Enhancing Co-Benefits and reducing Flood Risks through Nature-based Solutions and Assessments: A Case Study in the Dead Sea Region of Jordan

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ABSTRACT

The integration of Nature-Based Solutions (NBS) with Sustainable Development Goals (SDGs) is a crucial step in the restoration of ecosystems and the mitigation of the effects of urbanization and climate-induced flooding. Moreover, National Statistical Policies (NSP) and SDGs have notably diminished flood and hydrogeological risk in developed countries. Nevertheless, developing countries like Jordan have encountered difficulties in implementing NSP and SDG. Accordingly, the objective of the present study was to evaluate the feasibility of implementing NBS in the Jordanian Dead Sea (DS) area for the first time. To this end, a novel approach was proposed, integrating the NBS and SDGs with the SA-GIS and Fuzzy Analytical Hierarchy Process (FAHP) approaches, with the objective of addressing the severe issue of urban floods in the DS area. Furthermore, a life-cycle cost-benefit analysis was employed to comprehensively assess costs and benefits over a specified time frame, utilizing key indicators such as Net Present Value (NPV) and the Benefit-Cost Ratio (BCR). The findings revealed that detention ponds, vegetated swales, rain gardens, and rainwater harvesting have BCR values exceeding one, suggesting that incorporating co-benefits into economic assessments significantly enhances the economic efficiency and viability of NBS. In conclusion, the proposed method can be applied globally and serves as a viable strategy for advancing sustainable urban growth and reducing the risk of disasters in developing countries like Jordan.

Keywords-nature-based solutions; Dead Sea; economic assessment; flood risk; co-benefits

I. INTRODUCTION

Floods represent a significant global threat, affecting approximately 250 million people annually and resulting in economic losses exceeding $40 billion [1]. Such disasters have a significant negative impact on the capacity for sustainable development in the affected regions [2-5]. Consequently, the solution to this problem necessitates the allocation of financial resources toward the implementation of flood adaptation strategies that safeguard the well-being of individuals, the integrity of assets, the resilience of infrastructure, and the sustainability of the natural environment. Governments and corporations around the globe provide financial support to NBS initiatives with the objective of enhancing health, biodiversity, and the environment. The European Commission has commended NBS for its innovative and cost-effective environmental, social, and economic benefits. Drawing inspiration and encouragement from nature can enhance resilience [6]. NBS has the potential to enhance roofing [7] and protect or restore damaged land [8]. Furthermore, NBS is crucial for environmental and social demands to be fulfilled [9-18]. Consequently, countries financing NBS recovery must consider present and future investments to guarantee efficacy, equality, and benefit-cost predictability [19]. Several studies have concentrated on flood risk reduction rather than NBS benefits [20-24], demonstrating that NBS mitigates flood risk and enhances health, biodiversity, and the environment.

In general, flood control risk assessment frequently employs cost-benefit analysis. The implementation of flood control measures can yield benefits with regard to water quality, biodiversity, and habitat structure. It is therefore essential to forecast potential trade-offs and optimize the use of NBS. Those in positions of authority, government officials, and other interested parties may quantify these benefits with a view to optimizing expenditure and resource use. To fully utilize NBS and proactively address its limitations, a systematic approach for integrating these novel benefits into CBA is imperative [25]. A number of economic assessments have been carried out to investigate the advantages of performance or economic commitment, as well as the indirect and direct costs involved. A substantial number of economic assessments have evaluated the advantages and indirect and direct costs associated with performance or financial commitment [26, 27]. The costs associated with the implementation of NBS are numerous and include expenses related to design, land acquisition, execution, sustaining, managing, opportunity, and human compensation. These costs are a result of missed earnings from alternative uses of the NBS [24, 28]. The costs associated with NBS can vary significantly depending on the specific life cycle stage and geographical region in question [27, 29]. The costs associated with transactions are not readily ascertainable and are subject to fluctuations, which impedes the formulation of effective policy and planning strategies [30]. It is challenging to make a comparison of the financial benefits of different methods and methodologies [21, 31]. Furthermore, authors in [32, 33] have identified numerous locations with a lack of data regarding economic assessments of flood risk management. These include a restricted estimate of intervention costs, a narrow focus on expected flood damage reductions, and the absence of urban co-benefits for the river watershed.

The Arab desert country of Jordan is experiencing an increase in rainfall due to population growth and urbanization. In 2018, a flash flood caused twenty-one deaths and destroyed the Dead Sea bridge due to weather changes. Researchers have developed flood hydrology models to anticipate runoff quantities and control water demand [34]. Jordanian scholars have put forward a range of effective flood mitigation measures [14, 15, 17, 35-37]. Authors in [35] effectively reduced flash flood risk by using rainfall data and Digital Elevation Models (DEMs), while authors in [36] used annual rainfall and evapotranspiration to map the Wadi Mousa floodplains. Thematic maps identified regions that were at risk of unexpected and catastrophic floods, while authors in [37] utilized the 1990–2016 runoff data to evaluate how climate change would influence the Al-Hasa basin.

The authors assert that previous studies have not examined the economic impact of floods on Jordanian society, nor have they investigated the causes and consequences of such events. This study aims to present a framework for assessing the economic value of NBSs on a larger scale in the DS basin, filling information gaps. This method is more effective than standard flood management evaluations because it incorporates co-benefits and analyzes NBSs' economic, environmental, and economic components. A CBA uses NPV and BCR to examine economics. Furthermore, the financial factors of flood risk reduction, additional benefits, and NBS costs were assessed to achieve this. CBA provides a formal framework and significantly enhances transparency in decision-making. This research presents the cost and co-benefit statistics resulting from a comprehensive literature review and local data analysis. The benefits of reducing flood risk were simultaneously calculated. The study used a hydraulic model and data. Given the lack of local data, the research employs value transfer to analyze the co-benefits and costs of changing value in the regional context. It is essential that the economic evaluation of each NBS project is conducted in a comprehensive manner, taking into account all relevant costs, benefits, and uncertainties. This approach is necessary to ensure the accuracy and objectivity of the evaluation and to prevent the introduction of any potential biases. Conversely, practitioners, scholars, and planners may gain a more accurate understanding of the costs and benefits associated with the implementation of NBS through the utilization of this technique. The proposed study included five measures (green roof, rain garden, rainwater harvesting, vegetated swales, and detention pond) and four co-benefits (education, air pollution reduction, biological control, and carbon sequestration), while acknowledging the omission of some CBA benefits. Quantifying the biophysical features for NBS economic assessments, which combine co-benefits, requires significant effort. Determining the monetary worth of these assessments necessitates environmental and sociocultural economic competence.

II. MATERIALS AND METHODS

This proposed research aims to economically enhance the NBS assessment by considering additional benefits beyond their main purpose, namely co-benefits, as shown in Figure 1.

A. Dead Sea Study Area

The lowest point of Earth, the DS research area, covers 67 kilometers of the Jordan Rift Valley, as evidenced in Figure 2. The combination of Saharan and Mediterranean deserts results in a semi-arid to hyper-arid hot climate in the south and east. The region experiences peak precipitation from December to February and a rainy season from October to May, which contribute to its distinctive character. According to Ministry of Water and Irrigation statistics, the lowlands receive 100 mm of precipitation annually, while the highlands receive 450 mm, as projected by the conducted research. It should be noted that the DS area was discussed in greater detail and with greater comprehensiveness by authors in [34].

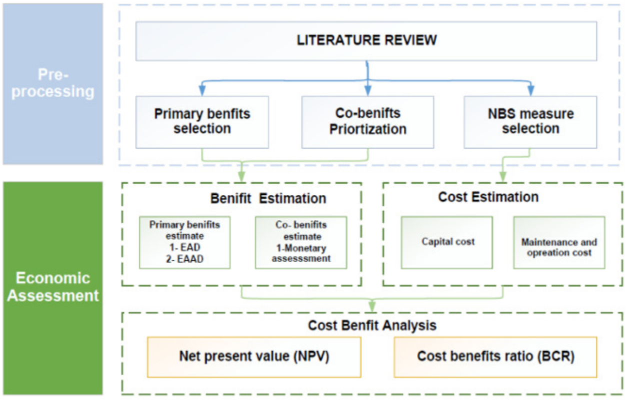

Fig. 1. Proposed methodology flow chart.

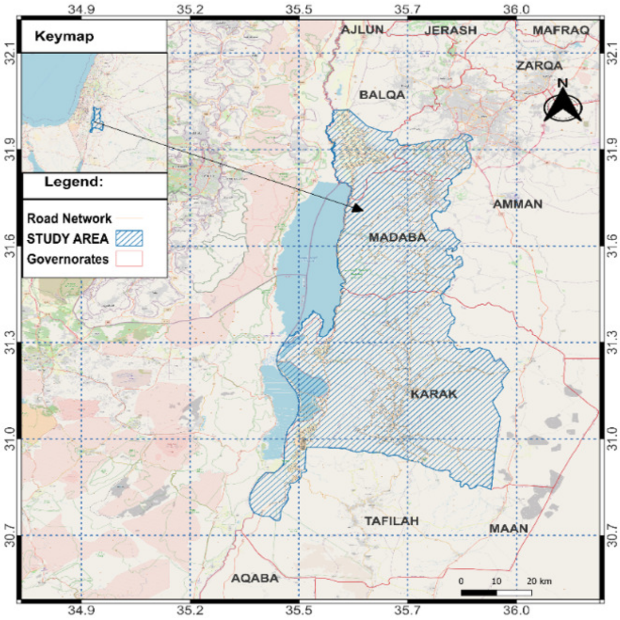

Fig. 2. The geographical location of the Dead Sea region.

B. Flood-Related NBS Measures

NBS is employed by numerous high-income municipalities on a global scale. As documented by the European Commission [6] and authors in [21], multiple high-income municipalities globally employ a range of innovative solutions to mitigate urban flooding, including the use of vegetated swales, green roofs, permeable pavements, rain gardens, detention basins, rainfall collection, and a cost-benefit analysis [38]. This research examines the global acceptance of these measures, while using the NBS explanation measurements presented by authors in [39, 40].

C. SDG Localization Occurs in Jordan/Dead Sea

Jordan, a developing Arab country with a population of 10 million, is facing significant challenges in achieving sustainability and resilience due to the rapid pace of urbanization. Local disputes and the expansion of urban areas due to the influx of migrants and asylum seekers are having a detrimental impact on the ecosystem. The sustainability movement has facilitated the creation and implementation of more effective policies in Jordan. However, the occurrence of regional crises in Iraq, Lebanon, Palestine, Syria, and the Arab Gulf has resulted in a deceleration of Jordan's sustainable growth. Notwithstanding these challenges, Jordan, currently ranked 80th globally, is firmly committed to the 2030 Sustainable Development Agenda and SDGs. The sustainable non-residential building development and green economics sectors demonstrate considerable potential for growth [41-43]. The United Nations (UN) in Jordan is dedicated to promoting the well-being of all individuals, with a particular focus on disadvantaged populations. The UN Sustainable Development Goals 2018–2022 framework represents a significant instrument for Jordan, facilitating the strengthening of institutions, the empowerment of people, and the expansion of economic, social, environmental, and political engagement. The Jordanian government and the United Nations are integrating Sustainable Development Goal 13, Target 13.1, which pertains to enhancing climate-related disaster resilience and adaptation while simultaneously promoting environmental preservation [44]. Nevertheless, recommendations for catastrophic risk management must be more detailed. It is imperative that Jordan's educational institutions integrate the SDGs into their curricula and adopt pedagogical approaches that align with the tenets of the SDGs. In response to the growing demand for sustainable development courses, college students are increasingly seeking greater exposure to the SDGs within their academic curricula. Students may choose to enroll in voluntary courses or pursue a university-level degree in sustainable development [45].

D. Cost and Primary Cost-Benefit Estimate

A Life Cycle Cost (LCC) analysis was conducted to inform the planning of NBS measures. The LCC analysis ensured that NBS would perform as intended throughout its projected lifespan. At the outset of the project, Capital Expenditure (CAPEX) encompasses research, land acquisition, and construction costs. The operation of a corporation necessitates the continual expenditure associated with maintenance and Operational Expenditures (OPEX). In accordance with the Flood Risk Management Appraisal Guidance, the evaluation of flood hazards and vulnerabilities contributes to quantifying the principal benefit of an optimistic bias, namely a positive and proactive approach to the reduction of flood risk. The fundamental metric for assessing flood risk, Estimated Annual Damage (EAD), enables decision-makers to quantify the annual economic losses incurred as a result of flooding. The EAD is calculated using the following equations: (1) predicts the annual impact of flooding and (2) suggests a continuous return time:

$$EAD = \int_{f=0}^{\infty} Damage\ (zf)df \qquad (1)$$

$$EAD = \sum_{i=1}^{n} \frac{(Damage\ i+1)+Damage\ i}{2} \times \left(\frac{1}{Ri} - \frac{1}{Ri+1}\right) \quad (2)$$

where f is the frequency of occurrence (inverse of return period), zf is corresponding to the event frequency f, *Damage i* is the flood damage corresponding to the return period event, R_i is return period event [Euro], and n is the number of return periods.

Authors in [46] illustrate the practical application of the EAD calculation, a process that directly informs flood risk management strategies, by summing the probability of exceeding the annual flood damage cost for all possible floods in a given year. In addition, the forecasts and costs exhibit the annual impact of flooding. Comparing the pre- and post-activity EAD yields the Expected Annual Avoided Damage (EAAD). The EAAD evaluates the co-benefits of risk reduction. This study demonstrates that NBS reduces flood risk and benefits both the society and the environment. A multi-criteria analysis in [47] shows the co-benefits of the case study. NBS impacts and biophysical indicators such as water storage and habitat establishment are examined. Benefits are valued using avoided damages, replacement costs, market value, travel costs, contingent choice benefits, transfer costs, and contingent valuation. Authors in [48, 49] review these approaches. A comprehensive assessment of NBS benefits should ensure reliable and thorough research. Economic studies of the co-benefits of NBS have the potential to impact environmental science, economics, and sustainability. Agriculture, green jobs, and carbon sequestration offer diverse benefits. Educational travel and real estate costs may change due to hedonic pricing, avoidance, and spending, including site inspection and degradation remedies. Co-benefit replacement costs can be utilized to estimate habitat development costs, such as resource replacement. Reduced damage costs can help avoid risks and injuries. Each NBS indicator has unique characteristics.

E. Cost-Benefit Analysis

Life Cycle Cost Benefit Analysis (LCCBA) is a standard NBS economic evaluation efficiency method. Long-term effects of NBS, such as operation and maintenance costs, are considered. During the project, the advantages and disadvantages are considered. Discounting calculates the decrease in future benefits by converting them to present values. This paper proposes the use of NPV and BCR as economic efficiency methods to calculate the benefits and costs of NBS. Equations (3) and (4) illustrate the metrics. NPV measures the difference between the present value of the benefits throughout a project and the projected expenditures, revealing the long-term net economic gains. The project is expected to provide more benefits than costs with a positive NPV:

$$NPV = \sum_{t=0}^{T} \frac{(EAD\ t,ref - EADt,measures)+CBt}{(1+dr)^{t}} - \left(Costexp + \sum_{t=0}^{T} \frac{OMt}{(1+dr)^{t}}\right) \times optimal\ bias \quad (3)$$

$$BCR = \sum_{t=0}^{T} \frac{(EADt,ref - EADt,measures)+CBt}{(1+dr)^{t}} \Big/ \left(Costexp + \sum_{t=0}^{T} \frac{OMt}{(1+dr)^{t}}\right) \times optimal\ bias \quad (4)$$

where *EADt, ref* is the expected annual damage of baseline scenario in the year *t*, *EADt,measures* is the expected annual damage of implementing measures in the year, *CB* is the total of the co-benefits from implementing yearly measures in the year, *dr* is the discount rate of future value, and the investment horizon *t* is the year, *Costexp* denotes the capital costs and *OMt* is the operation and management cost in year *t*.

However, a negative NPV indicates that the costs are greater than the benefits. Equation (3) calculates the NPV. The BCR evaluates the relative value of the investment benefits by dividing the total present value of the benefits with the total present value of the costs (4). A BCR > 1 indicates that the project is economically feasible, providing more benefits than costs. A BCR of less than 1 indicates that the project's costs will exceed its benefits.

F. Nature-Based Solutions Measures and Co-Benefit Selection

NBS actions were identified and stakeholder benefits were assessed using a multi-criteria approach. The study also ranks relevant activities and their most desired rewards based on local factors and individual and group preferences. The top three metrics and one stakeholder-suggested metric are selected. Green roofs, rain gardens, rainwater harvesting, vegetated swales, and retention ponds are the selected NBS. The research examines the benefits of statistical evaluation for biological control, carbon sequestration, air pollution reduction, and school field trips. Economic evaluations of NBS focus on flood risk reduction and ancillary benefits, with details of NBS measurements and locations being shown in Table I.

TABLE I. NBS MEASURE

NBS	Area [m^2]	% of Area	Description
Green Roof	840,763	42%	Rooftop vegetation supports buildings, provides urban greening, retains up to 90% of precipitation, and is a modern stormwater management approach.
Rain Garden	350,688	17%	A depression with absorbent soil and vegetation, capable of handling rain and flooding, is located away from buildings or site boundaries.
Rainwater harvesting	148,110	7%	The approach demonstrated collecting and reserving rainfall at the surface or subsurface aquifer to prevent its loss as surface runoff within the current urban drainage system.
Vegetated swales	452,312	22%	A drainage swale, or bioswale, is a system of densely planted channels that filter, slow, and infiltrate storm water runoff, reducing peak discharge rates.
Detention Pond	220,000	11%	Rainwater harvesting and storage typically occur in large, excavated areas, such as parking lots, parks, sports fields, and roadside areas.

III. RESULTS AND DISCUSSION

A. Features of Flood Zone Areas

The criteria maps from Figure 3 were employed to overlay zone areas in order to create target site spatial patterns. The areas on the left and those with steep inclines are less hazardous. The soil is classified as sandy loam. The growth of plants and the lack of fertility in the soil have a greater impact on the landscape than the presence of streams. Those areas exhibiting a relatively low risk include elevations of moderate height, sharp inclines, clay-loam soil, and sandy-clay-loamy lowlands. These areas, situated at a considerable distance from river systems, present a viable opportunity for development. In areas of moderate risk, a modest slope separates highland and lowland at an intermediate elevation. The soil composition varies, with clay-loam and sandy-clay-loamy soil types being the most prevalent. Despite the urbanization of the DS area, the moderate-risk zone is predominantly flat or sloping. Lowlands are composed primarily of clay-loam soils, which are situated in close proximity to urban centers and river systems. The majority of catastrophe zones are characterized by flat or moderately sloped topography, with clay-loam soil types prevalent in these areas. The presence of water, such as sea and streams, is also a common feature. The data derived from spatial risk assessments can prove invaluable to a diverse range of professionals, including urban planners, environmental engineers, and lawmakers. By providing insights into potential hazards and vulnerabilities, these assessments can inform the development of resilient and sustainable urban infrastructure and land use planning strategies, as well as the management of catastrophic risks.

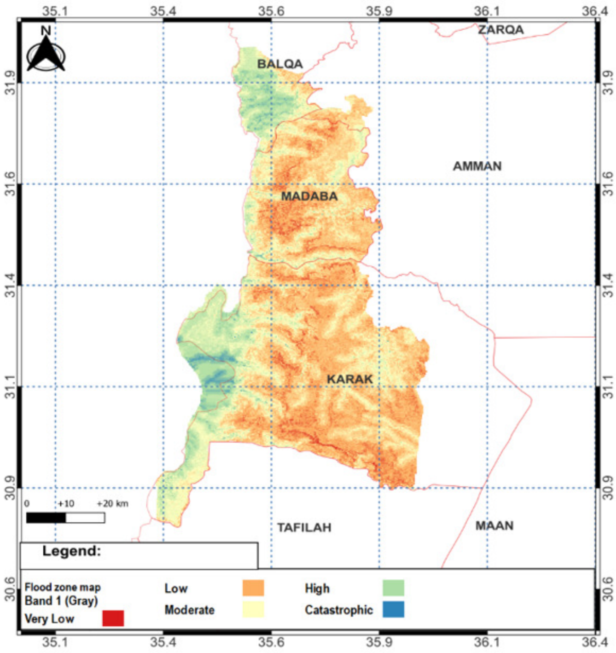

Fig. 3. Flood zone areas.

B. Implementing Appropriate NBS Measures for Floods in Identified Risk Zones

In comparison to the established design standards, NBS characteristics demonstrate compatibility with the designated target area. The 50% alignment allows for the facilitation of decision-making processes. All metropolitan locations, particularly those with impermeable DS surfaces, are suitable for NBS measurements. The map indicates the locations of floods, target areas, and natural remedies (Figure 4). The stable geography of the area is conducive to the classification of all DS zones and towns [50]. The presence of swales and transitional zones provides benefits to inhabitants of the mild zone. It should be noted that these structures may not remain intact in clay-loam or disaster-prone streams. The moderate slopes, clay-loam, and sandy-clay-loamy soils of rain gardens, in addition to their highland location, render them optimal for low-rise construction. The implementation of low-risk rain garden operations is constrained by the presence of steep slopes.

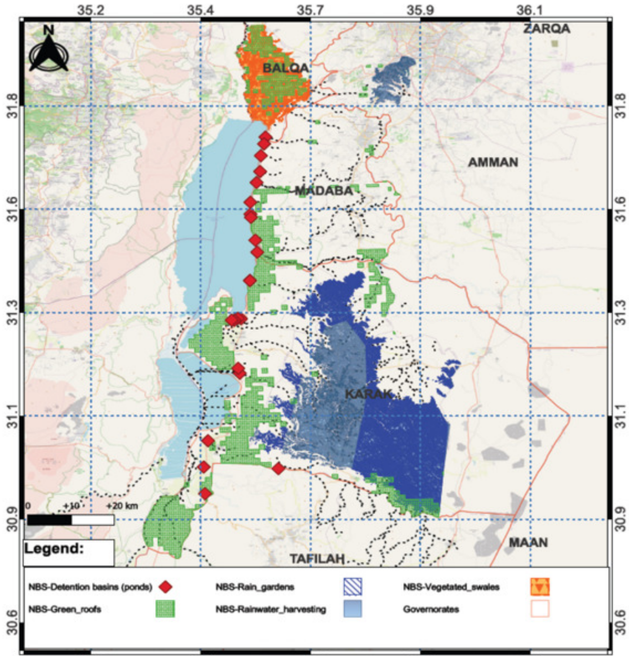

Fig. 4. NBSs target locations.

The research indicated that locations with minimal risk of precipitation collection were effective in gathering rainwater. The physical components and topography align with the established design criteria for rainwater collection. The practice of rainwater harvesting serves to reduce the occurrence of low-risk floods. Detention basins are effective for mitigating moderate, large, and catastrophic threats. The soil is low-lying and water-logged, with a low sand content. At the mouths of wadi streams, the relevant authorities construct retention ponds. The high infiltration capacity of porous pavements is beneficial for low, moderate, and extremely low risk zones. The use of porous and conventional pavements for the mitigation of urban floods, along with the presence of clayey soil, renders permeable pavement unsuitable for use in the main danger zone and five target locations, as outlined in [51]. The implementation of rain gardens, porous green pavement roofs, rainwater storage, and vegetated swales has been demonstrated to effectively mitigate the occurrence of flooding, although the use of NBS is a prerequisite. The efficacy of these measures in flood control hinges on their ability to enhance infiltration and curtail downstream discharge.

C. Cost Estimation

This research employs the LCC conceptual framework to ascertain the financial implications of a NBS strategy. It includes an analysis of capital investments, maintenance costs, and operational expenses. To estimate these charges, the current study deployed a methodology that entailed the utilization of unit cost literature and the extrapolation of numbers derived from other relevant studies. Previous researches on unit costs include that of the World Bank [52], Aerts [53], and Natural Water Retention Measures (NWRM) [54]. Following an analysis of the expenses, they were applied to Jordan with 2024 designated as the reference year to ensure homogeneity. In order to certify consistency in the evaluation of costs, the price per square meter was used for the green roof, while the price per cubic meter was deployed for the detention pond. In cases where multiple unit cost values are available, the mean value is employed. To ensure the accuracy of the project budget, bias recommended a 30% optimum for indeterminate components and uncertainties. Table II presents the annual costs associated with installation, maintenance, and operation. The advantages of NBS include a reduction in air pollution, an improvement in health outcomes, and a decrease in the costs associated with school trips. While educational organizations bear the financial responsibility for these visits, a comprehensive literature evaluation and data analysis must be conducted to ascertain their economic benefit. The valuation methods include market value, averted damage, and travel expenses. The market value method calculates the economic worth of carbon sequestration using the pricing of EU carbon permits.

TABLE II. YEARLY COSTS FOR IMPLEMENTATION, MAINTENANCE, AND OPERATIONS IN MILLION EUROS

NBS	Inv. cost €/m^2	Total cost	Cost/yrs	Maint. Cost 2.5%
Green roof	30	25.22	1.01	0.03
Rain garden	50	17.53	0.70	0.02
Rainwater harvesting	100	14.81	0.59	0.01
Vegetated swales	40	18.09	0.72	0.02
Detention pond	100	22.00	0.88	0.02

D. Primary Benefit Estimation - Expected Annual avoided Damage

A flood risk assessment is concerned with the hydrodynamic flood depth and the vulnerability of the land use in question. An examination of floods was conducted using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) and Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) models. The revision and calibration of the model to incorporate 1D–2D impacts facilitated the simplification of hydrodynamic simulations and flood scenario projections. The results of the hydrodynamic modeling of flood inundation were used to create high-resolution raster, and the ArcGIS intersect tool was employed to calculate flood damage based on flood depth. In order to compute the direct flood damage costs, the methodologies proposed in [45, 55] were adopted, which were used to predict the extent of flood inundation. The direct impact of flooding has resulted in damage to the infrastructure of roadways. It is widely accepted that the greater impact of floods is attributable to indirect losses, which are estimated to account for approximately 70% of the economic damage caused directly by flooding events [50, 56]. The research indicates that the indirect effects vary considerably and may be as significant as the direct effects. As the case study lacked data pertaining to indirect damage, indirect economic losses at 70% were evaluated, in accordance with the findings of earlier studies. Figure 5 illustrates the total damage estimates for five incidents with varying recurrence intervals. The available research indicates that the installation of retention ponds serves to mitigate damage during all return periods. In comparison to the baseline circumstances, the implementation of green roofs has been demonstrated to result in a reduction in damage costs.

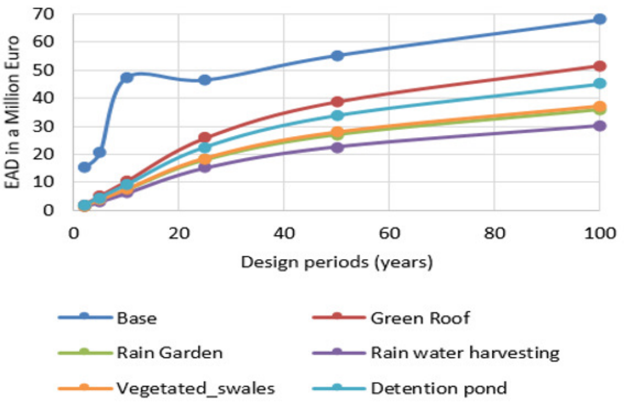

Fig. 5. An overview of total damage cost of various flood return periods for baseline and four NBS measures.

E. Cost-Benefit Analysis

The reduction of flood risk is based on the BCR, which has a significant influence on the outcome. It is possible that the reduction of flood damage may lead to a reduction of the BCR to a greater extent than other criteria, thereby increasing costs above benefits. The implementation of rain gardens, vegetated swales, and rainwater harvesting systems has been found to enhance BCR, therefore substantiating their intrinsic value. The implementation of flood protection retention ponds has been demonstrated to be a cost-effective solution, with an approximate BCR of twice that of other alternatives. Figure 5 portrays the results of the cost-benefit analysis (CBA) with a 3% discount rate over a 25-year period. The European Commission [57] is responsible for establishing the duration of infrastructure projects and the applicable discount rates. Figure 6 depicts the primary benefit, flood risk reduction, along with the NPV and cost for each measurement. It is possible that the implementation of green roofs and detention ponds may result in a net cost rather than a net saving with regard to flood risk. When co-benefits minimize floods, detention ponds are economically viable, while integrating flood mitigation into NPV calculations of vegetated swales, rain gardens, and rainwater harvesting can yield cost-effective benefits. Utilizing solely flood damage reduction methods is less effective than employing other strategies. With the exception of the green roof, vegetated swales, rain gardens, and rainwater harvesting, which are more cost-effective non-structural NBS options due to their increasing BCR. Detention ponds for flood risk mitigation have a double BCR.

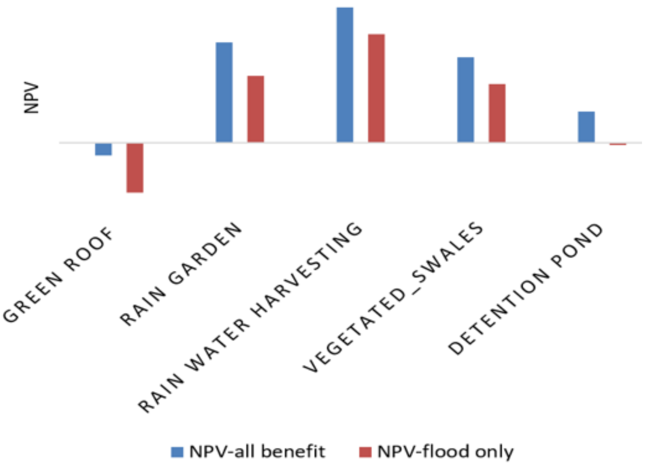

Fig. 6. CBA for NPV for 25 years design life cycle with a 3% discount rate.

IV. RESULTS AND DISCUSSION

The objective of the present study is to finalize the economic valuation of the DS NBS. The method employs the NPV-BCR, CBA approach, with a review of the economic literature examining the potential economic benefits of NBS, as well as the costs associated with flood risk reduction. A CBA is a necessary component of decision-making processes, facilitating transparency and accountability [16], and was conducted using both local data and a review of the relevant literature. The benefits of flood risk reduction are estimated using a hydraulic model and vulnerability data. In the absence of local data, the researchers employed transfer values to estimate co-benefits and costs, adjusting the figures to reflect area conditions. It should be noted that the cost and benefit estimates presented here differ from the primary focus of the study. The evaluation of NBS's economic value is conducted in a more systematic manner. Accordingly, the economic assessment must take into account potential errors and biases, as well as the costs, benefits, and uncertainties associated with the NBS project. This technique enables professionals, academics, and strategists to assess the benefits and drawbacks of NBS. This research investigates five nature-based methods (green roofs, rain gardens, rainwater collection, vegetated swales, and detention ponds) and four benefits (education, air pollution reduction, biological control, and carbon sequestration). In order to evaluate the economic value of NBS and its associated co-benefits, it is necessary to measure and quantify the relevant biophysical properties. Quantifying their value, and possessed competence in the social, environmental, and economic spheres, is needed. The research indicates that green roofs and retention basins contribute to mitigating the risk of flooding and subsequent damage. Conversely, the financial implications of damaging rain gardens and rainwater harvesting systems are comparatively minimal. It was estimated that green roof damage amounted to 840,763 m² (42%), while the captured rainwater area was 148,110 m² (7%). Despite employing a range of pricing methodologies to assess co-benefits, the cost of rainwater harvesting exceeds that of the green roof (€/m²), as illustrated in Tables II and III.

TABLE III. MONETARY VALUES OF CO-BENEFITS FOR EACH SCENARIO IN MILLION EUROS

NBS	CS	BC	APR	E-NBS	T
Green Roof	5.04E+03	2.52E+03	8.41E+04	-	9.00E-02
Rain Garden-Euro	1.05E+04	-	1.05E+06	5.47E+03	1.07E+00
Rainwater harvesting	7.41E+03	-	7.11E+05	3.85E+03	7.20E-01
Vegetated Swales	1.09E+04	7.24E+03	5.43E+04	-	7.00E-02
Detention pond	6.60E+03	4.40E+03	-	2.20E+01	1.00E-02

CS: Carbon Sequestration; BC: Biological Control; APR: Air Pollution Reduction; E-NBS: Education [NBS trips); T: Total in a million Euro

The market value technique assesses the impact of carbon sequestration, mitigates damages such as air pollution and biological management, and accounts for travel costs associated with education-related NBS visits. The implementation of rainwater harvesting and rain gardens has been found to yield considerably greater co-benefits than the construction of detention ponds. The former has been estimated to have a value of 0.72 million euros, while the latter has a value of 0.01 million euros. The discrepancy can be attributed to the fact that inundated plain projects encompass a relatively smaller area. The detention pond, with an area of 220,000 m², is a smaller-scale intervention than the green roof. The restoration of the floodplain yields a comparatively limited impact, thereby diminishing the benefits derived from it. The evaluation of co-benefits entails the utilization of a multitude of value methodologies, a necessity arising from the inherent discrepancies in measures and data. In order to conduct contingent valuation and choice experiments, it is necessary to carry out resident sample surveys [23]. The evaluation methodologies proposed for the study reveal the economic effects of NBS, but they are not without limitations. It may be necessary to enhance the EU carbon permit pricing-based carbon sequestration market value strategy in order to accommodate the evolving dynamics of carbon markets. It may be also required to give further consideration to the intangible advantages of carbon sequestration and the potential for local variations. While the avoided damage technique is useful, it is important to note that literature studies assessing air pollution and biological control damage reductions tend to be subjective and potentially erroneous. It may be thus prove necessary to incorporate the broad and often intangible educational benefits associated with nature-based activities into the analysis of the costs associated with the NBS trips. When flood risk mitigation is considered in absolute terms, the cost-benefit analysis indicates that all methods are costlier than the savings they generate. Figure 7 shows that detention ponds have a positive

NPV of 2.10 and a BCR of 1.13, in comparison to -0.06 and 1, both ensuring cost-effectiveness and economical gain.

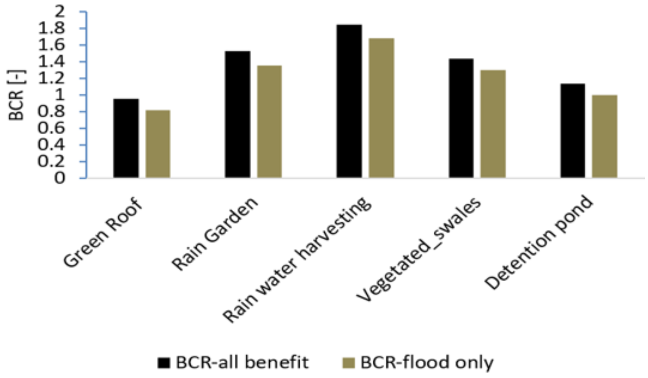

Fig. 7. CBA for BCR for 25 years design life cycle with 3% discount.

The economic effectiveness of NBS depends upon the presence of the co-benefits [58]. The inclusion of co-benefits in the NBS assessment may enhance confidence and adoption, thereby improving flood risk management [16]. The present study examined the potential co-benefits of CBA flood risk reduction. The individual measures were subjected to analysis to ascertain the economic value of each metric. A comparison of NBS and traditional flood control systems is required in order to identify the most cost-effective combinations. In consideration of the NBS technique, the identification of synergies and interactions facilitates the determination of optimal cost-benefit ratios. This approach would enhance the efficacy of NBS in stream basin management and decision-making, consequently reducing the likelihood of flooding.

V. CONCLUSIONS

The objective of this study is to enhance flood risk management by integrating monetary co-benefit analysis with Nature-Based Solutions (NBS) economic assessments. It was recommended that a Cost-Benefit Analysis (CBA) be conducted using the Net Present Value (NPV) and Benefit-Cost Ratio (BCR). The study presents a theoretical framework for assessing the economic advantages of NBS and a mechanism for adapting the assessment to unique sites, therefore ameliorating the accuracy of economic evaluations. To ensure comparability, adjustments have been made to prices and currency rates. The costs and benefits of this approach have been analyzed in the context of the Jordanian Dead Sea (DS) region, with and without additional benefits and the key findings are:

- An inadequate economic assessment of NBS is one that fails to consider co-benefits, which necessitates an understanding of social and environmental economics.
- The implementation of upstream flood mitigation techniques, such as vegetated swales and detention ponds, is effectively decreasing the risk of flooding.
- The implementation of rain gardens and rainwater harvesting techniques has been demonstrated to result in a reduction of damage in comparison to the base-case scenario.
- A variety of methodologies are employed to assess carbon sequestration, air pollution reduction, and biological control.
- The research highlights the need for more precise indicators of economic advantages and disadvantages to guide the development of a comprehensive evaluation method for NBS.
- The cost of all flood risk reduction options exceeds the benefit of reducing flood damage.

The study's scope was limited to an examination of historical flood damage costs in Jordan. The process of quantifying biophysical characteristics is inherently time-consuming, which in turn limits the economic assessment of NBS with co-benefits. In order to determine their value, it is required to possess skills in both environmental and social economics. A subsequent study should undertake a comparative analysis of NBS and conventional flood control measures, with a view to identifying the most cost-effective combinations. The analysis of NBS measures of synergies and interactions facilitates the identification of optimal combinations of benefits and cost-effectiveness. The application of this technique would render NBS a more feasible and applicable tool in the context of river basin management and decision-making.

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