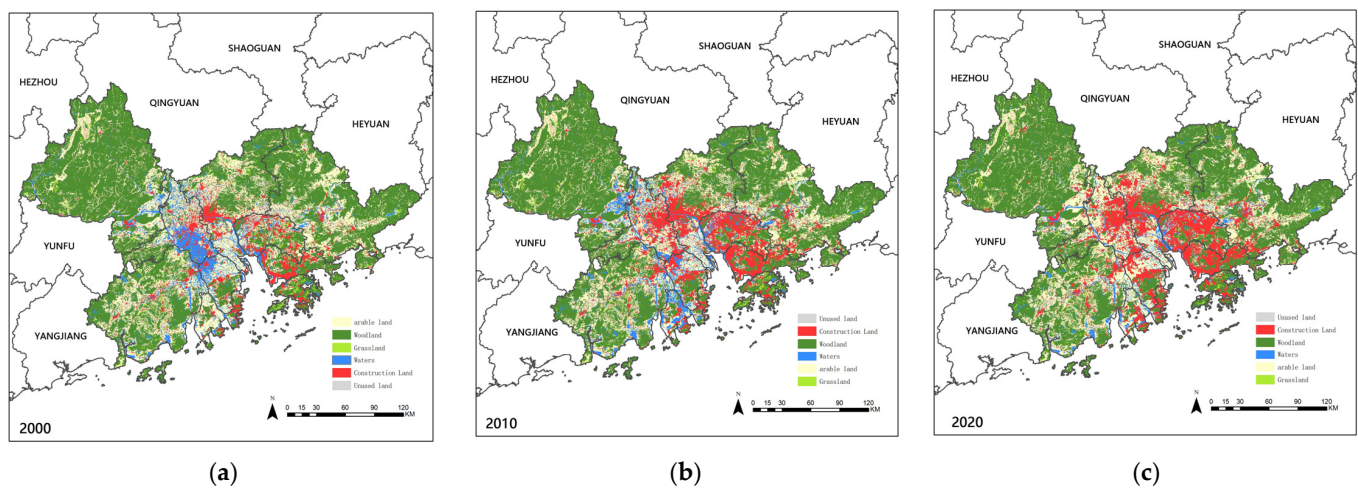


Figure 4. Schematic diagram of grid scale in the research area.

Table 2. Land Use Transfer Matrix for the Greater Bay Area of Guangdong, Hong Kong and Macau (km²).

2000	2010					
	Arable Land	Woodland	Grassland	Water	Construction Land	Unused Land
Arable land	11,794.79	200.47	6.57	640.16	1788.17	0.14
Woodland	146.54	29,617.05	23.74	65.25	755.93	0.39
Grassland	10.14	76.23	1063.23	11.52	64.40	0.03
Water	542.56	39.28	4.26	3152.38	511.80	0.03
Construction land	130.03	92.71	3.79	71.54	4135.00	0.05
Unused land	2.10	0.91	0.02	3.23	6.61	10.63

2010	2020					
	Arable Land	Woodland	Grassland	Water	Construction Land	Unused Land
Arable land	10,971.15	760.73	36.61	244.38	2407.70	9.73
Woodland	617.77	28,671.65	221.40	115.43	973.95	8.69
Grassland	42.13	270.49	820.73	11.59	79.91	0.71
Water	1169.43	144.25	11.69	2108.89	736.71	79.34
Construction land	232.96	122.17	5.63	34.43	4026.30	11.63
Unused land	3.44	1.85	0.14	0.18	6.74	11.17

3.1.2. Shift in Land Use Focus

From 2000 to 2020, the center of gravity of the grassland, unused land and water areas in the GBA shifted significantly. The main reason for this is the expansion of the urban land area and the excessive artificial reclamation, which led to the occupation of ecological land such as ponds, dike-ponds and lakes; the center of gravity of the grassland moved 22,897 m to the northwest, and the center of gravity of the urban construction land moved 3602 m to the north and then 936 m to the southeast. The results of the analysis show the impact of the reorientation of urban development in different periods on various types of land, and that the shift in the center of gravity of the land use indicates a change in the structure of the land use in the region, as the environmental carrying capacity and self-regulating ability of the GBA are affected, resulting in a change in the ESVs (Table 3).

Table 3. Land use focus shift in the Guangdong, Hong Kong and Macao Greater Bay Area (m).

Type of Land Use	2000–2010		2010–2020	
	Transfer Distance	Transfer Direction	Transfer Distance	Transfer Direction
Arable land	3733	Northwest	3625	West
Woodland	1171	Northwest	591	Southeast
Grassland	2935	Northwest	19,962	Northwest
Water	3448	South	4276	Southeast
Construction land	3602	North	936	Southeast
Unused land	11,086	East	24,404	Southwest

3.2. Analysis of the Spatial and Temporal Evolution of Ecosystem Service Values

3.2.1. Time Series Changes in Ecosystem Service Values

In terms of the changes in the total ESVs, there is an overall decreasing trend from 2000 to 2020; in terms of the magnitude of change, there is a greater change in the waters, woodlands and croplands, thus indicating a continuous decline in the environmental quality of the region (Table 4).

In terms of the change in the ESVs of the different land types, hydrological regulation, biodiversity and soil conservation have the highest contribution ratings, with all three contributing more than 44.8%, while the least contribution is made by recreation and food production, which account for less than 10%. Specifically, soil conservation, food production and biodiversity maintenance are the main service functions of arable land; the main service function of woodland is biodiversity; the main service function of grassland is soil conservation, but the overall contribution of grassland is low due to its small footprint and the main service function of the watershed area is hydrological regulation and waste disposal. It is worth mentioning that the ESVs of the watershed area declined significantly by 139.37×10^8 CNY from 2010 to 2020, which is mainly due to the destruction of watershed habitats as a result of the dike-pond reclamation project and urban expansion, with the watershed area decreasing year by year. Overall, the ESVs in the study area show a decreasing trend due to the expansion of urban construction sites and the increasing negative impacts of human disturbances such as industrial waste emissions, domestic waste and vehicle exhaust (Figure 5).

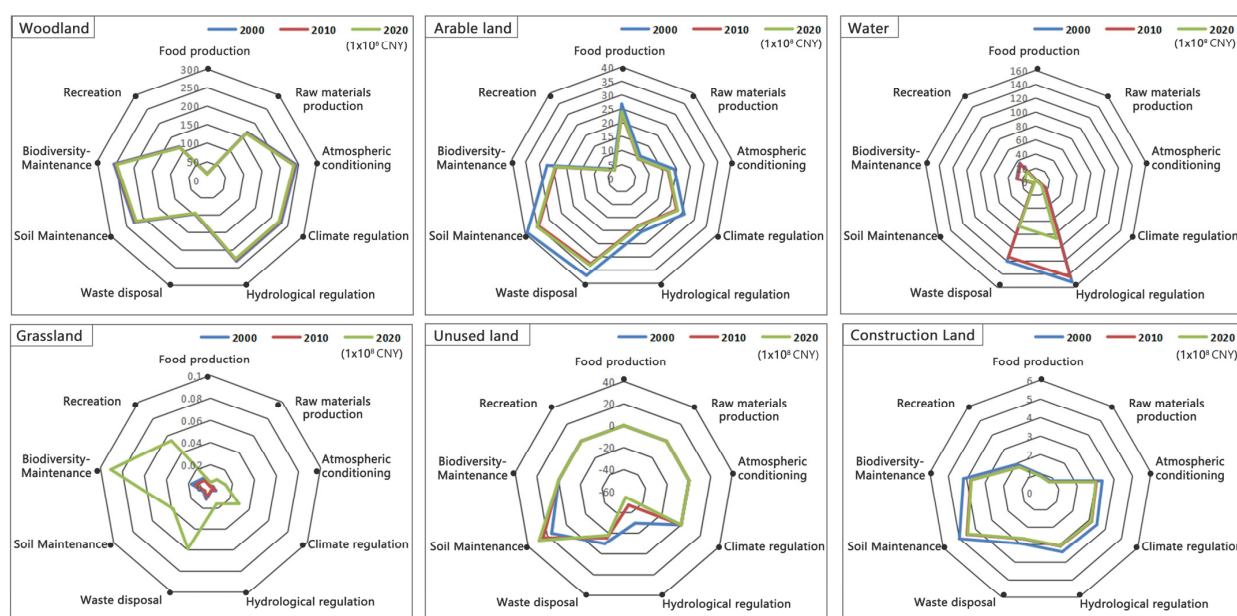
**Figure 5.** Land use interpretation map of Guangdong, Hong Kong and Macao Greater Bay Area in 2000 (a), 2010 (b) and 2020 (c).

Table 4. Changes of ecosystem service values (1×10^8 CNY) in the Guangdong–Hong Kong–Macao Greater Bay Area.

Ecosystem Service Functions	2000			2010			2020			
	ESV	Contribution Rate (%)	Class	ESV	Contribution Rate (%)	Class	ESV	Contribution Rate (%)	Class	
Supply Services	Food production Raw material production	50.55 182.23	2.33 8.41	9 7	46.69 177.95	2.25 8.56	9 7	45.29 175.06	2.36 9.12	9 7
Reconciliation Services	Atmospheric regulation	270.50	12.48	5	263.59	12.68	5	259.44	13.52	4
	Climate regulation	275.75	12.72	4	267.60	12.87	4	258.97	13.50	5
	Hydrological regulation	377.05	17.40	1	344.90	16.59	1	277.16	14.44	3
Support Services	Waste disposal	247.68	11.43	6	229.28	11.03	6	180.65	9.41	6
	Soil maintenance	289.92	13.38	3	289.89	13.94	3	290.58	15.14	2
	Biodiversity maintenance	313.71	14.48	2	304.34	14.64	2	291.28	15.18	1
Cultural Services	Recreation	159.83	7.37	8	155.27	7.47	8	140.34	7.31	8
Total		2167.22	100	-	2079.50	100	-	1918.76	100	-

3.2.2. Spatial Changes in Ecosystem Service Values

The results of ESVs in the GBA are classified into the following five standard classes: very low ($ESV < 15 \times 10^6$ CNY/hm²), low (ESV of 15×10^6 – 30×10^6 CNY/hm²), medium (ESV of 30×10^6 – 45×10^6 CNY/hm²), high (ESV of 40×10^6 – 60×10^6 CNY/hm²) and very high ($ESV > 60 \times 10^6$ CNY/hm²). In terms of the spatial distribution of the regional ESV class (Figure 6), the areas with a very high ESV class in the GBA are mainly located in the northeastern part of Zhaoqing, the northeastern part of Huizhou and the western and southern part of Jiangmen, which is mainly due to the rich woodland resources and good ecological substrate in the area. The very low ESV classes are found in the central part of the region, which is mainly due to the concentration of urban agglomerations in the region and the high level of disturbance from human activities, which accelerated changes in vegetation, climate and other related factors and led to a continuous decrease in the quality of water areas and water resources, with a large number of ponds and other water areas being encroached upon, as well as the negative impact of urban sewage on rivers and marine ecosystems, ultimately leading to a continuous decrease in the quality of habitats in the central urban agglomerations. Specifically, from 2000 to 2010, the area of low ESVs in the GBA expanded significantly. By 2020, low ESV areas became the dominant class type, accounting for 27.24% of the area, and still show an increasing trend, indicating that the ESVs in the GBA have been decreasing over the past 20 years. From the grid cells, the ESV cells in the GBA are mainly medium and low grade, and the high ESV area shows a small increase between 2000 and 2020, from 1534 cells to 1740 cells, which is mainly due to the related cities in the northwest of the GBA to increase the protection and restoration of forest land, slowing down the trend of reducing the forest land area. Among them, the proportion of high-grade cells in the Hong Kong and Macao special administrative regions is 3%, and it shows a small increase over 20 years, which is mainly due to the fact that the forest area in the Hong Kong and Macao special administrative region has increased by about 85 km² in 20 years, which contributed to the rebound of ESVs to a certain extent (Table 5).

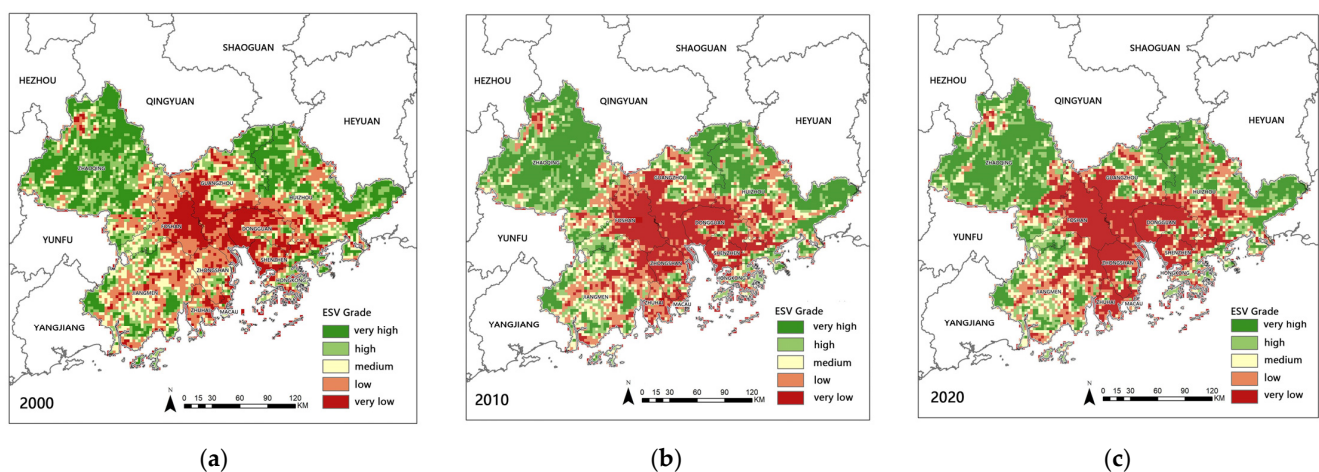


Figure 6. Individual ecosystem service values in the Guangdong–Hong Kong–Macao Greater Bay Area.

Table 5. Area statistics for different classes of ecosystem service values (number of cells).

Year	Very Low	Low	Medium	High	Very High
2000	1092	1577	1091	1157	1534
2010	1543	1159	933	1055	1761
2020	1757	992	916	1046	1740

In terms of the spatial changes in the ESV class, the overall ESV rank in the GBA remained stable from 2000 to 2010, with 34% of the regional ranks increasing, and 29% of

them decreasing, mainly because the economic growth in the GBA was still slow at the beginning of the 21st century, with less disturbance to the ecological environment and land. Among them, the nine cities in the Pearl River Delta have a high proportion of areas with no significant changes and small increases in the ES levels, while the Hong Kong and Macao special administrative regions have an increasing trend in the ES function levels, mainly because the ecological restoration of Mai Po Nature Reserve in Hong Kong was effective, and the restored mangrove and mudflat ecosystems can provide a better ecological benefit. During 2010–2020, the overall ES level of the GBA declined significantly, among which the ES level of nine cities in the Pearl River Delta declined significantly, which is mainly due to the continuous adjustment in urban construction and industrial structure, and the accelerated growth rate of economic development in Zhaoqing, Huizhou, Zhongshan and other cities. A total of 33% of the regional ESV levels in the Hong Kong and Macau special administrative regions showed a declining trend, among which the level in the coastal areas declined significantly, which is mainly due to the prosperity of land reclamation projects in coastal areas, the decline of the retention rate of the natural shoreline, and the large changes in the regional ecological environment quality and ecological pattern (Table 6). Overall, 38% of the regional ESV class in the GBA did not change significantly over the 20-year period, the proportion of decreasing regional cells was 35%, the proportion of increasing regional cells was 27% and the number of decreasing regional cells continuously increased, indicating that the regional habitat quality is deteriorating (Figure 7).

Table 6. Area statistics on changes in ecosystem service value class (number of cells).

Year	ESV Reduction Zone ($< -2.4 \times 10^6$ CNY/hm ²)	ESV No Significant Change Zone (-2.4 – 2.4×10^6 CNY/hm ²)	ESV Increase Zone ($> 2.4 \times 10^6$ CNY/hm ²)
2000–2010	1875	2387	2189
Proportion	29	37	34
2010–2020	2098	3373	980
Proportion	33	52	15
2000–2020	2286	2436	1729
Proportion	35	38	27

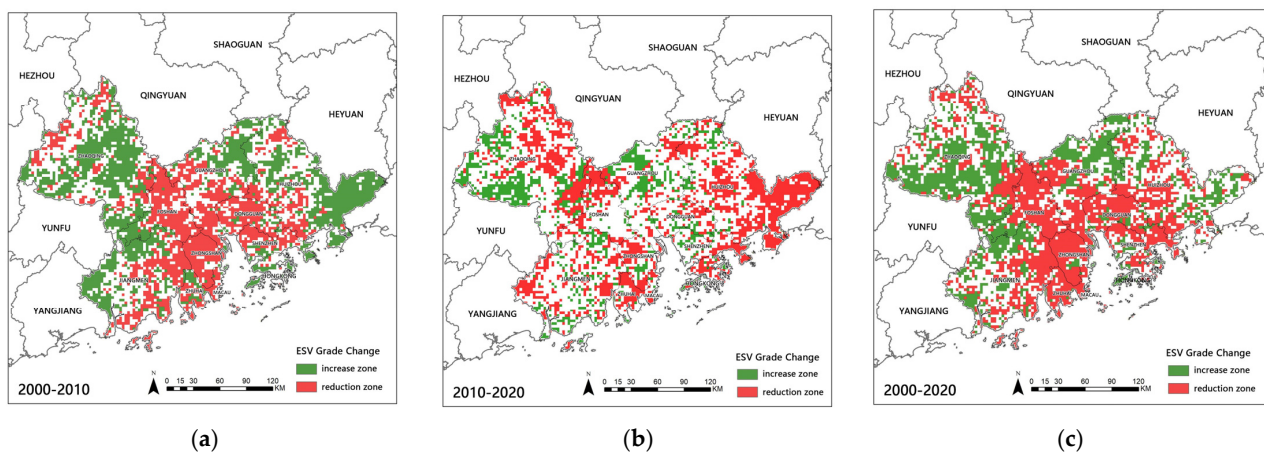


Figure 7. Ecosystem service values class for the Guangdong–Hong Kong–Macao Greater Bay Area in 2000 (a), 2010 (b) and 2020 (c).

In terms of the regional spatial correlation, the ESVs in the GBA show significant spatial aggregation, with “high-high” and “low-low” indicating the proximity of high-value and low-value areas of ESVs. The global Moran index of the study area shows an increasing trend from 2000 to 2020, indicating the increasing aggregation of ESVs in the GBA. Specifically, from 2000 to 2010, the “high-high” area continued to expand southward, which is mainly due to the obvious transfer of woodland to the south of the

GBA, the high vegetation cover of wetlands and river corridors, the better maintained landscape pattern and the more stable ecological land function structure. The “low-low” region is shifting from scattered distribution to patchy development, such as in Foshan, Zhongshan, Jiangmen and other cities, mainly because the concentrated development of construction land increased the intensity of land use and increased pressure on the ecological environment within the city. The Hong Kong and Macao special administrative regions also belong to the “low-low” region, mainly because of the limited space for urban development in the region, so a large number of land reclamation projects were carried out, encroaching on natural ecological land such as coastal shorelines and water areas, and the increase in the proportion of human-made land surface reduced the ESVs. From 2010 to 2020, the “high-high” zone continued to develop to the south, and the “low-low” zone is dominated by areas of concentrated urban agglomerations, which generate low ESVs due to a low intra-urban landscape diversity (Figure 8).

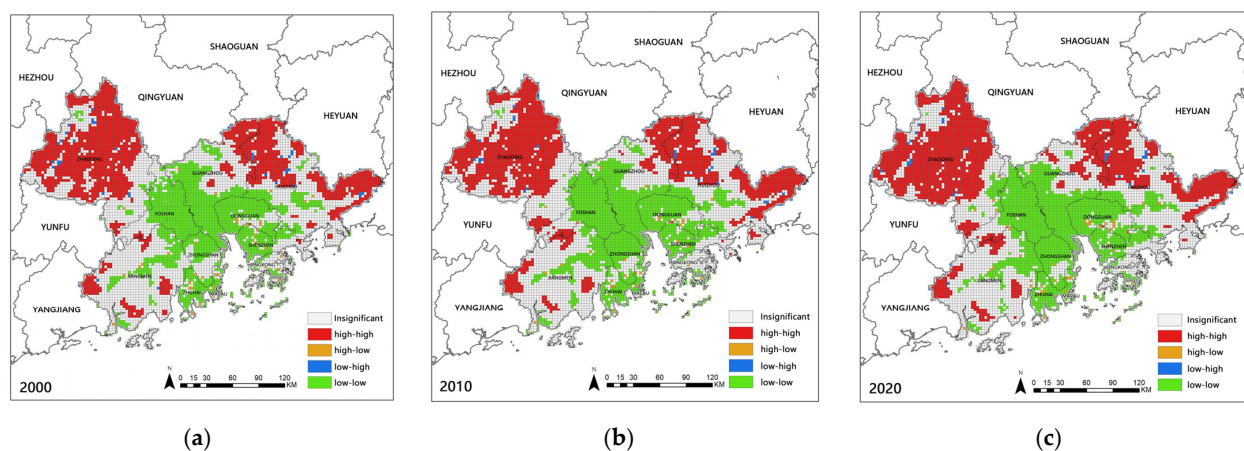


Figure 8. Areas of change in ecosystem service values class in 2000 (a), 2010 (b) and 2020 (c).

3.2.3. Forecasting the Ecosystem Service Values

By running the Markov model under the natural development scenario, the predicted ESV in 2030 reaches 1853.921×10^8 CNY, a decrease of 64.839×10^8 CNY compared to 2020, which is mainly due to the decreasing areas of watershed, woodland and grassland from 2000 to 2020, while the area of arable land shows stability in the context of policy protection. According to this pattern of development, the areas of watershed, woodland and grassland will keep decreasing in the future, resulting in a decreasing ESV in the forecast year 2030. At the same time, it can be observed that the future decline of water resources will remain a serious problem, and therefore, scientific and rational planning are needed to reduce damage to water resources and the near-coastal environment (Table 7).

Table 7. Projections of ecosystem service values (1×10^8 CNY) in the Guangdong–Hong Kong–Macao Greater Bay Area in 2030.

Ecosystem Service Types	Ecosystem Services	Arable Land	Woodland	Grassland	Water	Unused Land	Construction Land	Total
Supply Services	Food production	23.930	18.121	0.861	1.697	0.006	0.000	44.616
	Raw material production	9.333	163.641	0.721	1.121	0.012	0.000	174.828
Reconciliation Services	Atmospheric regulation	17.230	237.224	3.005	1.633	0.018	0.000	259.110
	Climate regulation	23.212	223.496	3.125	6.598	0.039	0.000	256.470
	Hydrological regulation	18.426	224.594	3.065	60.115	0.021	−60.090	246.131
Support Services	Waste disposal	33.263	94.450	2.644	47.560	0.078	−19.563	158.433
	Soil maintenance	35.177	220.750	4.487	1.313	0.051	31.314	293.093
	Biodiversity maintenance	24.409	247.658	3.746	10.985	0.121	0.000	286.918
Cultural Services	Recreation	4.068	114.219	1.743	14.220	0.072	0.000	134.322
Total		189.048	1544.154	23.395	145.244	0.419	−48.339	1853.921

3.3. Analysis of the Topographic Factor-Driven Effects of Ecosystem Service Value

The elevation and slope were selected as the topographic characterization factors of the study area with reference to the relevant literature. The results of the geographically weighted regression model (GWR) show that $R^2 > 0.8$ and local $R^2 > 0.8$, indicating that the model operation results meet the accuracy requirements. The results show that the local R^2 of the data from 2000 to 2020 changed significantly, showing a decreasing trend and then an increasing trend, indicating that the influence of topographic factors on ESVs generally show an increasing trend. The regression parameters of the topographic factors (Table 8) show that the local R^2 values are above 0.85 in all years, indicating a significant correlation between the topographic factors and the ESVs.

Table 8. Topographic Factor Regression Parameter Table for Guangdong, Hong Kong and Macau Greater Bay Area.

Year	2000	2010	2020
Local R^2	0–0.8541	0–0.8532	0–0.8584
R^2	0.8022	0.8267	0.8317
Adjusted R^2	0.7883	0.8146	0.8200
AICC	256,353.8	256,973.8	256,797.1

In terms of spatial distribution, the strongest influence of topography on ESV is found in the northwestern and northeastern parts of the GBA, where the correlation with the land use data shows that woodland, arable land and water are the main land types, while the influence of the land–water interface in the south is also evident. Elevation and slope have a direct influence on plant growth, which determines the vegetation cover of the area and, thus, has a further influence on the ESVs provided (Figure 9).

From the perspective of construction land, apart from parks and green belts within the city, most areas have poor green infrastructure, and grey infrastructure, human housing and other construction land directly change the ecological landscape pattern of the land, which shows that human factors have a very strong influence on the ESVs. From 2000 to 2020, the trend of the overall pattern of the GBA clusters into patches, which shows that the influence of topographic factors on ESVs is gradually increasing.

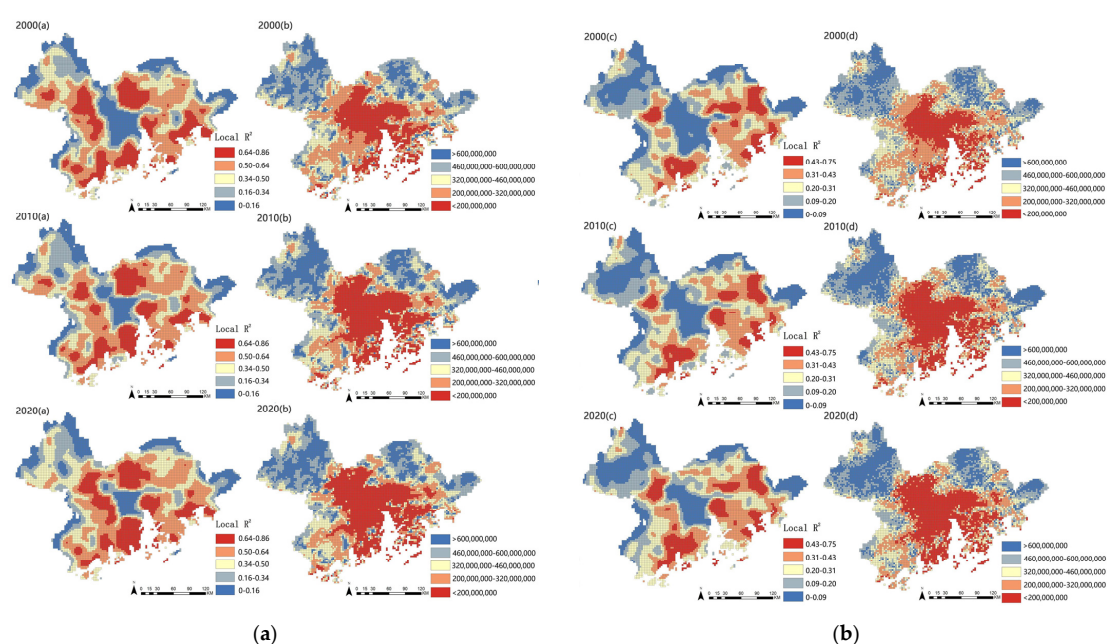


Figure 9. Local spatial autocorrelation of ecosystem service values in the Guangdong–Hong Kong–Macao Greater Bay Area in 2000 (a), 2010 (b) and 2020 (c).

4. Discussion and Conclusions

4.1. Discussion

4.1.1. Land Use Change Significantly Affects Ecosystem Service Values

Land is fundamental; the state and structure of the ecosystem are dependent on the land use approach, and the excessive repurposing of ecological land areas will cause the center of gravity of the land to continuously migrate, changing the landscape pattern of the region to a large extent, while affecting the supply of ESs. To achieve the sustainable development of the regional ecosystem, we must first pay attention to the adjustment of the land use structure; the regulation capacity and carrying capacity of the natural environment need reasonable planning of land use [54]. For example, in the areas around construction sites, the construction of nature reserves, the ecological restoration of rivers and lakes and the management of land reclamation projects can be strengthened to safeguard biodiversity, soil conservation and other ecological functions so as to safeguard the carrying capacity and self-regulating ability of the natural environment as a whole and enhance ESVs [55,56].

4.1.2. Spatial and Temporal Variation in Ecosystem Service Values and Strategies for Optimization

The spatial and temporal variations in ESVs in the GBA were significant from 2000 to 2020. Overall, in terms of the spatial distribution, the high-value areas are concentrated in the northwest, northeast and southwest regions where ecological land is widely distributed, while the low-value areas are mainly concentrated in the urban contiguous development areas and some coastal areas in the central part of the GBA, and the area of the low-value areas is still increasing. Specifically, in order to slow down the rate of diminishing ESVs, we should take the initiative to find entry points and explore optimization strategies in terms of human social life [57–59]. In terms of water resources, while the deep treatment and re-circulation of domestic fecal water and industrial wastewater should be carried out to achieve less or no discharge and improve the utilization rate of water resources, the rational use of water resources should be strengthened, water supply and drainage systems should be improved, land use planning should be carried out scientifically and reasonably and damage to water resources and the near-shore environment should be reduced [60,61]. In terms of energy use, the characteristics of each city in the GBA should be addressed, the upgrading of equipment for renewable and clean energy and the development of new energy sources should be enhanced to provide a reasonable and effective supplement [62]. In terms of solid waste treatment, while improving the harmless treatment of waste, the whole process of management and control should be implemented from all aspects of waste generation, collection, transportation, reuse and treatment to avoid causing adverse effects on the ecological environment and achieve control of waste generation.

4.1.3. Topographic Factors and Ecosystem Service Values

Topography has a direct impact on the growth state and diversity of plants, while the type, growth and distribution of plants have a critical impact on key regional ESs, such as soil and water conservation and water harvesting functions. The above analysis shows that there is a significant correlation between topographic factors and ESVs in the GBA, with an increase from 2000 to 2020. In the northwestern and northeastern parts of the region, the influence of topography on ES is particularly significant in areas such as woodland, arable land and the land–water interface, so that the protection and optimization of these areas is conducive to the sustainable development of the region, to the optimization of ESVs and to the construction of ecological security patterns across the region [63].

4.1.4. Sustainability in the Guangdong–Hong Kong–Macao Greater Bay Area

The results of the valuation of ESs in the GBA show that the region is currently facing significant ecological degradation and intensified resource and environmental constraints. At the same time, due to the GBA being located in the subtropical monsoon climate zone, its special geographical location and climatic conditions expose it to ecological risks such

as flooding, storm surges and sea level rise, which pose challenges to regional ecological restoration and the construction of ecological security patterns. In the face of the continuous decline of ecological and environmental quality in the GBA, it is necessary to gradually promote the formation of green and low-carbon production and lifestyle and urban construction and operation mode to realize the sustainable development of the GBA. Therefore, the future development planning of the GBA should pay attention to the delineation of ecological protection zones and the control of urban expansion boundaries, and resist ecological risks such as storm surges and sea level rise by building a resilient multi-objective, cross-habitat and land–sea integrated regional ecological security pattern, while promoting the ecological restoration of coastal wetlands and coastal zone maintenance to construct a coastal security barrier in the GBA to achieve sustainable development [41].

4.2. Conclusions

Based on the land use changes in the GBA from 2000 to 2020, this study measures the ESVs in the GBA at the grid scale, predicts the ESVs in 2030 and analyzes its spatial and temporal evolution characteristics and the influence of topographic factors in ESVs. This will provide scientific guidance for optimizing ESVs.

- (1) Over the past 20 years, in terms of the shift in the land area, the most obvious fluctuations are in the areas of water, arable land and construction land; the northwestern and northeastern areas with high vegetation cover gradually decreased, while the impervious area of the urban agglomerations in the central area is increasing, and the ecological land around the urban agglomerations, such as arable land and wetlands, is decreasing. In terms of the shift in the center of gravity of the land, the center of gravity of all types of land has shifted to different degrees, with the center of gravity of construction land shifting northward, while the center of gravity of grassland and unused land shifted westward, and the center of gravity of forest land has shifted northwestward, with significant contradictions between the survival of ecological land and the expansion of urban construction land.
- (2) From an overall perspective, the ESVs in the GBA from highest to lowest are the following: regulating services > supporting services > provisioning services > cultural services. Hydrological regulation, biodiversity and soil conservation are the three items that contribute the most to the values of individual ESs. In terms of temporal changes, the ESs in the GBA showed a decreasing trend in the overall and individual values over the 20-year period. In terms of the spatial changes in rank, the area with the lowest ESV rank is located in the dense urban area in the central part of the GBA, accounting for 35% of the total area and increasing in size, indicating the deteriorating quality of the habitat; the area with a relatively high ESV rank is located in the city of Zhaoqing, northeastern Huizhou and Jiangmen in the GBA, accounting for 27% of the total area. The Markov model predicts that the ecosystem service value in 2030 shows a decreasing trend under the development of a natural state.
- (3) The spatial distribution of ESVs in the GBA is aggregated, and there is a regional adjacency between the high-value and low-value areas of ESVs. From 2010 to 2020, the “high” area continues to develop to the south, and the scope of the low-value aggregation area is also expanding. The construction land in the low-value area is increasing, and the population and traffic pressure are becoming bigger and bigger, which has a great impact on the urban green space system and reduces the anti-disturbance ability of the inner-city green space ecosystem.
- (4) There is a significant correlation between topographic factors and ESV, where topographic factors have a strong influence on ESVs mainly in the northwestern and northeastern parts of the GBA, and the coupling analysis with the land use data show that the main land types in this area are forest land, arable land and water. At the same time, the influence of the water–land intersection zone in the south is also obvious; the weaker influence is mainly located in the central part of the study area and the border area, and the main land types are construction land, dike-ponds and forest land.

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鳳吟古韻，綠漾原鄉——連州鳳頭古村

落規劃設計

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中國建築文化研究會
Architecture and Culture Society of China



中共广东省委农村工作办公室
广东省住房和城乡建设厅
共青团广东省委
广东省教育厅
广东省精神文明建设委员会办公室
广东省扶贫开发办公室
南方报业传媒集团
广东省志愿者联合会

团粤联发〔2018〕12号

关于“美丽乡村·幸福蓝图”——“碧桂园杯”
南粤村庄（整治）规划设计大赛
获奖作品的通报

为认真贯彻落实省委、省政府关于打赢脱贫攻坚战、推进新

— 1 —

农村建设的战略部署，2017年7月，省委农办、省住房城乡建设厅、团省委、省教育厅、省文明办、省扶贫办、南方报业传媒集团、省志愿者联合会等单位共同实施了“我为美丽乡村绘蓝图”——2017年南粤村庄（整治）规划志愿行动，广泛动员城乡规划设计及相关专业人员，以志愿服务的形式推进省定贫困村村庄（整治）规划编制，集中社会力量助力农村人居环境综合整治。

按照《关于开展“我为美丽乡村绘蓝图”——2017年南粤村庄（整治）规划志愿行动的通知》（团粤联发〔2017〕44号）工作安排，主办方配套举办了“美丽乡村·幸福蓝图”——“碧桂园杯”南粤村庄（整治）规划设计大赛。根据设计大赛有关规定，经评审，共有181个村庄（整治）规划作品符合参评条件，其中惠来县隆江镇孔美村、连州市大路边镇顺泉村和英德市浛光镇鱼咀村3个村庄（整治）规划作品荣获特等奖（每个奖励团队10万元），连州市连州镇巾峰村等6个村庄（整治）规划作品荣获一等奖（每个奖励团队5万元），连州市龙坪镇龙坪村等19个村庄（整治）规划作品荣获二等奖（每个奖励团队4万元），徐闻县南山镇芒海村等26个村庄（整治）规划作品荣获三等奖（每个奖励团队3万元），阳山县杜步镇旱坑村等127个村庄（整治）规划作品荣获优秀奖（每个奖励团队2万元），以上奖金由支持单位提供。

希望获奖单位和志愿服务团队珍惜荣誉，再接再厉，示范带

动城乡规划设计及相关行业专业力量，积极投身我省精准脱贫攻坚和社会主义新农村建设，为助力广东决胜全面建成小康社会贡献青春和力量。

附件：“美丽乡村·幸福蓝图”——“碧桂园杯”南粤村庄
(整治) 规划设计大赛获奖名单



中共广东省委农村工作办公室



广东省住房和城乡建设厅



共青团广东省委员会



广东省教育厅



广东省精神文明建设工作委员会办公室



广东省扶贫开发办公室



南方报业传媒集团



广东省志愿者联合会

2018年3月22日

附件

“美丽乡村·幸福蓝图”——“碧桂园杯” 南粤村庄（整治）规划设计大赛获奖名单

特等奖（3个）

序号	单位（志愿服务团队）	村庄名称
1	华南理工大学	惠来县隆江镇孔美村
2	广东省城乡规划设计研究院	连州市大路边镇顺泉村
3	广东博意建筑设计院有限公司	英德市浚光镇鱼咀村

一等奖（6个）

序号	单位（志愿服务团队）	村庄名称
1	华南农业大学	连州市连州镇巾峰村
2	深圳市城市规划设计研究院有限公司	连州市瑶安瑶族乡田心村
3	华南农业大学	连州市保安镇保安村
4	华南理工大学	惠来县隆江镇凤红村
5	广东省城乡规划设计研究院·广州大学	东源县义合镇下屯村
6	广东海洋大学	雷州市英利镇青桐村

二等奖（19个）

序号	单位（志愿服务团队）	村庄名称
1	广东省建筑设计研究院	连州市龙坪镇龙坪村

序号	单位（志愿服务团队）	村庄名称
2	深圳市蕾奥规划设计咨询股份有限公司	陆丰市河东镇浮洲村
3	广东博意建筑设计院有限公司	连州市大路边镇东大村
4	华南农业大学	连州市大路边镇黄太村
5	韶关学院	始兴县隘子镇风度村
6	华南农业大学	连州市星子镇马水村
7	广东省城乡规划设计研究院	连州市星子镇周联村
8	华南农业大学	连州市星子镇沈家村
9	深圳市新城市规划建筑设计股份有限公司	惠来县华湖镇溪洋村
10	暨南大学	清远市清新区浸潭镇塘坑村
11	华南农业大学	连州市保安镇湾村村
12	广州大学	东源县船塘镇黄沙村
13	肇庆学院	云浮市云城区前锋镇矮岭村
14	深圳市城市规划设计研究院有限公司	连州市瑶安瑶族乡大营村
15	华南农业大学	连州市星子镇姜联村
16	广州大学	东源县上莞镇新民村
17	华南理工大学	惠来县隆江镇风光村
18	肇庆学院	云浮市云城区河口街道红阳村
19	中山大学	连州市西岸镇东江村

三等奖（26 个）

序号	单位（志愿服务团队）	村庄名称
1	湛江市海建城乡规划设计院有限公司	徐闻县南山镇芒海村
2	广东顺建规划设计研究院有限公司	连州市保安镇新塘村
3	广州大学	紫金县苏区镇永坑村

序号	单位（志愿服务团队）	村庄名称
4	仲恺农业工程学院	阳山县杨梅镇杨梅村
5	华南农业大学	韶关市浈江区犁市镇大村村
6	广东财经大学	和平县优胜镇新联村
7	顺德职业技术学院	雷州市纪家镇上郎村
8	佛山科学技术学院	连州市西江镇大田村
9	华南师范大学	东源县柳城镇柳城村
10	广东省建筑设计研究院	惠来县仙庵镇华园村
11	深圳市新城市规划建筑设计股份有限公司	陆丰市河东镇大屯村
12	广东博意建筑设计院有限公司	阳山县杜步镇杜步村
13	中山大学	连州市保安镇黄村村
14	中山大学	连州市丰阳镇柯木湾村
15	广东工业大学	陆丰市南塘镇南湖村
16	雅克设计有限公司深圳分公司	惠来县葵潭镇门口葛村
17	华南农业大学	连州市连州镇龙咀村
18	韶关学院	始兴县太平镇乌石村
19	顺德职业技术学院	连州市保安镇万家村
20	广东省城乡规划设计研究院	连州市大路边镇大坳村
21	华南师范大学	东源县灯塔镇柯木村
22	广东省建科建筑设计院有限公司	揭西县钱坑镇钱北村
23	雅克设计有限公司深圳分公司	惠来县葵潭镇石田村
24	广东省建筑设计研究院	阳山县秤架瑶族乡秤架村
25	肇庆学院	云浮市云城区思劳镇云贡村
26	韶关学院	韶关市浈江区犁市镇下陂村

优秀奖 (127 个)

序号	单位 (志愿服务团队)	村庄名称
1	广东博意建筑设计院有限公司	阳山县杜步镇旱坑村
2	广东中誉设计院有限公司	阳山县青莲镇青莲村
3	广东博意建筑设计院有限公司	连州市龙坪镇袁屋村
4	广东财经大学	和平县古寨镇三联村
5	广东海洋大学	雷州市调风镇企树村
6	广东睿博建筑设计研究有限公司	连州市大路边镇油田村
7	广东中誉设计院有限公司	阳山县青莲镇南塘村
8	广州大学华软软件学院	始兴县沈所镇兴仁村
9	华南理工大学	惠来县隆江镇西塘村
10	华南理工大学	惠来县隆江镇海埕村
11	华南师范大学	揭阳市蓝城区白塔镇红坡村
12	肇庆学院	云浮市云城区高峰街道赤黎村
13	肇庆学院	云浮市云城区安塘街道安塘村
14	中山大学	连州市连州镇沙子岗村
15	中山大学	连州市丰阳镇湖江村
16	河源市岭南城乡规划设计院	龙川县黄石镇长洲村
17	华南师范大学	东源县骆湖镇江坑村
18	华南师范大学	乐昌市坪石镇陈家坪村
19	广州大学	东源县仙塘镇龙利村
20	广州大学华软软件学院	始兴县澄江镇暖田村
21	广州大学华软软件学院	始兴县罗坝镇角田村
22	华南农业大学	连州市星子镇上庄村
23	江门市规划勘察设计院	连州市大路边镇汛塘村

序号	单位（志愿服务团队）	村庄名称
24	清远市城乡规划设计院	阳山县七拱镇新圩村
25	中山大学	连州市三水瑶族乡云雾村
26	佛山科学技术学院	连州市星子镇东红村
27	佛山科学技术学院	连州市瑶安瑶族乡新九村
28	广东工业大学	陆丰市金厢镇下埔村
29	广东省建筑设计研究院	连州市星子镇四方村
30	广州大学	东源县漳溪畲族乡群星村
31	广州大学	东源县仙塘镇东方红村
32	华南师范大学	连州市龙坪镇黄芒村
33	肇庆学院	云浮市云城区腰古镇腰古村
34	中山大学	连州市西岸镇溪塘村
35	广东博意建筑设计院有限公司	连州市星子镇水源村
36	广东工业大学	陆丰市南塘镇乌石村
37	广东工业大学	陆丰市南塘镇溪南村
38	广东海洋大学寸金学院	湛江市南三岛滨海旅游示范区 南三镇巴东村
39	广东省建科建筑设计院有限公司	惠来县靖海镇资深村
40	韶关学院	南雄市湖口镇三角村
41	肇庆学院	云浮市云城区前锋镇前锋村
42	仲恺农业工程学院	连州市大路边镇东联村
43	广东工业大学	陆丰市南塘镇潭头村
44	江门市规划勘察设计院	连州市连州镇龙口村
45	清远市城乡规划设计院	阳山县黎埠镇水井村
46	肇庆学院	云浮市云城区南盛镇枫岭村
47	东莞理工学院城市学院	紫金县好义镇小古村
48	广东工业大学	陆丰市湖东镇竹林村

序号	单位（志愿服务团队）	村庄名称
49	广东省城乡规划设计研究院	连州市大路边镇荒塘村
50	河源市岭南城乡规划设计院	龙川县丰稔镇高坑村
51	华南师范大学	东源县灯塔镇灯塔村
52	暨南大学	南雄市水口镇翦过村
53	珠海市建筑设计院	惠来县葵潭镇土角寮村
54	福建农林大学	惠来县华湖镇池畔村
55	广东博意建筑设计院有限公司	阳山县七拱镇塘坪村
56	广东省城乡规划设计研究院	连州市星子镇昌黎村
57	广东财经大学	和平县上陵镇三乐村
58	广东工业大学	陆丰市湖东镇竹湖村
59	广东工业大学	陆丰市上英镇玄溪村
60	广州大学	东源县义合镇曲滩村
61	广东海洋大学	吴川市黄坡镇平城村
62	广东财经大学	和平县贝墩镇武联村
63	广东顺建规划设计研究院有限公司	连州市保安镇本公洞村
64	华南师范大学	乐昌市廊田镇廊田村
65	惠州学院	东源县黄村镇三洞村
66	中山大学	连州市丰阳镇夏湟村
67	广东白云学院	阳山县小江镇沙寮村
68	广东博意建筑设计院有限公司	阳山县七拱镇隔坑村
69	广东科贸职业学院	韶关市武江区重阳镇万侯村
70	华南师范大学	普宁市大南山街道什石洋村
71	暨南大学	清远市清新区浸潭镇丁坑村
72	韶关学院	乐昌市廊田镇葫芦坪村
73	珠海市建筑设计院	惠来县隆江镇竹湖村

序号	单位（志愿服务团队）	村庄名称
74	广东海洋大学寸金学院	湛江市南三岛滨海旅游示范区 南三镇五里村
75	广东省城乡规划设计研究院	连州市星子镇赤塘村
76	华南师范大学	乐昌市廊田镇马屋村
77	韶关学院	始兴县隘子镇满堂村
78	广东博意建筑设计院有限公司	英德市黎溪镇恒昌村
79	广东工业大学	陆丰市金厢镇十二岗村
80	广州大学	东源县新港镇青溪村
81	华南师范大学	乐昌市廊田镇白平村
82	广东工业大学	陆丰市城东街道高美村
83	广东中誉设计院有限公司	阳山县青莲镇江佐村
84	暨南大学	清远市清新区浸潭镇根竹村
85	韶关学院	始兴县太平镇水南村
86	佛山科学技术学院	连州市保安镇麻北村
87	广东博意建筑设计院有限公司	始兴县沈所镇黄所村
88	广东省建科建筑设计院有限公司	阳江市阳东区大八镇走马坪村
89	广东文艺职业学院	连州市龙坪镇石桥村
90	广州大学华软软件学院	始兴县罗坝镇东二村
91	中山大学	连州市西岸镇冲口村
92	珠海市建筑设计院	惠来县隆江镇井美村
93	东莞理工学院城市学院	连州市西江镇斜磅村
94	福建农林大学	惠来县神泉镇前湖村
95	广东工业大学	陆丰市湖东镇樟田村
96	广东海洋大学	湛江市南三岛滨海旅游示范区 南三镇光明村
97	广东省建筑设计研究院	阳山县岭背镇蒲芦洲村

序号	单位（志愿服务团队）	村庄名称
98	暨南大学	阳山县岭背镇水建村
99	韶关学院	始兴县沈所镇花山村
100	深圳市市政设计研究院	惠来县靖海镇驿后村
101	肇庆学院	云浮市云城区南盛镇横岗村
102	广东工业大学	陆丰市湖东镇长溪村
103	广东南华工商职业学院	惠来县靖海镇西锋村
104	中山大学	连州市东陂镇东塘村
105	广东工业大学	陆丰市湖东镇深田湖村
106	暨南大学	阳山县秤架瑶族乡大陂村
107	肇庆学院	云浮市云城区南盛镇料洞村
108	中山大学	连州市西岸镇东村
109	广东财经大学	和平县合水镇中和村
110	韶关学院	始兴县沈所镇沈南村
111	广东博意建筑设计院有限公司	阳山县江英镇英阳村
112	广东工业大学	陆丰市金厢镇望尧村
113	广州城建职业学院	阳山县七拱镇西路村
114	华南理工大学	惠来县隆江镇见龙村
115	华南师范大学	揭阳市蓝城区龙尾镇新丰村
116	广东财经大学	和平县阳明镇梅径村
117	华南师范大学	惠来县靖海镇葛山村
118	广东博意建筑设计院有限公司	阳山县江英镇马坪村
119	广东南华工商职业学院	惠来县隆江镇北洋村
120	广东睿博建筑设计研究有限公司	连州市龙坪镇青石村
121	东莞理工学院城市学院	连州市西江镇铁坑村
122	东莞理工学院城市学院	连州市西江镇西江村

序号	单位（志愿服务团队）	村庄名称
123	广东科贸职业学院	始兴县马市镇联俄村
124	江门市规划勘察设计院	连州市大路边镇新水罗村
125	广州大学华软软件学院	始兴县澄江镇澄江村
126	中山大学	连州市西岸镇三水村
127	广东工程职业技术学院	雷州市乌石镇那毛村

序号	单位名称	联系人	联系电话
1	广州市团委	李俊	13922222222
2	广州市青年联合会	李俊	13922222222
3	广州市青年商会	李俊	13922222222
4	广州市青年企业家协会	李俊	13922222222
5	广州市青年就业创业促进会	李俊	13922222222
6	广州市青年志愿服务中心	李俊	13922222222
7	广州市青年宫	李俊	13922222222
8	广州市青年宫	李俊	13922222222
9	广州市青年宫	李俊	13922222222
10	广州市青年宫	李俊	13922222222

共青团广东省委员会办公室

2018年3月22日印发

(共印 320 份)

证 明

2017年7月，团省委、省委农办、省住房城乡建设厅、省教育厅、省文明办、省扶贫办、南方报业传媒集团、省志愿者联合会共同开展了“我为美丽乡村绘蓝图”——南粤村庄（整治）规划志愿行动，并配套举办了“美丽乡村·幸福蓝图”——“碧桂园杯”南粤村庄（整治）规划设计大赛。我校十支队伍在活动中取得优异成绩，具体获奖名单见附件及活动主办方颁发的荣誉证书。

特此证明。

共青团华南农业大学委员会

2018年6月1日
华南农业大学
委员会



附件:

“美丽乡村·幸福蓝图”——“碧桂园杯”南粤村庄（整治）规划

设计大赛获奖情况公布表

奖项	作品名称	项目负责	学院	参与人员	工号/学号
一等奖	连州市连州镇巾峰村整治创建规划	赵建华 (30002328)、 卢丹梅 (30003921)	林学与风景 园林学院	韦通洋	201430540313
				梁嘉瑶	201430540310
				徐文发	201430540315
				黄泳姿	201518210112
				包秋香	201518210101
				严文俊	201518210126
一等奖	连州市连州镇保安村整治创建规划	卢丹梅 (30003921)、 赵建华 (30002328)	林学与风景 园林学院	陈丹	201430540301
				郭楚怡	201430860163
				刘淑瑜	201430540213
				李易燃	201518210114
				王如珂	201518210122
				黄嘉仪	201518210111
二等奖	连州市大路边镇黄太村整治创建规划	余美萱 (30002605)、 陈思颖 (30004143)	林学与风景 园林学院	林蔚（教师）	30004407
				赵晓铭（教师）	30003313
				练东鑫	201518210115
				莫莉	201518210118
				邓可欣	201518210204
				赖嘉娱	2016307113
				张晓敏	201430540154
				谭杰琪	201518210221
二等奖	连州市星子镇沈家村整治创建规划	陈思颖 (30004143)、 余美萱 (30002605)	林学与风景 园林学院	赵晓铭（教师）	30003313
				林蔚（教师）	30004407
				刘维东	201430540311
				张冰	201430540319
				韦瑶	201430540314
				张金娜	201518210228
				叶梦婷	201518210226
				陈秋菲	201518210106
二等奖	连州市连州镇湾村整治创建规划	卢丹梅 (30003921)、 赵建华 (30002328)	林学与风景 园林学院	卓友庆	20173071041
				谢楠	20173071033
				季莹莹	201430540306
				马燕虹	201430540216
				郭大为	201518210110
				许心怡	201518210125
二等奖	连州市星子镇姜联	王凌	林学与风景	王婷(教师)	30002930

产主
★
南农业
委员会

	村社会主义新农村示范村整治创建规划	(30001130)	园林学院	李家裕	201430540307
				杨燕娟	201430540316
				唐敏婷	201518210222
				陈伟旋	201518210203
				林腾	201430540211
				刘剑翔	201430540212
二等奖	连州市星子镇马水村社会主义新农村示范村整治创建规划	王婷 (30002930)	林学与风景园林学院	王凌(教师)	30001130
				陈小芮	201430540202
				谭超群	201430540218
				黄宇轩	201430540206
				陈雨忱	201430540316
三等奖	韶关市浈江区犁市镇大村村社会主义新农村示范村村整治规划	杨文越 (30004211)	林学与风景园林学院	王衡	201430540219
				赵晓铭(教师)	30003313
				叶昌东(教师)	30003674
				刘冬妮	2016307120
				梁惠兰	20173071015
				甄新瑜	201430540322
三等奖	连州市连州镇龙咀村社会主义新农村示范村整治创建规划	赵建华 (30002328)、 卢丹梅 (30003921)	林学与风景园林学院	莫樱梅	201518210219
				林蔚(教师)	30004407
				冼颖婷	201518210124
				陈小洁	201518210107
				蔡雅颖	201518210103
				蔡晓丽	201518210102
优秀奖	连州市星子镇上庄村整治创建规划	陈思颖 (30004143)、 余美萱 (30002605)	林学与风景园林学院	张童浩	201430540320
				吴宝娜(教师)	30002931
				黄建林	201518210208
				温炜彤	201518210223
				杨善惠	201518210224
				黎诗韵	201518210212
				张晓晴	201518210229
				王鑫	201430540148

荣誉证书

林蔚：

被评为2018-2020年度华南农业大学
优秀班主任。

特发此证，以资鼓励。

华南农业大学
二〇二一年七月

荣誉证书

《连州市保安镇保安村社会主义新农村示范村整治创建规划
——立足乡村特质的贫困村脱贫致富规划探索》

获 2019 年度广东省优秀城市规划设计奖
三等奖

获奖单位：华南农业大学 广州维深城市规划设计有限公司

获奖人员：卢丹梅 赵建华 陈思颖 王潇文 李易燃 林 蔚 卓友庆 谢 楠 李小琦
黄嘉仪 王如珂 黄泳姿 阳文韬 李 俊 蔡健婷

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