Supplementary materials:

Small Island City Flood Risk Assessment: The Case of Kingston, Jamaica

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Number of pages : 27
Number of figures : 11
Number of table : 2
Ethic approval form :

Supplementary A: Data Inputs for the inVEST Coastal Vulnerability Model

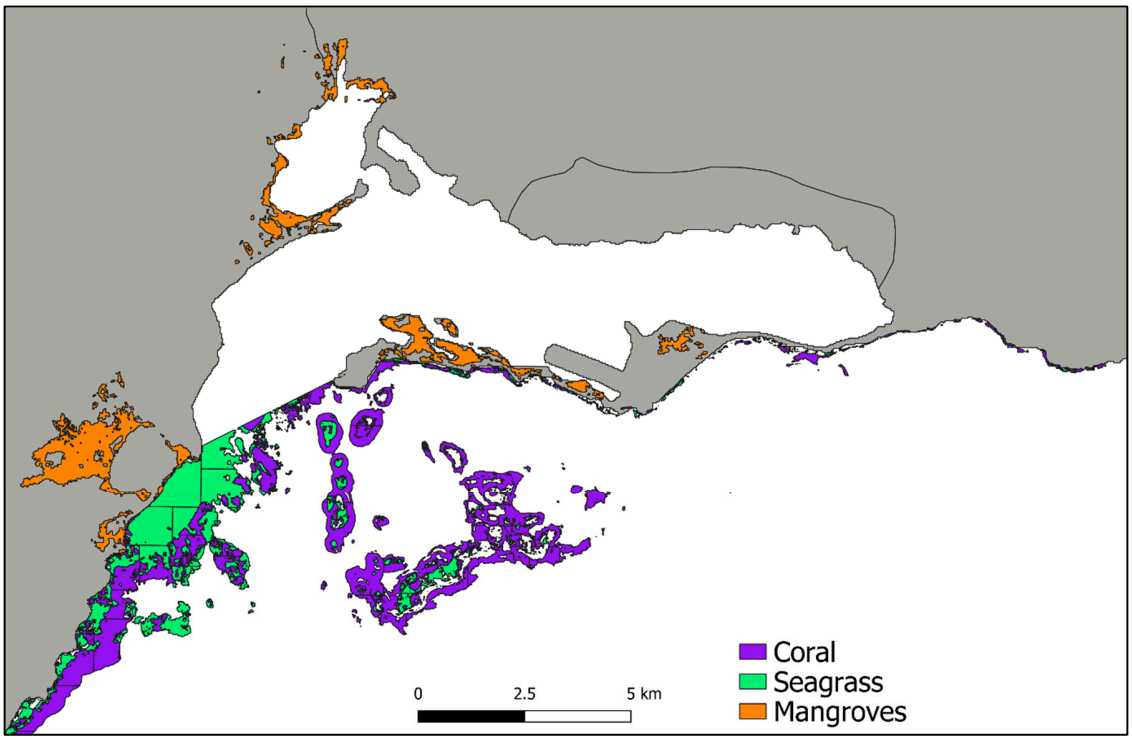


Figure S1. Distribution of coastal habitats across the studied area. Coral and sea grass distribution sourced from Allen Coral Atlas [39], mangroves distribution sourced from Sayre et al., [40].

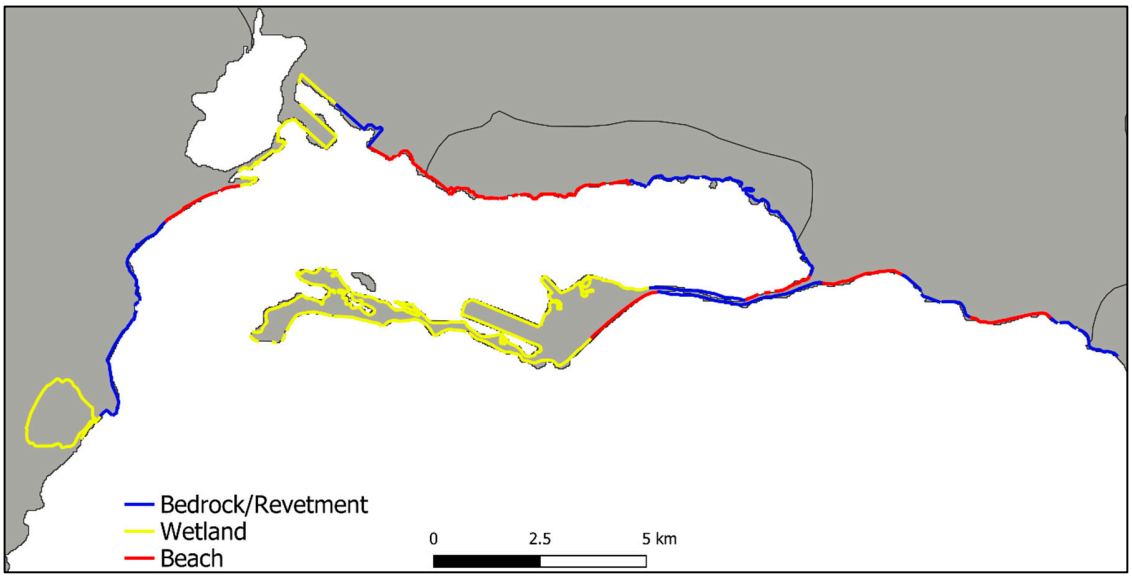


Figure S2. Shoreline geomorphology classification of the studied area sourced from Allen Coral Atlas [39].

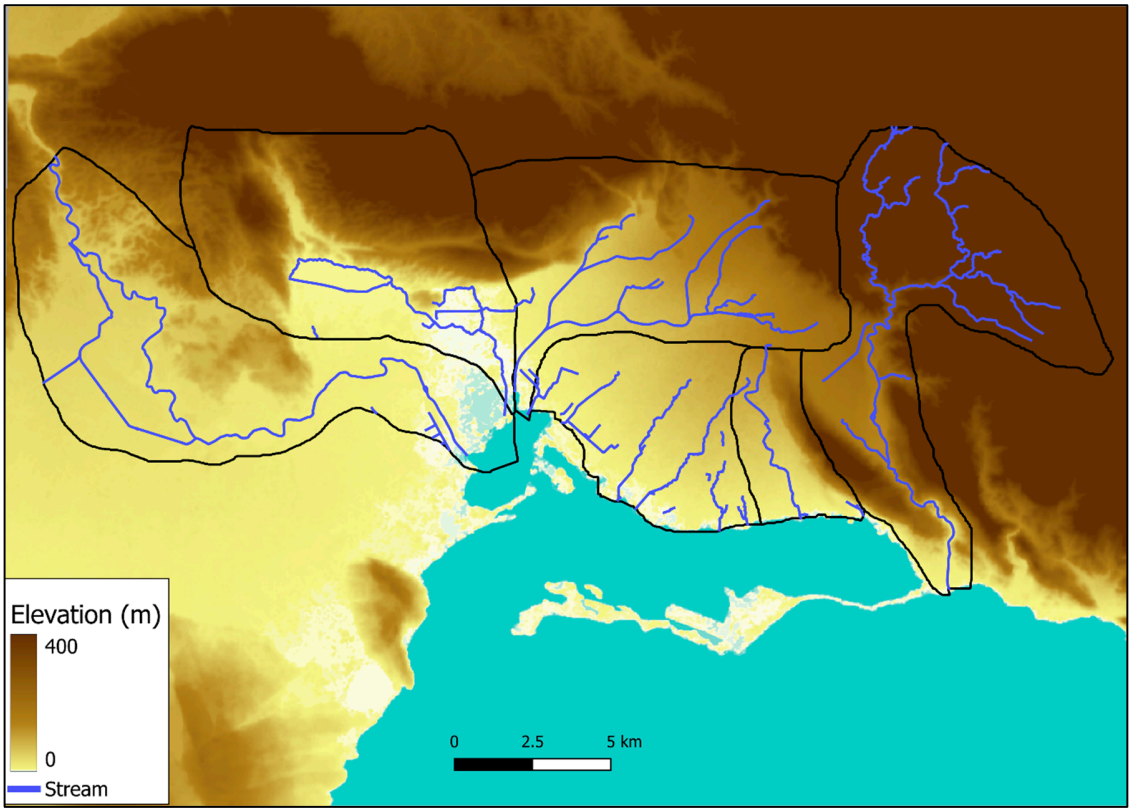


Figure S3. Digital Elevation Model for the studied area extracted from the Shuttle Radar Topography Mission [38]. The six studied catchments are delineated in black with blue lines representing the streams and gullies sourced from OpenStreetMap [57].

Sensitivity Analysis of Geomorphology Ranks

As shown in Figure S4, the coastal exposure index does not significantly change using a geomorphology rank of 3, as used in this study and suggested by Silver et al. [34], or 1, as suggested by Ai et al. [46]. The only visible differences are found in the Palisadoes road between NMI and the mainland and for some segments along the western side of the harbour shipping channel. In the first case, the difference is not significant as the hotspot analysis (Figure 5) reveals how exposure along that segment of the Palisadoes is not significant. Regarding the shipping channel, the difference is observed in unpopulated areas of coastline hosting high cliffs, so the difference in exposure does not have any impact on the local population or assets. In contrast, the same Coastal Exposure Index is found in all the key areas of high risk, including Kingston downtown, KCT and Port Royal (Figure S4).

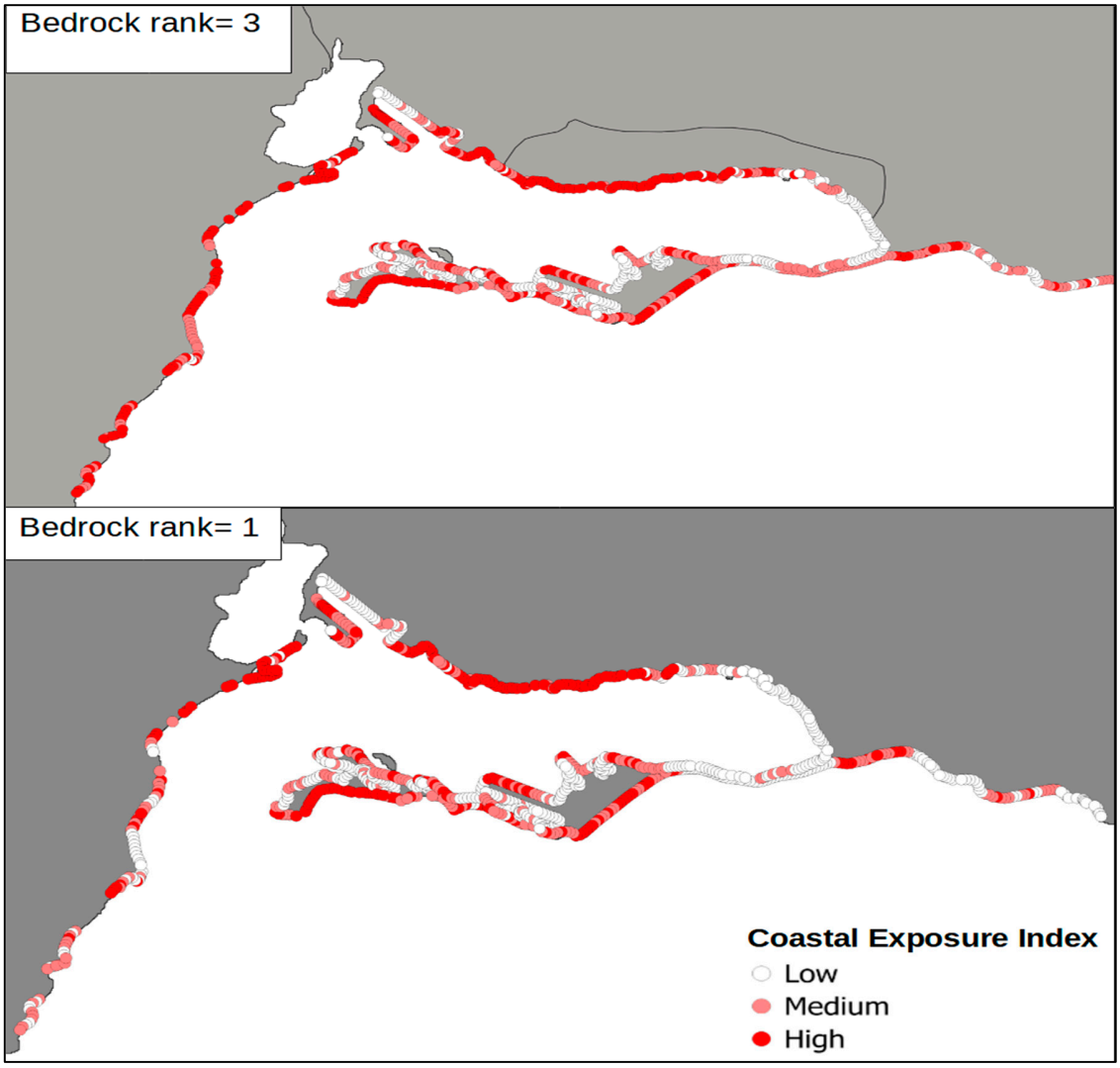


Figure S4. Coastal exposure index under current SLR calculated with bedrock exposure ranks of a) 3 (as for Figure 4) and b) 1.

Supplementary B: Data Inputs for the inVEST Urban Flood Mitigation Model and calculation of FVI

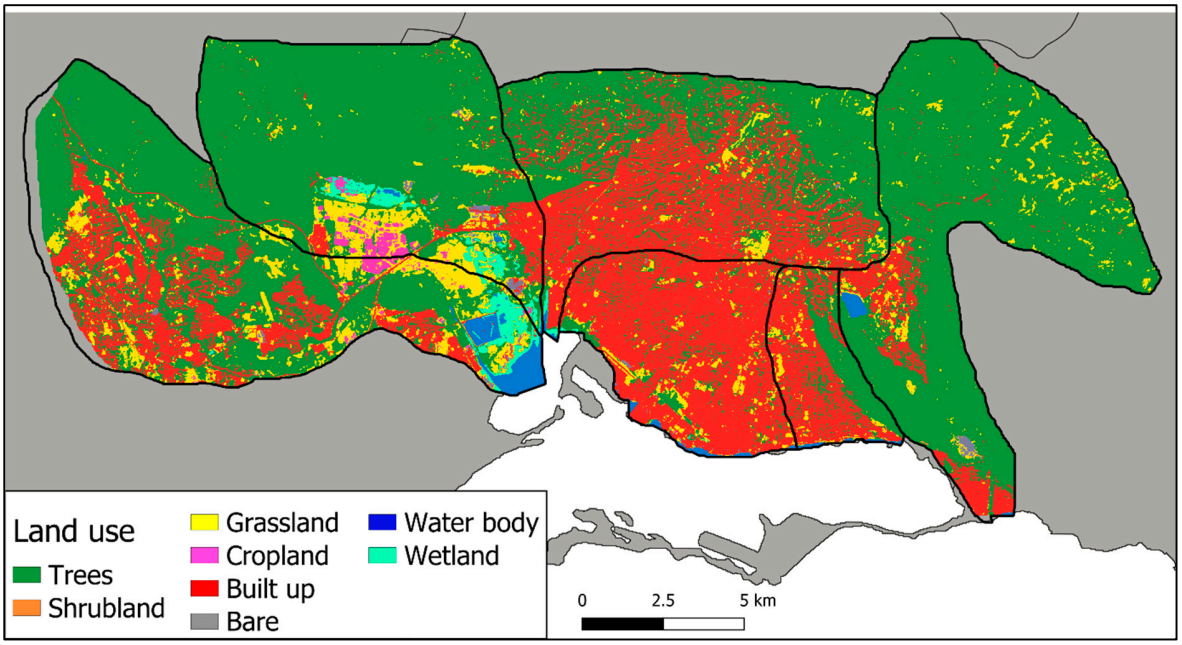


Figure S5. Land cover classes for the studied area sourced from the ESA World Cover database [58].

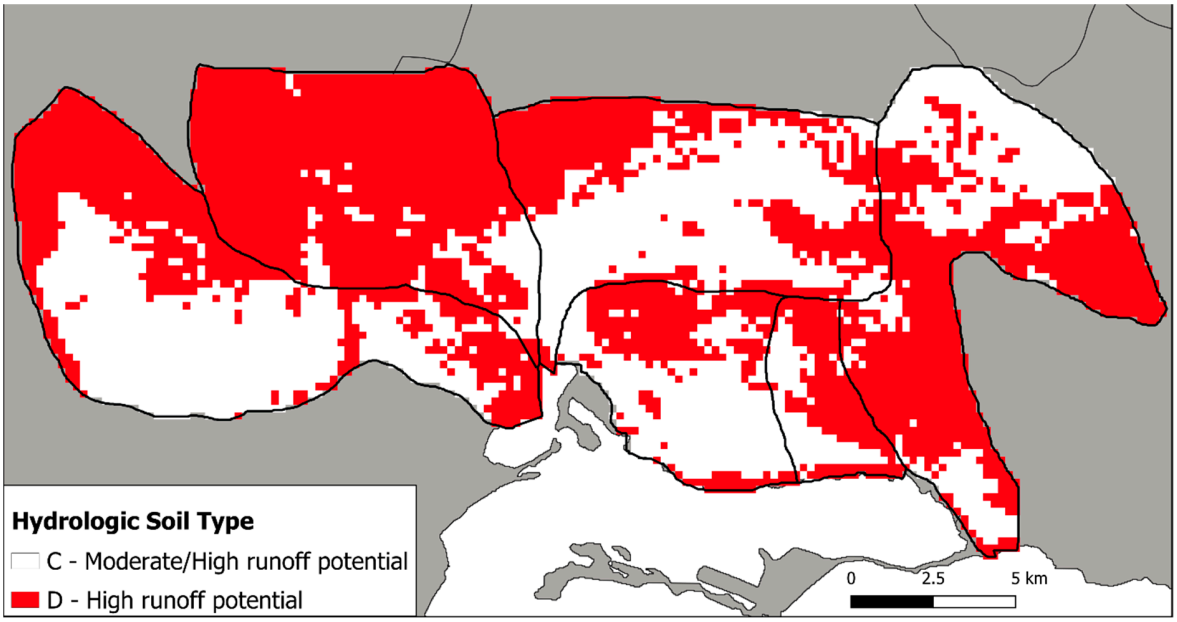


Figure S6. Hydrologic soil type in the studied area sourced from the HYSOG 250 m dataset [122].



Figure S7. Building footprint of the studied area sourced from OpenStreetMap [57].



Figure S8. Road network of the studied area sourced from OpenStreetMap [57].

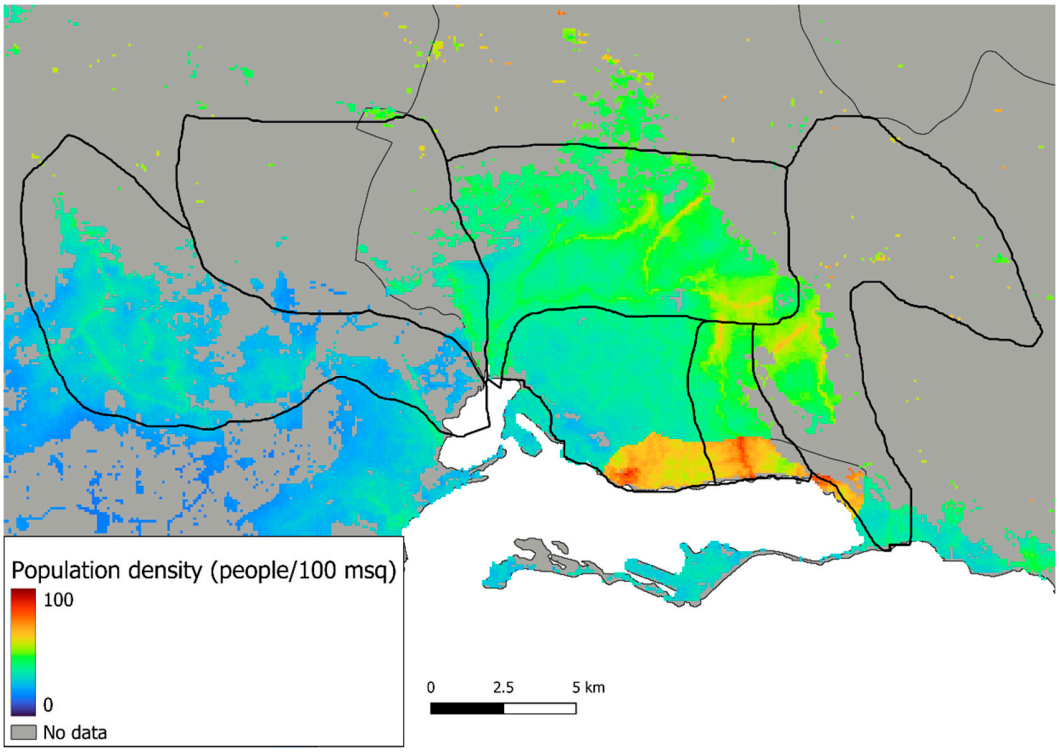


Figure S9. Population density (people/100 m²) calculated with QGIS field calculator [65] dividing the total population data [59] for the surface area of area of each catchment.

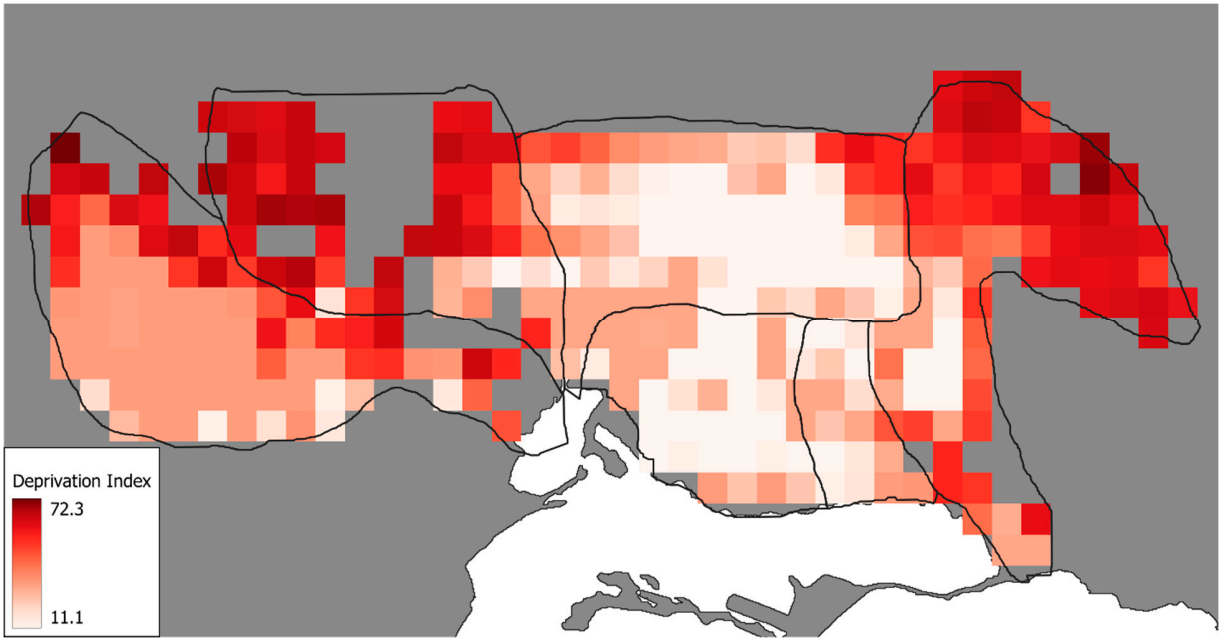


Figure S10. Deprivation index sourced from CIESIN [60]. The scaling of the index is relative to the national context of Jamaica, with a value of 100 (0) representing the highest (lowest) relative deprivation. The index is composed of six indicators of deprivation: child dependency ratios, infant mortality rates, a subnational human development index, building footprints per square kilometer, and nighttime lights (both current and recent changes).

Normalization of physical and social parameters used in the calculation of the FVI.

Being X one of the physical or socioeconomic parameters considered to calculate the FVI (e.g., tree cover, building density, deprivation index etc.), the normalization was carried out for each catchment using the min-max method [63] as shown in Equation 1:

$$Xs=(X-Xmin)/(Xmax-X) \quad (1)$$

where Xs is the scaled parameter, X is the original data for a given catchment and Xmax (Xmin) is the highest (lowest) original data among all the catchments. The scaled parameters were then used to rank the studied catchments from 1 to 5 in order of increasing flood exposure. Ranks are assigned based on the quintile each scaled parameter belongs to. Table S1 offers an example of the normalization and ranking process considering the deprovation index data.

Table S1. Normalization and ranking of the original deprivation index data for all the studied catchments.

Catchment	Original deprivation index	Scaled Parameter (quintile)	Rank
Cobre	40.39	0.59 (3)	3
Fresh	54.88	1 (5)	5
Sandy	23.79	0.12 (2)	2
Hope	50	0.86 (4)	4
Mountview	23.38	0.11 (2)	2
Minor	19.45	0 (1)	1

SCS Curve-Number Method for Runoff Calculation

The inVEST UFRM model uses the SCS-Curve Number method to estimate generated and retained runoff in the studied area. The SCS-CN method is a well-established method in flood exposure assessments, and it provides an estimate of runoff generation (and retention) based on land cover and hydrologic soil characteristics [50]. At every point in the studied area, the soil runoff retention capacity is estimated as a function of the Curve Number, an empirical parameter relating the land cover to the hydrologic soil type. Curve numbers used in this study are reported in table A1. Land cover data were extracted from the ESA World Cover database at 10 m resolution [58], while the hydrologic soil groups were sourced from the HYSOG 250 m gridded dataset [122] (Figures A1 and A2). In this classification, each soil type (A, B, C and D) represents a class of increasing runoff potential based on the soil saturated hydraulic conductivity and depth.

Table S2. Curve Numbers of the land covers relevant for this study for each hydrologic soil type. A higher number represents a higher runoff generation potential.

Land cover	Hydrologic soil type			
	A	B	C	D
Tree	36	60	73	79
Shrubland (wood grass combination)	43	65	76	82
Grassland (fair condition grass 50-75%)	49	69	79	84
Cropland (row crop)	64	75	82	85
Built up (dense urban)	98	98	98	98
Bare	68	79	86	89
Water body	98	98	98	98
Wetland	72	81	88	91
Mangroves	98	98	98	98

Supplementary C: Runoff Generation

Figure S11 shows the runoff generation (mm/10 m²) calculated with inVEST UFRM in the study area.

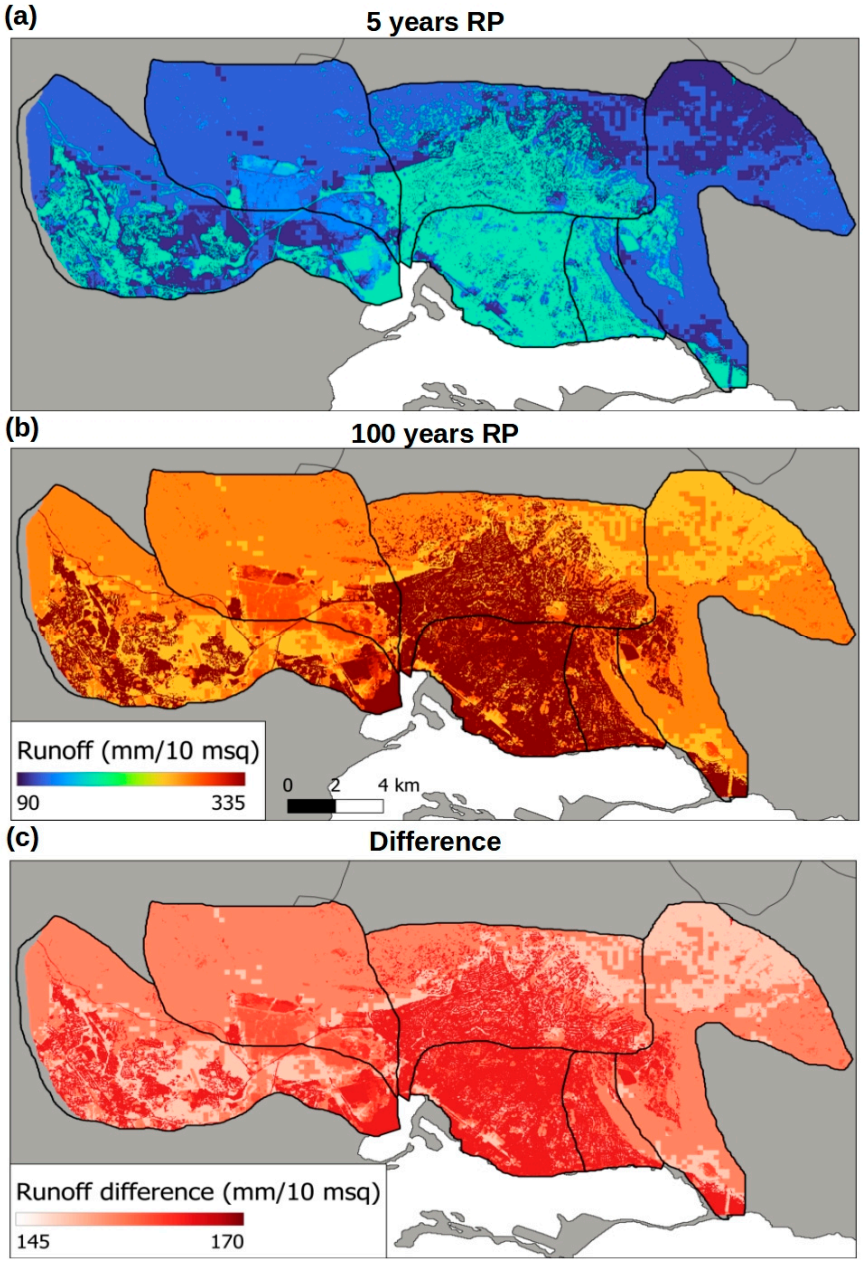


Figure S11. Runoff generation (mm/10 m2) for a) 5-year RP storm (178 mm rainfall/24 h) and b) 100-year RP storm (342 mm rainfall/24 h), with the difference between the two scenarios shown in c).

Supplement of Ethics Approval Form

Imperial College London

We thank you for your time spent taking this survey.
Your response has been recorded.

Below is a summary of your responses Download PDF

Research Ethics Application Form - CEP

Principle Investigator and Student Details (to be completed by all students)

Section 1a: Details of Principal Investigator (PI)

For all projects the PI must be employed by Imperial College London or hold an honorary contract.
For all student projects, the student's supervisor must be named as PI. Student, co-investigator and collaborator details must be added to Section 13.

1. Supervisor (PI) name (incl. title)

Dr Nigel Forrest

2. Academic position (at Imperial College London)

Teaching Fellow in Sustainable Business

3. Faculty

Faculty of Natural Sciences

4. Division/ School/ Department

Centre for Environmental Policy

5. PI Email (Imperial College)

n.forrest@imperial.ac.uk

7. Summary of PI skills (experience relevant to the study and in any procedures to be used) (350 characters max)

14 years research experience at 4 universities in various roles (independent research, collaborative research, supervisory, project admin) using mostly qualitative methods (case study, interviews, participatory workshops, survey), and some quantitative (survey / descriptive statistics, lifecycle assessment).

Section 1b: Student Details

8. Student name

Andrea Rivosecchi

9. Student email (Imperial College)

ar3922@ic.ac.uk

Section 2: Research Type

1. Is your study considered low risk?
'Low Risk' includes collecting data from individuals or groups that can give consent, or using secondary data that you have permission to use

consent, or using secondary data that you have permission to use.
See the Research Term Guidance document for more information and consult with your supervisor.

- (●) **Yes**
- ( ) No

2. Does your study only involve analysis of secondary data which is publicly available, and permission is not required to access the data? This includes extended or systematic literature reviews.

- (●) **Yes**
- ( ) No

Section 3: Filter for ICREC and SETREC

1. Is the primary aim of the research answering a human health related question?

- ( ) Yes
- (●) **No**

2. Is the primary aim of the research answering a non-health related science, social science, engineering or technology related question?

- (●) **Yes**
- ( ) No

3. Is the primary aim of the research to answer an educational question?

- ( ) Yes
- (●) **No**

Section 4: Risk level categorisation

This section determines the research risk level and if the application requires full committee review.

Meeting dates and submission deadlines ICREC/SETREC

Meeting dates and submission deadlines ICREC/SETREC.

High risk

	Yes	No
a) Does the research involve drugs/medication? If yes, please attach the SmPc.	○	◉
b) Does the research involve genetically modified materials? If yes, please also complete appendix two and attach the GM Safety Committee letter.	○	◉
c) Will you be recruiting vulnerable participants? i.e. children (15 years or younger), adults (16 years or over) who are unable to consent, people in care, the mentally ill or individuals with learning difficulties?	○	◉
d) Will participants take part in the study without their explicit consent? i.e. studies involving deception.	○	◉
e) Will you be recruiting prisoners or young offenders?	○	◉
f) Is there any aspect of the proposed research which could potentially cause harm to the reputation of the College? i.e. could	○	◉

	Yes	No
the research be considered controversial or prejudiced?		
g) Could participants disclose any illegal or harmful activity due to the nature of the research?	○	◉
h) Will personally sensitive subjects be discussed that have the potential to induce stress, anxiety or negative consequences for the participant?	○	◉
i) Will the researcher be in a position of influence or authority over the participants that could give rise to a perceived pressure to participate? i.e. lecturers/teachers and students.	○	◉
j) Does the study involve physically intrusive procedures, administration of substances, use of bodily fluids, tissues, DNA or RNA? Use of relevant material must be registered with Imperial College Tissue Bank under the College HTA license.	○	◉
k) Does the study involve ultrasound or sources of non-ionizing radiation? i.e. radiation, MRI, or fMRI.	○	◉
l) Are there any		

	Yes	No
potential conflicts of interest, or what could be perceived by an outside observer as conflicts of interest?	○	◉
m) Will undue incentives for participants be offered? Incentives should be proportionate to the burden imposed and justified by the benefits.	○	◉
n) Are you using any medical device in the UK that is CE/UKCA marked but is being used outside its product limitation? Or are you using any non-CE/non-UKCA marked product(s)? For more information on regulating medical devices.	○	◉
o) Does the proposed research raise any ethical issues that are not covered above?	○	◉

If you have answered NO TO ALL of the above questions, your project is considered low risk and you can proceed with the rest of the ethics form.

Section 5: Project Description
(to be completed by all)

1. Full title of study

Assessing pluvial and coastal flood risk in Kingston (Jamaica) using inVEST models

Assessing pluvial and coastal flood risk in Kingston (Jamaica) using InVEST models

2. P code or cost code and study funder
(only if applicable to study)

N/A

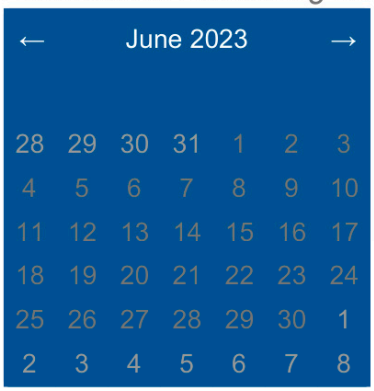
3. Lead organisation
(who has overall responsibility for the study)

Imperial College London, CEP

4. List of location(s) where study will be conducted

Desk-based project carried out in London at Imperial College or researcher's home

5. Proposed start date
From start of advertising and/or recruitment



01/07/2023

5. Proposed end date
To end of data collection





06/09/2023

Section 6: Project Summary

Provide a summary of the project in **lay terms**, this should include:

- a brief description of reasons for doing the study (justification for the research)
- the aims (research aim/question)
- how data will be disseminated
- any expected benefits to the participant, researchers or others.

(500 words max)

Over the past 30 years, storm-related flood events have caused almost 5000 casualties and produced 980M USD worth of damage in the Caribbean Island states (Glas et al., 2017). As it lies on the main Caribbean storm track, Jamaica is among the most impacted countries in the region, with hurricanes representing the most frequent natural hazard (Nandi et al., 2016). Between 1978 and 2010, Jamaica suffered 198 flooding events causing average annual losses of 96M USD (Burgess et al., 2015). Jamaica is highly exposed to flooding risk as the main settlements and industries developed the low-lying coastal floodplains (Glas et al., 2017). This is also the case of Kingston, built on the southern coast between two main watersheds (Hope River and Rio Cobre). Due to the low elevation, the city is exposed to coastal flooding, with some critical infrastructures, like Norman Manley International Airport, lying less than 10 m above sea level. Thus, there is an urgent need for a local-scale assessment of Kingston's flood vulnerability to develop an effective adaptation strategy. Such analysis is currently unavailable in the literature, with flood risk only addressed at country-wide scale with coarse spatial resolution (Burgess et al., 2015) and for other catchments across Jamaica (Mandal et al., 2016; Glas et al., 2017). The overarching aim of the project is to assess storm-related flood risk in Kingston (Jamaica), analyzing the pluvial and coastal components of flood risk. Two models belonging to the Integrated Valuation of Ecosystem Services and Trade-offs (inVEST) suite will be used to carry out the flood risk analysis (Natural Capital Project, 2022). The Urban Flood Risk Mitigation model will be used to assess the vulnerability to pluvial flooding of the watersheds located within Kingston urban area and estimate economic damages to buildings and infrastructure following an extreme rainfall event (100 years return period). The Coastal Vulnerability model will be used to assess the relative vulnerability to coastal flooding of Kingston shoreline, identifying areas of

highest coastal risk for people and infrastructure under present and end-of-century sea level conditions. The research results will be primarily disseminated through a published master's thesis.

Section 7: Research Methods

What methods will you be using in this study?
Briefly describe in **lay terms**:

- what will happen
- the number of times
- any data collection techniques

(500 words max)

The pluvial flood vulnerability of Kingston will be assessed through a Flood Vulnerability index considering physical (road density, building density, vegetation cover etc) and social parameters (population density, deprivation index). One of the physical parameters considered is the runoff retention potential, which will be calculated through the inVEST UFR model for each of the studied catchments in Kingston. Data requirements for UFR (Kadaverugu et al., 2022) to calculate the runoff retention potential are shown in table 1. The inVEST CV model will be used to assess the relative vulnerability to coastal flooding through a coastal vulnerability index. Data requirements for CV (Silver et al., 2019) are shown in table 2. All data sources are publicly available and free to access. Table 1. Data requirements and sources for the UFR model. Data, Source Rainfall depth, User-defined Hydrologic soil groups, HYSOGs250m (Ross et al., 2018) Land-use/cover, ESA World Cover (Zanaga et al., 2021) Watersheds, OpenStreetMap Buildings type and location, OpenStreetMap Digital Elevation Model, Shuttle Radar Topography Mission (Farr et al., 2007) Table 2. Data requirements and sources for the CV model Data, Source Coastal geomorphology, Mao et al. (2022) Digital Elevation Model, Shuttle Radar Topography Mission (Farr et al., 2007) Coastal and Marine natural habitats, Global Mangrove Watch (Sayre et al., 2019)Allen Coral Atlas (2020) Sea level rise projections, IPCC AR6 (Garner et al., 2021) Exposure to wind and waves, NOAA WAVEWATCH3 (embedded in model) Distance from continental shelf (storm surge potential), Embedded in model

STUDY OBJECTIVES

What are you hoping the study achieves? List the primary, secondary and other study objectives.

List the specific research objectives. Again, this can be copied from your research proposal

In essence, the objectives of the project are: 1. Provide an assessment of the relative pluvial flood vulnerability of the catchments within Kingston urban area through the development of a Flood Vulnerability Index accounting for both physical and social parameters. 2. Provide an assessment of the relative coastal flood risk of Kingston shoreline under present-day and end-of-century sea level conditions using the Coastal Vulnerability index produced by the invest CV model.

PUBLICATION POLICY

The study publication policy should be described in full.

In most cases, you should just state that this work is being prepared for publication as an MSc thesis at Imperial College London. If you intend to write a report for some external party or you intend to publish in the academic/peer reviewed literature you should say that too

This work is being prepared for publication as an MSc thesis at Imperial College London. The findings may also be used in presentations.

STUDY DESIGN

Detail how this study will be conducted from advertising to data processing. Make sure your design is explicitly described and appropriately justified. **Repeat for each method you use**. Include the following bullet points below:

- Type of study method: survey, interviews, focus groups, simulator study.
- Recruitment methods: how you will recruit participants, use of participant information sheets and consent forms
- Duration of study from advertising and recruitment to end of data collection
- Number of participants. This should be justified.

This should describe what variables you will be measuring, how you will be measuring them, how often they will be measured (just once, or is there a follow-up or repeat measurement) and whether this will be done through survey, interview, focus group or other means. Describe here how many people you are looking to recruit and how you will recruit them. Any further details about inclusion criteria will be given in the next sections.

The study is designed as a modelling study using invest UFR and CV models to assess flood risk. All data is from secondary sources that are publicly available and do not require permission to access (see above for specific datasets). It does not involve interviews or any sort of primary data collection.

Section 8: Participant Recruitment

Provide details of methods of recruitment, participant inclusion and exclusion criteria and the number of participants you are aiming to recruit. Please include:

- Details of any incentives (such as financial reimbursement).
- Recruitment and advertising material (email, poster, social media

Section 9: Informed Consent

Include details of how you will be obtaining consent.

i. Detail the process for ensuring informed consent of all research participants.

n/a

ii. The withdrawal process(es).
Describe procedures for
• stopping early
• when can a participant withdraw from the study
• how and who to contact.
Include details of data usage once participant has withdrawn if the data be used once it has been anonymised.

n/a

iii. If participants whose first language is not English are to be recruited, state clearly how the details of the study will be explained, and the consent processed.

n/a

Section 10: Ethical Summary

Has any part of this proposal received prior ethics approval?
e.g. if project part of a larger project that has already gone through ethics, then an amendment to that ethics approval will need to be sought via College committees – may be lengthy – avoid if possible, unless minor.

- ○ Yes
- ◉ **No**

Is this study subject to local ethics approval to where research is being conducted?
e.g. through another university or institution

- ○ Yes
- ◉ **No**

Section 11: Documentation checklist

a. Do Imperial College's insurers need to be notified about your project?
If your project is running abroad and is not qualitative or data only, or if your project is interventional and involves pregnant women, children under 5 or more than 5000 participants you may need additional insurance cover. Insurance for studies, email the insurance team with any insurance enquiries.

If yes, please provide confirmation that insurance cover has been agreed.

- ○ Yes
- ◉ **No**
- ○ In Process

b. Has your research project been independently peer reviewed?
This can be organised by the Peer Review Office (within the RGIT). If you answered yes to any questions in section 3, you may be asked to ensure the study is peer reviewed. However, the study does not have to use the RGIT's office for peer review.

- ○ Yes
- ◉ **No**
- ○ In Process

c. Are you developing a mobile app?
See the mobile app webpage for more information.

- ○ Yes
- ◉ **No**
- ○ In Process

d. Have you had a Disclosure and Barring Service (DBS) check carried out? If yes, when (add date).
For more information about DBS, check government guidance and the College website.

- ○ Yes
- ◉ **No**
- ○ In Process

e. Do you need a contractual agreement in place? For further information, please contact your supervisor in the first instance.

- ○ Yes
- ◉ **No**
- ○ In Process

f. Do you have permissions to use the data in your study? This may be required if you are looking at secondary data.
Postings on social media may not be considered public for research uses – please check

- ◉ **Yes**
- ○ No
- ○ In Process
- ○ Public data, permission not required

g. Has Imperial College's Risk Assessment procedure been followed? Contact your departmental administrator for further information.

- ◉ **Yes**
- ○ No
- ○ In Process

Section 12: Confidentiality and management of personal and other research data

I understand it is the responsibility of the researcher to ensure all research data is securely stored during and after the study in accordance with College Guidelines, Codes of Practice, Policies and Procedures.

- (●) Yes

I confirm that all the processing of personal information related to the study will be in full compliance with the GDPR. Including but not limited to, the creation of all necessary documentation (PIS, Data Protection Impact Assessments, Consent forms etc.)

- (●) Yes

Describe how you will preserve the confidentiality of participants taking part in the study and fulfil transparency requirements under the General Data Protection Regulation.
Best practice requires that all participants information be entirely anonymised. If you are not doing this please give well-justified reasons for keeping personal and traceable information.
All data should be stored on a GDRP-compliant service e.g. Imperial College OneDrive or Sharepoint.

n/a

Section 13: Co-investigators/ Collaborators (second supervisor or external collaborators)

(to be completed by all)

If there are more than four co-investigators (second supervisor or external collaborators), please use a separate sheet and follow the format below.

1. Name of Co-investigator/ Collaborator

Dr Minerva Singh

2. Position Incl. organisation, company, institution

Research fellow at Imperial College London

3. Role in the study (what contributions you will make and relevant experience)

Second Supervisor

4. Email (Work, not personal)

minerva.singh07@imperial.ac.uk

Do you have another Co-investigator/ Collaborator (second supervisor or external collaborators)?

- ○ Yes
- ◉ **No**

PI Declaration

I declare that:

- I undertake to abide by the ethical principles underlying the Declaration of Helsinki (1964) and subsequent amendments and good practice guidelines on the proper conduct of research.
- I undertake to abide by the Data Protection Act 2018 and General Data Protection Regulation (Europe) and any applicable local laws.
- I undertake to abide by all local laws and regulations for non-UK

research.

- I will report any adverse or unforeseen events or protocol violations and deviations which occur to the Ethics and Research Governance Co-ordinator within 24 hours.
- I will provide an annual progress report of the project until the end of the study.
- If I register my study on a public database, i.e. ClinicalTrials.gov, I will report results on that database within one year of study completion.
- I will provide notification of the end or early termination of the research project.
- I will provide notification of amendment to the CEP Ethics Panel if there are any changes to the research protocol or personnel which affect the ethical aspects of the project.
- I will assist the CEP Ethics Panel in any continuing review of the project deemed necessary by the Committee or Faculty Members.
- All information on this form is correct.

PI Name (please print)

Nigel Forrest

PI Signature: PI must sign and date this section after you have submitted and downloaded the PDF form
(Note: PDF copy of form can be downloaded on final page of survey following submission)



Date

28/6/23

Any attendance required by the CEP Ethics Panel must be made by the PI named in section one. Attendance at the meeting will give you the opportunity to answer any ethics questions raised by the committee.

Please note, this is the last section of the form. When you press the 'next' button, you will submit your ethics application form. Please ensure you are ready to submit, as you can't go back and amend once you press the 'next' button. Once submitted, all forms should be downloaded using the 'Download PDF' button on the final survey response page and then sent to your supervisor for checking and signing off.