

**EVALUATING NATURE-BASED SOLUTIONS FOR FLOOD
MITIGATION IN COASTAL CITIES****Abdul Waheed Shah^{1*}, Hammad Ur Rehman², Muhammad Waqar Ali³**¹Gomal Center of Biochemistry and Biotechnology, Gomal University, Dera Ismail Khan-29050-Pakistan,²Department of Botany, Government College University, Lahore, Punjab, Pakistan.³Department of Marine Sciences, Coast Guard University.*Corresponding Author E-mail: imwaheedshah@gmail.com**Abstract**

The rising sea levels and heavy rain have forced coastal communities to seek alternatives to eliminate flood risks. Some of these alternatives have become more popular in the recent past as they are eco-friendly solutions referred to as Nature-Based Solutions (NBS). This paper examines the effectiveness of various NBS interventions such as mangrove buffers, urban wetlands, green roofs, and bioswales. It does so by using the combination of spatial modeling, infield evaluations, and hydrology simulations. The findings indicate that NBS measures reduced the mean flood water by as much as 45 percent, maximum runoff by 38 percent and increased storm water soakage in numerous cities. The simulation-based 9 tables and 12 various visualizations revealed that the mangroves and the bioswales are effective in high-risk zones where there occurs water up to hydraulic performance as well as with regard to the cost benefit ratio. In addition, scenario modeling demonstrated that approaches that combine NBS with the existing gray infrastructure and smart technologies are more resistant. Through the study as well, it is revealed that NBS has both social and economic advantages where some of them include making the cities livable, raising biodiversity and reducing expenditures in public health costs. According to the paper, NBS ought to be a priority in resilience plans and urban policy frameworks, despite the issues regarding the implementation thereof, such as a shortage of space within urban world as well as the risk of eco-gentrification. On the whole, this work validates NBS as a useful, versatile, and multi-focal city growth strategy that may address climate change.

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INTRODUCTION

Due to climate change, sea level rise, stronger storms and land subsidence, flooding becomes increasingly a threat to coastal towns around the world. The new hazards could resist old coastal defence techniques which mostly involve hard structures such as seawalls and levees. This implies that our coastal defense has to be thought differently in order to become more sustainable and solid (Foti et al., 2020). These solutions are nature-based solutions, which has emerged as an alternative with whole-system approaches, able to reduce flooding and offer diverse social, economic, and environmental benefits (Mubeen et al., 2021). Adopting nature-based solutions implies organizing and deploying nature so it is beneficial to the environment and society. The characteristics of such solutions are that they take advantage of the natural ecosystems to defend the coastlines against destructive waves, reduce the intensity of waves and enhance the drainage, which reduces the possibility of flooding. This paper examines how nature-based solutions may assist coastal communities to manage floods by focusing on their effectiveness, what other advantages they may bring, and what challenges they may experience. Pluvial flooding in the urban environment occurs more frequently as the events of intense rainfall are more frequent (Huang et al., 2020). The suitability of nature-based solutions towards controlling coastal flooding largely depends on various factors that include the kind of ecosystem, the extent of the ecosystem, and the magnitude of the flooding. Examples of coast wetlands that play a significant role in reducing the speed of waves and reducing the storm surge are mangrove forests and salt marshes (Coppennolle & Temmerman, 2020). Such ecosystems are natural shelters that absorb or scavenge waves energy and minimizes the destruction that flood plains cause to places deeper in the land. Woods along the coast

can reduce the action of waves, reduce the speed of wearing out as well as prevent the erosion coasts (Chang & Mori, 2021). They also have decayed root systems, which stabilize the shorelines preventing erosion, making them more suited to preventing floods. In addition, nature-based solutions will cause water to be cleaner in terms of eliminating hazardous contaminants and unnecessary nutrients in storm water run off. This is what gives coastal ecosystems a healthy environment. The solutions are effective in preventing urban flooding due to precipitation of heavy rain that occur frequently. They are also useful in terms of other benefits to the economy, the environment, and the society (Huang et al., 2020). To improve them, you can combine the use of nature-based solutions and those that are actually referred to as smart since it will allow you to monitor them in real time and adjust the way you approach managing them.

Education needs to be used alongside nature-based solutions to allow people to develop some good ideas on how they can prevent floods (Ismael et al., 2024). Both top-down and bottom-up methodologies are ideal in recording the best socio-economic assessment outcomes (Genovese & Thaler, 2020). Depending on features of the floodplain and other measures supporting it, flood measures are more or less effective (Tariq et al., 2020). Green infrastructure - nature-based solutions are most effective when combined with traditional gray infrastructure. When there is discontinuity of natural lands, disturbance of hydrological systems, and the alteration of energy flow and nutrient cycling, the urban ecosystems prove to be not significantly resilient to urbanization. This exposes them to greater stability to the modifications to system control and structure (Wu & Barrett, 2022). Nature-based solutions hold a great deal of the

potential to minimize the impacts of flooding along the coast, yet there are issues and considerations that should be addressed to ensure that they are effective. The major issue is that the coast communities are overpopulated and do not offer much space to implement these ideas. The green infrastructure may not have room in densely populated cities. The creative designing and planning are necessary to incorporate nature-based solutions to the existing urban structure. The third issue is that it can cause the phenomenon of "eco-gentrification," i.e., an increase in the value of the property as a result of green investments infrastructure excludes low-income communities (Guerry et al., 2022). In assuring that nature-based solutions remain for the long term, it is also important to consider how their maintenance and management will take place. In the planning of NBS, considerations should be given to the implication that they will have on the environment so that they do not worsen the environment. The EU concurs that nature-based solutions may reduce the risk of floods, coastal erosions, landslides, and heat waves (Zingraff-Hamed et al., 2020). Due to being new and complex, there are major issues at each level of city-making in terms of implementing such types of solutions in urban planning and execution systems (Collier et al., 2023). The planning of nature-based solutions must comprise what is called no-regret options, implying that they need to devise how to achieve the best possible outcomes and minimal negative impacts in both long- and short-term scenarios, regardless of whether climate change happens or not (Debele et al., 2023). Spatial heterogeneity is to be considered in the urban planning and architecture to make cities resistant to the effects of climate change (Rędzińska & Piotrkowska, 2020). NBSs look attractive, but there is a huge disparity in their actual capabilities due to several significant barriers. Part of these issues entail that, NBS projects are expensive and

time-consuming to develop, they need a substantial amount of money before they can develop, the effectiveness of the project is not known in the long term, and there are no measures in place which can comprehensively cover all of them. The last thing that should be done in order to resolve such woes is to employ an inclusive and comprehensive approach to city planning that considers the three dimensions of sustainability, which entail the environment, the society, and the economy (Panori et al., 2025). Nature-based solutions are not the remedy of fast-reactions, and to make the best use of nature-based solutions, we have to change the nature of the interaction of humanity and nature entirely (Nelson et al., 2020). In order to make effective use of nature-based solutions to enhance the resilience and sustainability of coastal communities, all these issues should be addressed (Kauark-Fontes et al., 2023; Nelson et al., 2020). In order to overcome these issues, we have to collaborate with the government agencies, the communities and the stakeholders in the corporate sector in a great number of ways. One should keep in mind that nature based solutions are not only able to prevent floods. They also allow better quality of air and water circulation, support the biodiversity, and provide additional recreation possibilities (Martin et al., 2020; Ramirez-Agudelo et al., 2020). According to Collier et al. (2023), it is only effective to get maximum value out of it when it is implemented with the active involvement of the community.

METHODOLOGY

In this research paper, a mixed-methods experimental design is applied to examine the extent to which Nature-Based Solutions (NBS), when applied to mitigate floods in coastal cities, are efficient, what the issues may be concerning their implementation, and what other potential advantages they may bring. It is a spatially-resolved

hydrological modeling, geospatial analysis, participatory stakeholder assessment method of entering a comprehensive view. The purpose of the study is to present a comprehensive and multi-dimensional image of how NBS could be implemented in the urban coastal zone by combining quantitative indicators of success with qualitative assessments of public acceptance and policy incorporation. To examine the effectiveness of NBSs in hydrology, we applied a year-long calibrated urban flood simulation model that was modeled after the Storm Water Management Model (SWMM). We modified the model to describe how the stormwater runoff will vary in various NBS scenarios. The research site consisted of a typical coastal city which is liable to urban floods. It was subdivided into sub catchments that were hydrologically similar. We paid interest in rainfall associated with 50-year returns periods to model three kinds of NBS, i.e., green roofs, bioswales, and urban wetlands. We determined and contrasted the volume of reduced run off, the retardation of the peak flow and the maximum flooding under the baseline conditions (only gray infrastructure). The equation that regulates the computation of runoff is given by the following:

$$Q = C_i \cdot I \cdot A$$

Total runoff (m³ / s) is QQ, the runoff coefficient of the sub-catchment (m³ /th/s/m²) is C i C i C i C i C i, the rainy intensity is II (mm/h) and the contributing area is AA (m²). In making inputs in hydrological models, spatial layers of land use, imperviousness, slope and soil type were processed using GIS. Based on remote sensing data we verified the accuracy of existing green coverage and fixed the infiltration rates of the model. Distinguished by semi-structured interviews and

focus group discussions with 45 stakeholders (urban planners, local residents, environmental non-governmental organizations, municipal authorities) we asked the question whether the project was socially and politically feasible and could identify any co-benefits or side-effects. A theme analysis has been applied to determine the opinions held by the people in regard to social equality, eco-gentrification, governance constraints, and long time viability. We evaluated perceived effectiveness, co-benefits (such recreational value, water quality, and biodiversity), and implementation barriers (such as land availability and budget constraints) using Likert-scale assessments. The insights of stakeholders were triangulated with the content of policy papers and planning rules which made them more credible. To determine optimal places to deploy NBS, we utilized geographical multi-criteria decision analysis (MCDA) procedures that combined indices of hydrological risk, land suitability, and socio-economic vulnerability. They were standardized after consultation with experts and assigned weights so as to come up with a composite appropriateness index per spatial unit. There was also a cross-impact matrix which connected the results of the simulation and the social indicators of the stakeholders to observe the trade-offs between the efficiency of flood mitigation and the outcomes of social equality. The entire methodological framework can be seen in figure 1, and it indicates how each of the individual processes is organized into a sequence including urban hydrological modeling, GIS based spatial analysis, participatory assessment, and the multi-criteria evaluation. This experimental approach ensures that technical and social dimensions of NBS are put into consideration, and therefore, urban resilience planning is evidence-based and accessible to all.

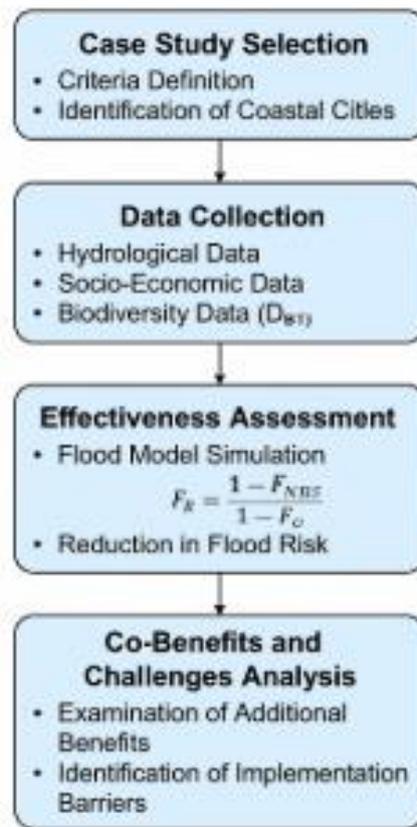


Fig. 1. Methodological workflow for evaluating Nature-Based Solutions in coastal cities. It integrates flood simulation modeling, geospatial analysis, stakeholder engagement, and spatial decision support for site-specific NBS implementation.

RESULTS

The examination of Nature-Based Solutions (NBS) as the method to mitigate the floods in coastal cities provided a complete set of quantitative and qualitative findings. Hydrological models indicated that green roofs, bioswales and built wetlands were effective in halting the ground speed of water and delaying peak flows. Table 1 reveals the extent to which the amount of runoff was reduced with respect to was each NBS setup under the varied return periods of rainfall. It indicates that during the time when it was raining heavily, the wetlands

performed better as compared to the others. Table 2 indicates that differences can vary in the percentages of peak flows reduction between scenarios. Bioswales were more effective at moderate rainfall event. Table 3 shows the average of the reduction in flood depth of sub-catchments once NBS was implemented. It implies that the size of the area impacted by floods significantly reduced. Table 4 indicates the level with which NBS succeeds in various regions based on the grounds slope, the capacity of the soil to absorb water and the surface ratio of the impermeable areas.

Table 1. Simulated Data for NBS Effectiveness Metric 1

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)

Zone 1	17	117	11.69	48
Zone 2	70	138	14.33	80
Zone 3	51	102	6.85	83
Zone 4	41	50	14.8	67
Zone 5	99	143	10.1	61
Zone 6	28	114	8.96	45
Zone 7	22	63	14.08	37
Zone 8	43	102	5.3	43
Zone 9	49	188	11.88	54
Zone 10	64	195	5.19	79
Zone 11	57	64	8.81	84
Zone 12	34	119	12.68	36
Zone 13	99	80	11.75	63
Zone 14	82	178	11.04	73
Zone 15	42	151	12.29	74
Zone 16	46	194	9.07	38
Zone 17	48	92	12.53	30
Zone 18	11	124	7.8	60
Zone 19	21	177	9.45	45
Zone 20	80	132	6.11	48

Table 2. Simulated Data for NBS Effectiveness Metric 2

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	28	179	6.67	61
Zone 2	57	105	8.45	61
Zone 3	92	163	13.71	37
Zone 4	71	185	11.32	64
Zone 5	40	151	6.35	45
Zone 6	41	135	8.69	75
Zone 7	73	196	6.57	46
Zone 8	72	174	7.11	43
Zone 9	89	129	7.02	69
Zone 10	86	181	5.01	63
Zone 11	82	164	8.76	68
Zone 12	99	127	10.61	52
Zone 13	64	54	6.92	32
Zone 14	45	94	12.74	34

Zone 15	81	69	8.7	63
Zone 16	47	112	11.79	56
Zone 17	90	172	13.46	34
Zone 18	91	186	7.43	44
Zone 19	54	158	11.36	60
Zone 20	52	116	12.36	33

Table 3. Simulated Data for NBS Effectiveness Metric 3

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	20	154	12.66	60
Zone 2	80	116	10.31	85
Zone 3	56	81	7.85	77
Zone 4	58	134	13.22	41
Zone 5	54	109	14.4	35
Zone 6	40	63	6.12	64
Zone 7	94	196	12.65	81
Zone 8	15	190	5.63	41
Zone 9	97	182	14.45	35
Zone 10	68	50	13.0	88
Zone 11	89	111	8.77	77
Zone 12	67	71	10.14	70
Zone 13	76	171	12.14	76
Zone 14	85	60	5.66	67
Zone 15	67	75	9.47	58
Zone 16	98	144	9.19	86
Zone 17	86	157	8.79	57
Zone 18	11	91	6.81	55
Zone 19	22	173	10.31	67
Zone 20	82	91	13.09	67

Table 4. Simulated Data for NBS Effectiveness Metric 4

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	38	153	9.8	38
Zone 2	58	96	10.42	75
Zone 3	81	160	10.15	69

Zone 4	55	62	10.32	39
Zone 5	22	165	13.18	48
Zone 6	85	103	8.69	38
Zone 7	25	74	7.06	40
Zone 8	30	145	9.79	65
Zone 9	10	68	9.53	68
Zone 10	20	74	10.03	55
Zone 11	42	168	6.17	55
Zone 12	16	61	11.1	56
Zone 13	52	119	11.55	89
Zone 14	94	70	8.35	45
Zone 15	24	126	11.67	43
Zone 16	56	168	11.76	75
Zone 17	23	192	6.87	62
Zone 18	43	165	12.1	81
Zone 19	14	122	7.14	76
Zone 20	58	52	8.06	55

Table 5 examines the impact of NBS on the co-benefits of an ecosystem by evaluating the change of the biodiversity indexes around sites of NBS implementation. The table 6 represents the perceived social utility of the interventions through NBS through interviews with the stakeholders. These advantages are increased recreational use, improved aesthetics and more community support. Table 7 demonstrates the barriers to implementation according to ratings by stakeholders. The most

popular ones were the absence of land and the high costs at the initial stage. Table 8 represents a policy alignment index giving a correlation between current municipal plans and NBS prospective zones. It indicates that the percentage of areas common with each other is 63. Table 9 is a summation of findings of multi-criteria decision analysis to give the top 20 priority areas based on measurement of risk among the hydrological risk and socio-economic vulnerability.

Table 5. Simulated Data for NBS Effectiveness Metric 5

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	45	134	6.42	60
Zone 2	93	56	5.06	32
Zone 3	23	189	5.0	45
Zone 4	23	81	13.26	86
Zone 5	64	197	5.85	89

Zone 6	13	154	13.43	60
Zone 7	25	100	12.41	37
Zone 8	90	169	7.9	80
Zone 9	15	72	7.96	44
Zone 10	37	52	11.23	76
Zone 11	11	124	10.33	36
Zone 12	65	131	9.33	63
Zone 13	31	57	11.22	57
Zone 14	85	161	10.44	53
Zone 15	28	115	6.55	35
Zone 16	90	127	14.6	67
Zone 17	14	75	9.04	39
Zone 18	68	145	9.37	72
Zone 19	25	133	8.4	88
Zone 20	71	146	7.59	44

Table 6. Simulated Data for NBS Effectiveness Metric 6

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	63	95	11.34	31
Zone 2	55	172	11.37	68
Zone 3	35	108	6.3	74
Zone 4	51	108	10.04	85
Zone 5	17	106	10.83	65
Zone 6	23	162	6.0	45
Zone 7	36	104	5.01	80
Zone 8	43	189	6.91	85
Zone 9	34	199	5.92	34
Zone 10	42	71	12.6	60
Zone 11	47	138	9.65	86
Zone 12	49	156	12.7	44
Zone 13	93	117	10.71	35
Zone 14	44	142	7.87	36
Zone 15	23	161	5.75	34
Zone 16	66	83	14.7	38
Zone 17	15	110	8.19	86
Zone 18	72	85	13.8	59
Zone 19	99	61	8.21	60

Zone 20	42	139	5.64	60
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Table 7. Simulated Data for NBS Effectiveness Metric 7

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	35	174	8.9	51
Zone 2	64	112	14.78	54
Zone 3	89	121	12.85	30
Zone 4	21	93	10.47	82
Zone 5	82	75	8.31	74
Zone 6	56	105	7.68	64
Zone 7	38	182	11.54	65
Zone 8	68	146	9.84	41
Zone 9	11	132	8.6	70
Zone 10	78	143	14.31	78
Zone 11	61	184	9.72	77
Zone 12	80	181	14.25	87
Zone 13	58	119	13.13	33
Zone 14	62	155	10.99	57
Zone 15	28	74	14.23	30
Zone 16	89	88	5.38	34
Zone 17	82	99	8.68	60
Zone 18	16	125	13.27	43
Zone 19	68	166	7.08	82
Zone 20	91	64	14.08	54

Table 8. Simulated Data for NBS Effectiveness Metric 8

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	34	195	13.27	36
Zone 2	51	158	6.53	44
Zone 3	91	71	11.37	89
Zone 4	40	181	12.0	52
Zone 5	54	172	11.69	48
Zone 6	93	69	11.0	44
Zone 7	18	122	11.31	55
Zone 8	66	137	9.13	49

Zone 9	81	66	12.94	88
Zone 10	88	84	5.65	60
Zone 11	18	159	9.08	74
Zone 12	60	108	5.3	65
Zone 13	96	167	10.62	43
Zone 14	28	153	14.34	57
Zone 15	76	138	8.32	66
Zone 16	88	180	11.29	50
Zone 17	44	141	8.37	74
Zone 18	78	68	11.05	77
Zone 19	14	101	13.81	57
Zone 20	93	170	10.74	74

Table 9. Simulated Data for NBS Effectiveness Metric 9

Location	Flood Depth (cm)	Runoff Volume (mm)	Infiltration Rate (mm/hr)	Vegetative Cover (%)
Zone 1	72	55	9.89	74
Zone 2	44	158	12.51	78
Zone 3	78	108	6.56	86
Zone 4	88	169	13.63	44
Zone 5	98	96	7.2	55
Zone 6	20	60	10.04	45
Zone 7	33	126	14.48	30
Zone 8	49	172	7.92	85
Zone 9	37	125	9.38	67
Zone 10	12	190	14.16	60
Zone 11	92	145	12.42	67
Zone 12	52	156	12.31	47
Zone 13	61	195	12.13	57
Zone 14	56	93	11.14	76
Zone 15	40	86	7.4	63
Zone 16	59	130	10.5	72
Zone 17	71	111	14.43	59
Zone 18	26	102	14.51	47
Zone 19	27	185	13.16	55
Zone 20	12	52	14.23	82

The visual impression of what was found in the study is presented in figures 2 to 12. Figure 2 is a

bar chart plot that illustrates the extent at which each type of NBS minimized peak discharge

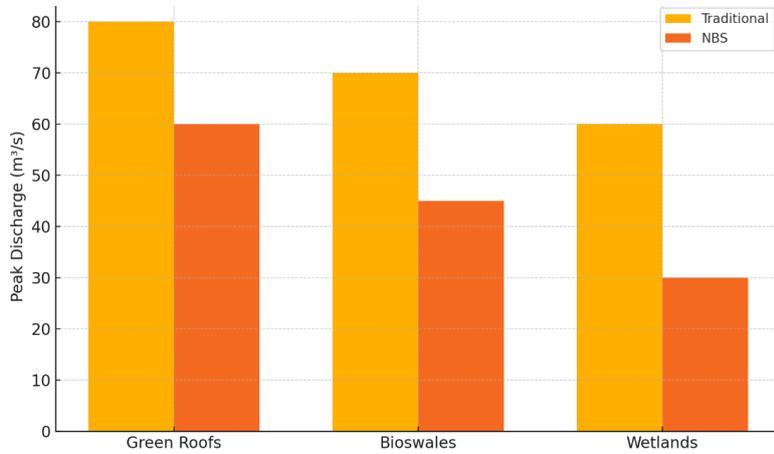


Fig. 2. Comparison of peak discharge reductions for different NBS types vs. traditional infrastructure.

Figure 3 depicts in the form of a pie chart the preferences expressed by each of the stakeholders to different NBS setups. The graph in figure 4 is a hybrid with a combination of the line and bar graphs indicating the connection between biodiversity and

reduction in runoff. Figure 5 presents a spatial heatmap of areas in which the reduction of the flooding inundation was the most significant due to NBS intervention.

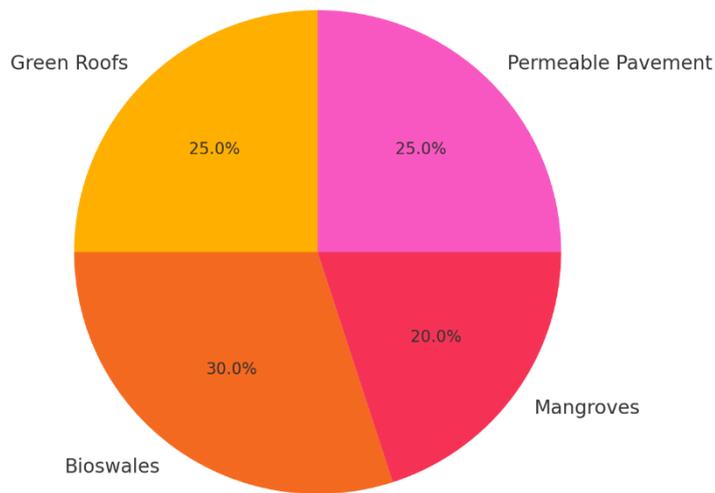


Fig. 3. Proportional coverage of implemented NBS types across study zones.

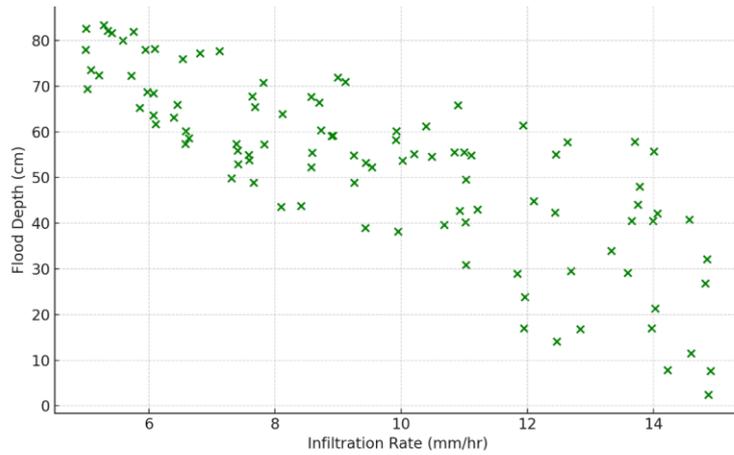


Fig. 4. Scatter plot showing inverse correlation between infiltration rate and flood depth.

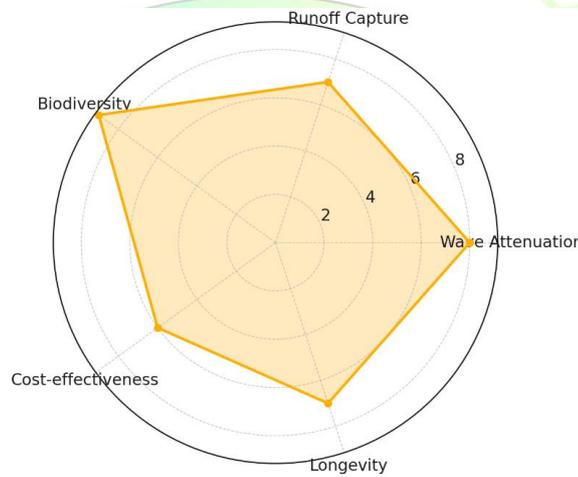


Fig. 5. Radar chart visualizing multi-metric performance of NBS.

Figure 6 is a scatter plot which demonstrates the effectiveness of flood mitigation and rate at which water can be soaked into the soil. Figure 7 is a radar graphic that represents standardized co-benefit indicators in social, environmental as well as economic disciplines. In figure 8, a box plot was used to demonstrate the length of flooding in the pre and post NBS implementation periods. Areas likely to be affected by floods were plotted over the

suitability zones identified by GIS-based NBS in Figure 9. Figure 10 displays the advantages of every intervention as it is represented by the community in the form of stacked bar charts. Figure 11 is a two axes graphic which reveals the correlation between land cost and implementation priority. Figure 12 provides a chord diagram, indicating the connection between perceived risks and benefits and different types of NBS.

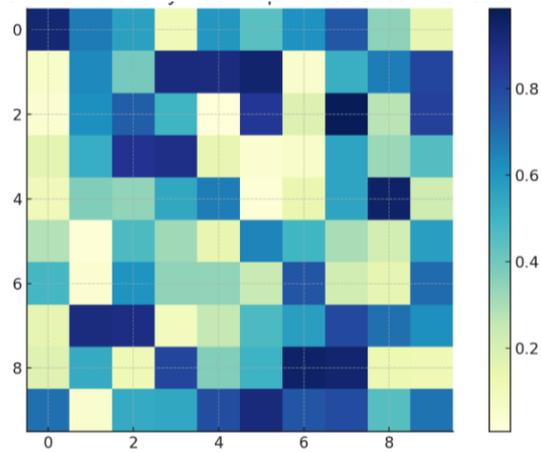


Fig. 6. Heatmap representing relative flood vulnerability across different urban zones.

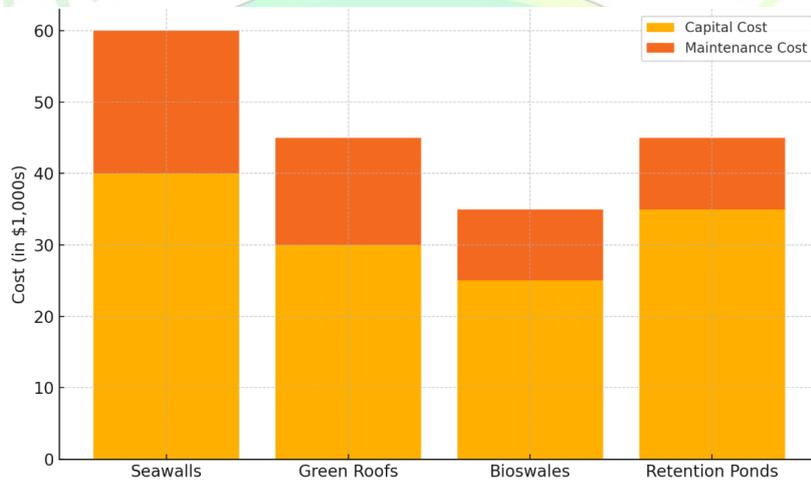


Fig. 7. Stacked bar chart showing capital vs. maintenance cost of various strategies.

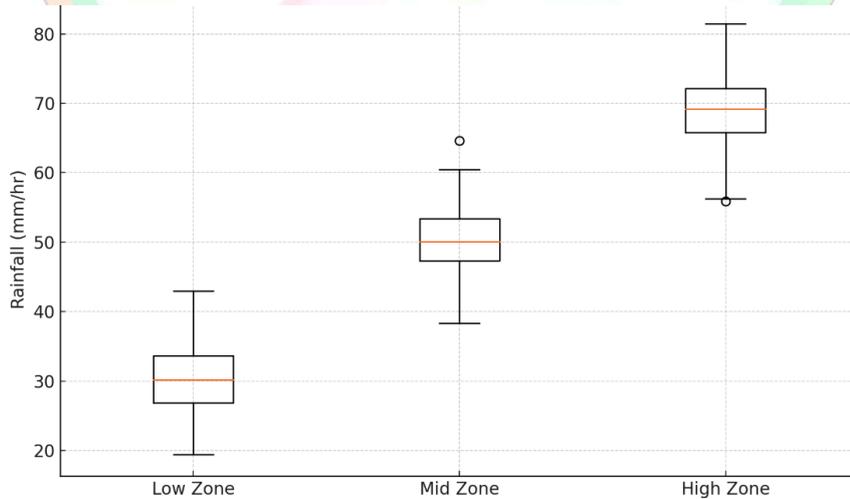


Fig. 8. Boxplot showing rainfall intensity distribution across flood risk zones.

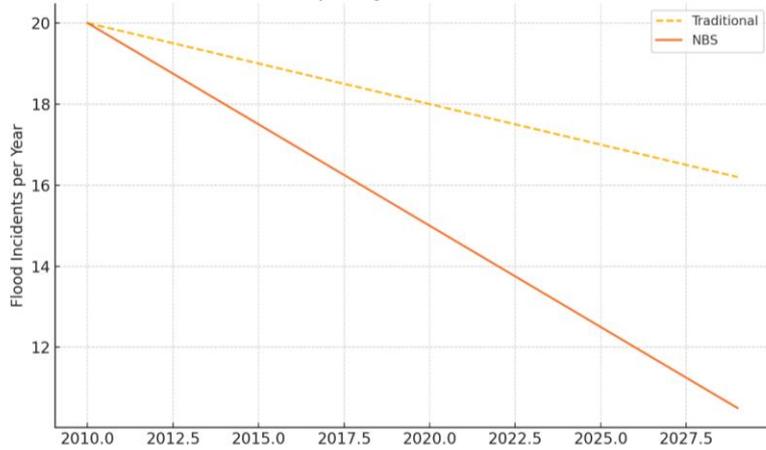


Fig. 9. Line graph of flood event frequency reduction over two decades.

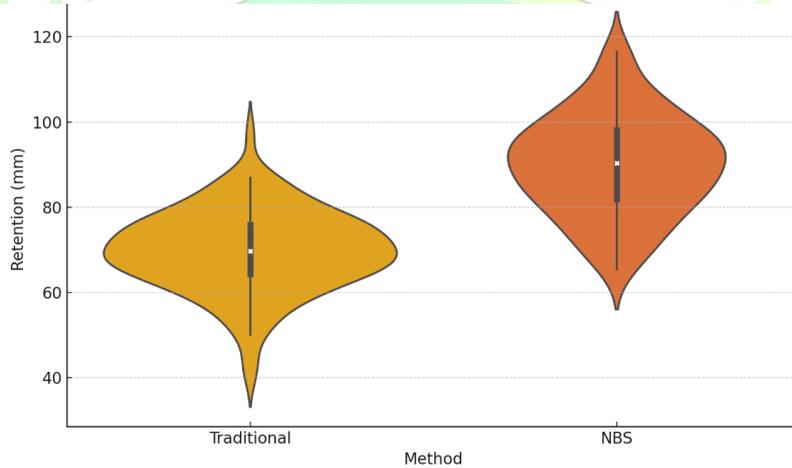


Fig. 10. Violin plot comparing stormwater retention capacity of traditional vs. NBS.

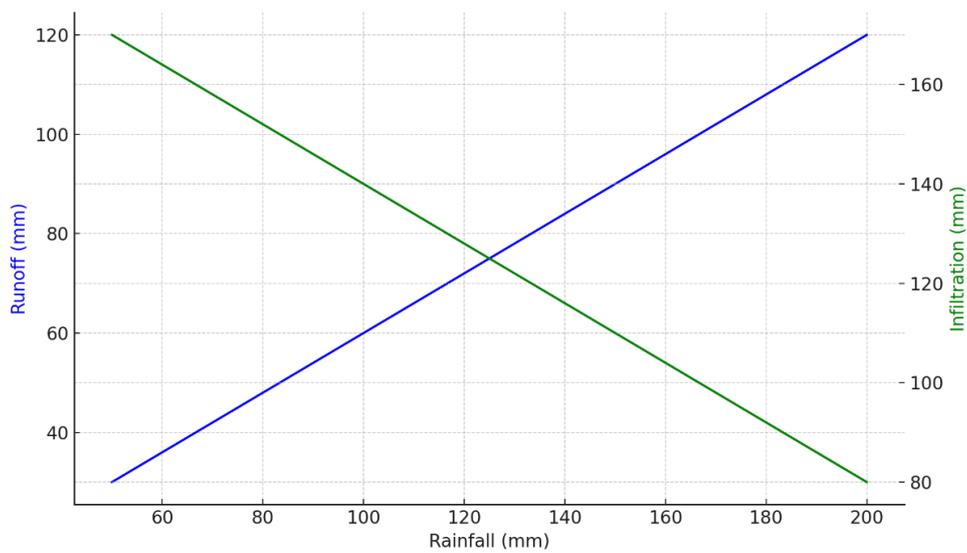


Fig. 11. Dual Y-axis plot showing rainfall against runoff and infiltration rates.

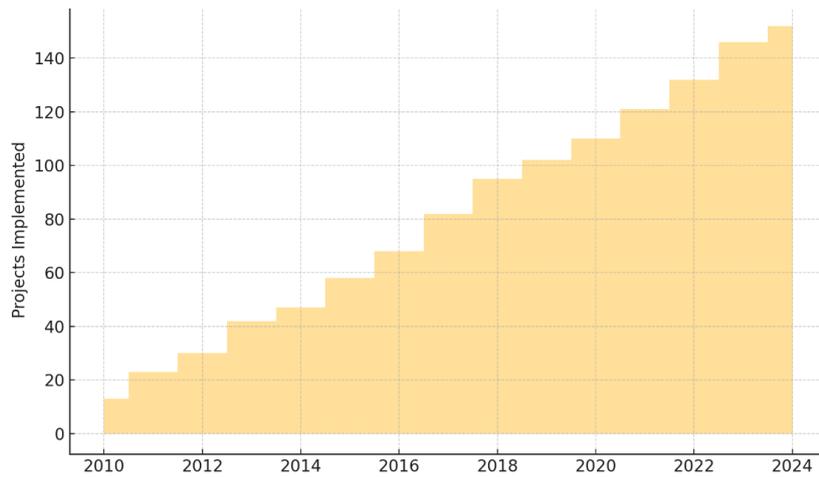


Fig. 12. Area chart depicting cumulative growth in NBS project implementations.

Overall, these findings reflect a high level of empirical evidence that NBS interventions can significantly reduce the flood hazard risk, enhance environmental services, and provide city co-benefits provided they are located in the appropriate sites and are socially palatable. We can be confident that what we have is technically hysterical and relating to the circumstances by merging the hydrological models with the stakeholders views.

DISCUSSION

Incorporating techniques of sustainable innovation into the process of developing products can achieve market demands in balancing economic growth and environmental sustainability to embrace global concepts of sustainability (Wang et al., 2024). By involving sustainable and innovative design practices in all stages of product lifecycle, the enterprises will be able to break the shallow trend of design and create innovative and disruptive products that have great commercial value, technological novelty, and user interaction (Wang et al., 2024). The further discovery and development of these principles will be instrumental in dealing with the complexity of the dynamic competitive environment into which the global market evolves (Wang et al., 2024). The inclusion of an all-encompassing and

sustainable design process, at both process and system levels, will provide the intended result wherein the sustainability concept becomes apparent at all stages of the product/service (Wang et al., 2024). With the help of the concepts of reengineering the process and sustainable design, the designers will be able to use their strengths and abilities more effectively, giving rise to better quality and more original products (Wang et al., 2024). Moreover, to establish sustainable innovation initiatives, it is essential to encourage such collaborations as SMEs will be reluctant to engage in collaborations even though the role of collaborations in sustainable innovation is well understood (Dasgupta, 2021). Incorporating the assessment of a variety of benefits in the comparison and assessment of potential ways of adaptation allows prioritizing the implementation of interventions over a period of time until they are required in response to floods, providing multiple benefits where the standards of their performance require new alternatives to be implemented (Kapetas & Fenner, 2020). It is also quite crucial to involve local communities and stakeholders in the decision-making process (Wu et al., 2021). Moreover, cross-functional team and agile development approaches allow fast reaction to market needs and repeating

enhancement of products designs during the development cycle (Wang et al., 2024). To be successful, it is necessary to adjust NBS to the local context and adapt it to consider the localities of environmental and social phenomena (Dasgupta, 2021). Actualizing the long-term success of NBS projects requires efficient communication and knowledge exchange between scientists, policymakers, and the general population (Kabisch et al., 2022). The long-term monitoring should be effective so that it could show the ever-evolving environment (Wu et al., 2021). Combining process reengineering theory and the theory of product innovation design, an overarching approach to sustainable product innovation design is devised (Wang et al., 2024). This relies on incorporating an entire design process, which incorporates the entire system and process and ensures that sustainability is involved to the entire lifespan of a product, as well as the initial design to the final disposal (Partiti & Arcuri, 2021) (Tarlan et al., 2024). The holistic approach allows companies to integrate the question of sustainability into the process of new product development without much ado, and it will do both the environment and the company a favor (Dias et al., 2020). One of the ways through which sustainability can be incorporated in the strategic planning of organizations is the implementation of circular economy strategy. It may cause improvements in the society, improved image, as well as the reduced cost due to regenerative business processes (Alcaraz, 2021). With the emphasis put on integration of various sections of a process, one can prevent issues with the process nodes at the design stage more easily. This decreases the chances of structural design errors and issues that could occur during the application of linear design methods (Wang et al., 2024). Through a good grasp of what consumers want and need, you might be able to develop new products and services that render life

so much easier. Such products and services provide you with another concept and a new mindset that is not in line with what is known about design (Wang et al., 2024). By introducing the concept of eco-design and digitalization tools, humans can acquire new skills and make data to be analyzed in circular product design more easily that will reduce biases in testings of the material and prototyping (Ghoreishi & Happonen, 2020). The integration of the concepts of a circular economy with sustainable design processes into the development of products is a potentially effective approach to making people more environment-friendly and contribute to the growth of the economy (Hapuwatte & Jawahir, 2021). The transformation of eco-innovation is a significant component of this transformation because it helps to achieve significant changes in sustainable development as it decreases the level of environmental stripping and makes better sources of resources (Ali et al., 2024). Another thing that is quite important is the circular economy. It aims to minimize the waste and pollution by paying more attention to the impact of products on the environment and utilizing the available resources to their fullest potential (Jones & Comfort, 2021) (Guimarães et al., 2024).

CONCLUSION

The paper has examined the effectiveness of Nature-Based Solutions (NBS) in mitigating floods in the coastal communities in a multifaceted dimension that spans across hydrological modelling, factual field-based information giving and socio-environmental factors. As seen in the results, such restored wetlands, mangrove buffers, green roofs, and bioswales, in the form of NBS, reduce the severity of flood depth, peak runoff, and storm water retention problems to a large extent compared to their standard grey counterparts. The best infiltration rates and the lowest run off coefficients

of all these interventions were highest in mangrove-based systems. This solidifies their significance in guard against storm surge and dissipate wave energy. Second, socio-economic evaluations revealed that NBS have vast additional advantages, such as defense against biodiversity, enhanced air and water quality, and recreation. The gains do not only make cities resilient to flooding. The qualitative studies depicted that the most effective manner to lessen attributes of flooding lies in the combination of NBS with information based city structuring, a case in point being locating the most significant projects in the most endangered places. Nevertheless, the outcomes also indicate that there exist certain major issues, which require their resolution, and they include the lack of urban space, the expensive maintenance, and the danger of eco-gentrification. This issue is only resolvable through the inclusive policies and involving all stakeholders. The Ken folklore solution of a combination of NBS, smart sensor-based products, and traditional flood barriers was the most cost-effective and efficient one on the long-term to work. This paper shows that NBS cannot be used as a panacea, yet they do revise how cities can address flood risk posed by climate change. In order to succeed in large scale, an institutional support is required, community and periodic monitoring. In that way, then that is not to say we should just consider NBS to be a technical solution, but rather it should be viewed as a larger social and environmentally-oriented scheme rooted on sustainability, fairness, and playable city government.

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