Spatial Multi-Criteria Analysis for Discovering Nature-Based Solutions Location for Urban Flood Mitigation in Accra

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Abstract

In recent years, Nature-Based Solutions (NBS) have become instrumental in restoring ecosystems and reducing the negative effects of hard surface developments. Existing studies have shown the potential of NBS in mitigating urban floods and reducing overall hydrogeological risks, especially in high-income areas. However, there is limited knowledge on area-specific NBS implementation and the locational suitability of areas to support different NBS for urban flood mitigation in medium to low-income regions. A methodology based on Spatial Multi-Criteria Analysis (SMCA) has the potential to spatially combine and synthesize information to elicit spatially-specific opportunities for NBS implementation. However, an SMCA tool to determine suitable locations for different NBS measures for urban flood mitigation does not yet exist. In order to address this research gap, this study developed an SMCA methodology to identify different target areas where specific urban flood-related NBS measures can be implemented to minimize urban flood occurrence in Accra, Ghana. The study revealed different locations where urban flood-related NBS measures could be applied. It also demonstrated how specific NBS measures could be tailored to the characteristics of different areas in Accra to ensure effective urban flood mitigation. The suggested methodological approach provides a spatial knowledge base for flood management institutions to integrate NBS into flood management schemes. The approach has application potential for other geographic contexts facing urban flood risks. Future research could focus on possible ways of integrating NBS into the spatial development of cities.

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Introduction

In recent years, cities across the globe have adopted "Nature-Based Solutions" (NBS) to restore natural areas and ecosystems and reduce the environmental challenges linked with hard surface development (Medrano, 2019). The European Commission (2020) defines NBS as actions inspired by, supported by, or copied from nature that are used to address a variety of social, economic, and environmental challenges sustainably. The need for NBS became more urgent with current climate change effects and the undesirable trend of ongoing urban expansion being a significant challenge for most cities in low, medium, and high-income countries (Kabisch et al., 2016; Fritz, 2017). The concept of NBS and other interrelated concepts like Ecosystem-based Adaptation, Urban Green Infrastructure, and Ecosystem Services are being promoted to address urban challenges such as urban floods, urban heat islands, air pollution, water supply, erosion, groundwater depletion, and recreational-related problems (Liu et al., 2021; Gehrels et al., 2016; Santiago-Ramos & Hurtado-Rodríguez, 2022).

Urban floods are the most frequently occurring natural disasters worldwide and affected about 178 million people in 2010 (Jha et al., 2011). Using NBS measures to address urban flood challenges is now becoming "a new way to go," considering the rate of urbanization and how cities are developing (Stagakis et al., 2019). Due to rapid urbanization, the natural landscape in most metropolitan regions of the world has been transformed into hard surfaces (Kabisch et al., 2016). As a result, urban surfaces' permeability and infiltration capacity decrease, leading to higher surface runoff and inundation (APFM, 2012). Additionally, the increased sedimentation from an unprotected surface like bare soil and solid waste production in rivers and other drainage infrastructure also affect the free flow of water, contributing to urban floods (APFM, 2012).

The African continent, comprised mainly of medium to low-income countries, is seen as one of the fastest urbanizing regions globally (Güneralp et al., 2018). The urbanizing population is growing twice as fast as in other regions (Güneralp et al., 2018). This high population growth has influenced most African cities' rapid physical expansion (Yiran et al., 2020). The expansion sometimes happens in hazard-prone areas (Acheampong & Ibrahim, 2016). Consequently, as highlighted by Ahiablame and Shakya (2016), the devastating urban flood occurrences in Africa are not exclusively linked to climate change but also to urbanization dynamics, which affirms an urgent need for NBS in the region to increase the permeability of urban surfaces to minimize urban floods.

NBS usage to minimize urban environmental challenges such as floods is mostly seen in cities in high-income countries (Kumar et al., 2020). As such, different methodological approaches have been generated to using NBS measures to mitigate urban floods. On the environmental dimension of using NBS for urban flood mitigation, studies evolve around the potential contribution of NBS in reducing overall hydrogeological risk. For instance, Magliocchetti and Fasolino (2021) and Ruangpan et al. (2020) used a literature review and case study approach to reveal the benefits of multiple NBS measures to mitigate urban floods. Lee et al., (2018a,

2018b) also employed in-depth empirical case studies in determining suitable NBS for different areas within a jurisdiction. Furthermore, Dahan and Al-Komaim (2017) applied spatial analysis to support an effective implementation of NBS focusing on a single measure, namely rainwater harvesting.

In contrast, there is limited knowledge on applying NBS measures to mitigate urban floods in medium to low-income countries, including the African region (Kumar et al., 2020). Urban flood mitigation studies are rather focused on engineering solutions (Soz and Stanton-Geddes, 2016). These engineering solution studies consequently influence urban flood management strategies in the region (Soz and Stanton-Geddes, 2016). However, according to Tengan and Aigbavboa (2016) and Ogie et al. (2020), existing urban flood strategies in most medium to low-income areas have not successfully resolved the urban flood situations to expectation.

Stagakis et al. (2019) argue that the design and implementation of NBS measures should be area specific. Therefore, NBS studies and approaches developed in most high-income countries may not be applicable in medium to low-income countries (Stagakis et al., 2019). Also, limited studies capture the locational suitability of areas in support of multiple NBS measures for urban flood mitigation. Concerning the limited locational suitability studies for NBS, a methodology like Spatial-Multi-Criteria Analysis (SMCA) can synthesize different types of information to inform decisions and assess their spatial implications (Malczewski & Jankowski, 2020). Yet, there has not been an SMCA tool for determining suitable locations or target areas for different NBS measures for context-specific urban flood mitigation.

To address this gap, this paper aims to develop an SMCA methodology to identify different target areas where specific urban flood-related NBS measures can be implemented to minimize urban flood occurrences focusing on Accra, Ghana. Over the years, Accra, the capital and largest city in Ghana, has seen an increasing rate of urban flood occurrences partly due to uncontrolled rapid urban expansion (Amoako & Boamah, 2014). Hence, this study answers questions on where NBS measures can be instilled in cities for urban flood mitigation.

This paper is structured in five sections. The second section elaborates on the research methodology. It describes specific urban flood-related NBS measures and further explains the research design, study area description, research data, and analysis. The third section presents results based on the study objectives and questions, while the fourth and fifth sections further discuss the study findings and give conclusions, respectively.

Methodology

This paper adopts a case study approach since it allows an in-depth exploration of urban flood issues and NBS-related matters about a jurisdiction (Crowe et al., 2011). It employs a mixed-method approach, combining SMCA methodology and qualitative comparative analysis to achieve the paper's aim. In the following subsections, we briefly introduce the specific urban flood-related NBS measures, study area, and its justification, followed by the data used and its analysis.

Urban Flood-Related NBS Measures

Several urban flood-related NBS measures are being used worldwide. The European Commission (2015) and a state-of-the-art review by Ruangpan et al. (2020) reveal six NBS measures used by most high-income areas across the globe to tackle urban flood situations. These six urban flood-related NBS measures will be the focus of this study, and they include green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements. Table 1 highlights the description of the mentioned NBS measures.

Study Area

In Ghana, uncontrolled rapid urban expansion is primarily observed in major metropolitan areas, including Accra and Kumasi (World Bank, 2015). The Greater Accra Metropolitan Area (GAMA), for instance, is the smallest region in Ghana in area, yet, it accommodates about 25% of Ghana's urban population (Ghana Statistical

Table 1 Description of the specific urban flood-related NBS measures

NBS measure	Description
Green roofs	A flat or sloped rooftop that supports vegetation on top of buildings
	Provides urban greening for buildings, people, or the environment
	Ability to retain up to 90% of the precipitation that falls on them
	Serves as one of the modern approaches to stormwater management
Vegetated swales	It can also be called a drainage swale or bioswale
	Shallow stormwater channels densely planted with a variety of grasses, shrubs, and trees designed to filter, slow, and infiltrate stormwater runoff
	Reduce peak discharge rate and total runoff volume
	Used as a pre-treatment approach for other structural water best management practices (BMPs), especially from roadway runoff
Rain gardens	Shallow depression, with absorbent yet free-draining soil covered with vegetation
	Ability to absorb rainwater and withstand occasional surface runoff and temporary flooding
	Situated some distance from buildings or site boundaries
Rainwater harvesting	The technique of collecting and storing rainwater at the surface or in a sub-surface aquifer before it is lost as surface runoff
	Additional measures to existing urban drainage infrastructure
Detention basins	Used to gather and temporarily store rainwater
	Could be large, excavated areas purposely designed at vantage locations for collecting surface runoff
	Incorporated mostly on parking lots, parks, sports fields, and roadside areas
Porous pavements	Also known in some areas as permeable or pervious pavement
	Designed to permit stormwater to penetrate through void spaces
	Used in place of conventional pavements for both pedestrian and vehicular traffic routes, without the need for any additional stormwater management feature

Sources: (Magill et al., 2011; Longobardi et al., 2019; Pennsylvania, 2006; Bray et al., 2011; IRICE, 2006; Ammar et al., 2016; Lee et al., 2018a, 2018b; Oregon Sea Grant, 2011)

Service, 2014). According to Ghana Statistical Service (2013), GAMA's population increased from 1,431,099 in 1987 to 4,010,054 in 2010. The presence of the urban population in the region is the reason for the 35% increase in the area's physical expansion between 1985 and 2015 (Ministry of Environment, Science, Technology, and Innovation et al., 2017).

The UNCT Humanitarian Support Unit (2015) considered the uncontrolled rapid urban expansion in GAMA as part of the causative agents of urban floods in the area. However, there is also limited attention to the use of NBS in tackling urban flood occurrences. Flood mitigation studies, projects, and tools in GAMA and Ghana are generally geared towards constructing and desilting drains (Ahadzie & Proverbs, 2011) and how proper solid waste management can help reduce the frequency and intensity of urban floods (Marinetti et al., 2016). Unfortunately, the existing tools and projects have not served their functions of mitigating urban flood events (Tengan & Aigbavboa, 2016). The underserviced urban flood management tools and projects call for adjustments and innovative strategies like NBS. In GAMA and Ghana, the absence of NBS-related tools and projects might be linked to the lack of a comprehensive spatial study that provides basic locational knowledge of urban flood-related NBS measures to mitigate urban floods.

Case Study Selection

As this study seeks to identify different target areas where urban flood-related NBS measures can be implemented, the study area was purposely selected based on the following criteria: The area should have seen a rapid physical expansion in the last ten years. Secondly, the area has experienced increasing urban flood events in the last ten years. Finally, the area's landform should not be flat to capture the different potential flow dynamics that could benefit from different NBS measures.

The terrain of GAMA is generally flat, with undulating features in the peripheral areas (Stow et al., 2016). Oduro et al. (2015) also revealed that the peripheral areas in GAMA covering Ga South, Ga West, Ga East, Adentan, and Kpone Katamanso Municipalities have experienced a rapid urban expansion in the last two to three decades. These areas were also highlighted by Ackom et al. (2020) as areas experiencing increasing flood events in recent years. Hence, the Ga East Municipality was randomly selected from the mentioned peripheral areas in GAMA for the study.

Description and Justification of Ga East Municipality

Ga East Municipality is one of the 16 municipalities making up GAMA (Ghana Statistical Service, 2014), and it is one of the fastest-growing areas in GAMA. The Ghana Statistical Service (2014) stipulated that 71.1% of people living in the municipality are migrants from other regions of Ghana, and the migrant composition is the reason for about 20% of GAMA's expansion being observed in the Ga East municipality (Amfo Otu et al., 2012). The rapid urban expansion is characterized by residential, industrial, and commercial developments (Ackom et al., 2020). On flooding, areas in the municipality that were without flood records

some years back are recently experiencing flood events, negatively affecting quite a number of inhabitants in the area (Ackom et al., 2020). Therefore, looking at the relationship between the rapid urban expansion and the increasing flood events in recent years, the Ga East Municipality is one of the typical areas in GAMA that will need NBS measures as an alternative and complementary approach to resolve its flood situation.

The municipality is located in the northern part of GAMA, covering 83.5 km^2. It is bounded by Accra central to the south, Ga West Municipality to the west, Adentan Municipality to the east, and Akwapim South District to the north (see Fig. 1). According to Ghana Statistical Service (2014), the municipality falls within the savannah ecological zone. The area's average temperature ranges between 25.1 °C (the coolest) in August and 28.4 °C (the hottest) in March, with an overall 26.8 °C average. The annual rainfall pattern is around 730 mm (Ghana Statistical Service, 2014). There are two rainy seasons, which are also the same for the entire country, thus from April to July and September to November, with peak periods recorded in June and October. The municipal's relief is generally gentle and undulating in some parts, with heights ranging from 42 to 374 m (Ghana Statistical Service, 2014). There are major rivers and seasonal streams that run through the municipality. They include the Odaw river, Sesemi, and Dakubi streams (Ghana Statistical Service, 2014).
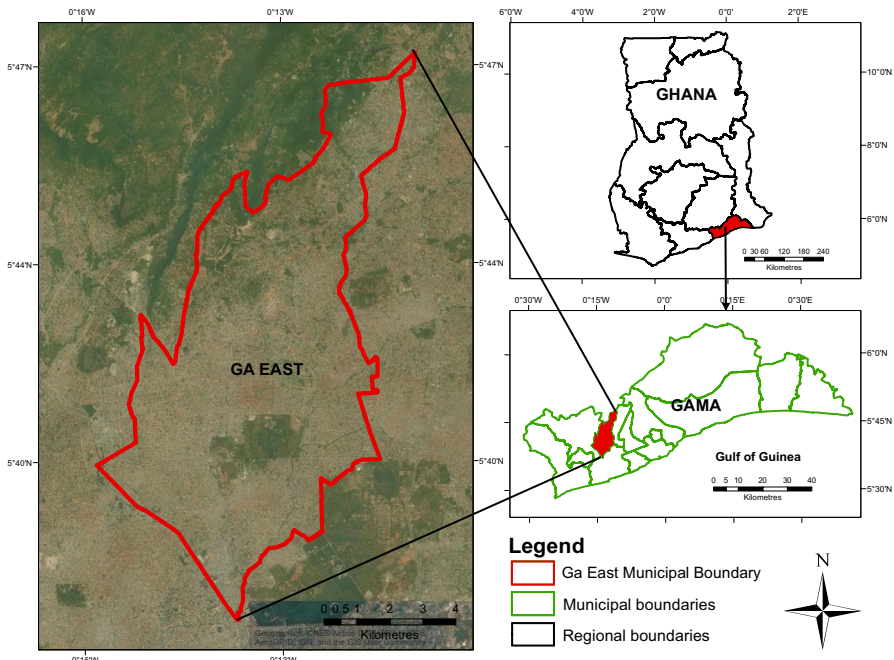

Fig. 1 Contextual map of Ga East Municipality. Sources: (CERGIS-University of Ghana, ESRI, OSM)

Data Sources and Collection

To achieve the study objectives of developing an SMCA-based methodology to identify different target areas where urban flood-related NBS measures can be implemented and highlight different locations where specific NBS measures will be effective in urban flood minimization in Accra, mainly secondary data were used. The data included the location of rivers/water bodies, soil texture map, Digital Elevation Model (DEM), and satellite (Landsat) image (2020) of the study area. Also, literature on specific urban flood-related NBS measures (green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements) was used to derive desired design conditions in building the NBS measures. These data were obtained from government and research institutions and online platforms. Additionally, interviews were conducted with ten urban flood management experts and professionals to rank the criteria used in the SMCA. Purposive sampling was used to select the experts for consultation. The experts were planners, engineers, and technical officers working in flood management institutions. Table 2 summarises the data used and their sources.

Spatial Data Processing and Image Classification

For preparing the LULC map, 2020 Landsat image was downloaded from USGS—Earth Explorer website (see Table 3 for the Landsat image details). The Landsat image downloaded contained different band images which were stacked into one single multispectral image. Then, a sub-setting was done to delineate and carve out the study area. This was done because the Landsat image covered a larger area not needed for this study. Afterwards, the image was projected into the Universal Transversal Mercator (UTM) zone 30N to align the geographic reference with the reference of other spatial data used for the study.

The supervised classification maximum likelihood algorithm was used to classify the stacked image. This classification algorithm was used due to its strong theorical foundation and its ability to categorizes image pixels into classes taking into consideration the spectral properties of the pixels (Al-doski et al., 2013). In this regard, 50 training samples were gathered for each identified landcover type by creating polygons around the landcover type features. The polygons were created purposely to cover all sections of the study area and to capture the spectral variability under each land cover type. The training samples were collected with the help of Google Earth and the researchers' familiarity with the study area. The training samples were further converted into Region of Interest (ROI), which were used as signature files to classify the study area image into four major land cover types, including bare land, forest, grassland, and built-up. An accuracy of 86.75%, with a kappa value of 0.74 was achieved for the performed classification.

Table 2 Data used for the study

Data type	Data format	Resolution	Year	Source
Land use land cover (LULC) map	Raster	30 m	2020	Authors' image classification (using 2020 Landsat image from USGS—Earth Explorer)
Soil texture map	Raster	30 m	2019	CERSGIS, University of Ghana
Digital Elevation Model (DEM)	Raster	30 m	2019	CERSGIS, University of Ghana
Location of rivers/ water bodies	Vector	-	2019	CERSGIS, University of Ghana
Transcribed interviews	Text	-	2021	Field
Written documents on selected NBS measures	Reports and journals,	-	2010 or newer	Scopus, Web of Science, Google Scholar, etc

Table 3 Characteristics and properties of the 2020 Landsat image used

| Acquisition date	Path/Row	Landsat	Sensor	Spatial resolution	Number of Bands
02/01/2020	193/056	Landsat 8	OLI—TIRS	30 m	11

Analysis of Data

The analysis consisted of two parts. First, the SMCA was done by developing and calculating a Target Area Index (TAI) to identify target areas for implementing specific urban flood-related NBS measures in the Ga East Municipality. Secondly, to determine appropriate NBS measures for different target areas, a qualitative comparative analysis of the SMCA results and the design conditions of the specific urban flood-related NBS measures was done. The flowchart in Fig. 2 shows the generic steps of the study analysis.

Spatial Multi-Criteria Analysis (SMCA)

SMCA is also termed GIS-based Multi-Criteria Analysis (GIS-SMA) (Malczewski & Jankowski, 2020). The approach ensures an effective identification and structuring of spatial decision problems and geographically presents a systematic analysis of alternative decisions, as compared to other decision-making methodologies (Gonzalez & Enríquez-De-Salamanca, 2018). Therefore, SMCA is seen as a useful approach to identifying suitable locations for implementing specific NBS measures.

The SMCA was executed in ArcGIS 10.8 by developing and calculating a TAI based on worse off and better off areas in terms of runoff and inundation to delineate and identify the different areas where the specific urban flood-related NBS measures can be implemented. The TAI was calculated in four steps: (1) selection of criteria, (2) standardization of criteria maps, (3) determination of weights for the criteria, and (4) final TAI calculation.
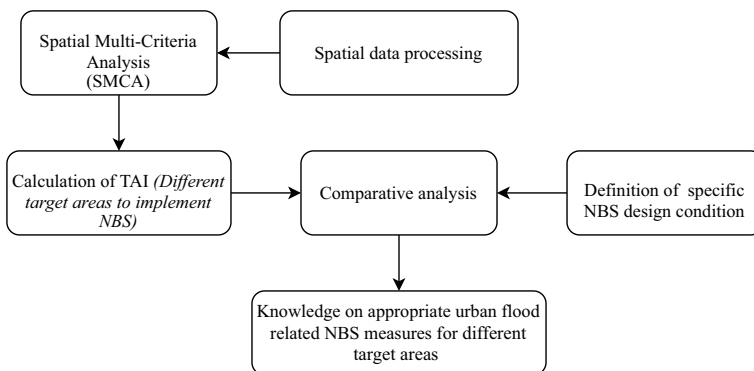
Fig. 2 Generic flowchart of analysis steps

Criteria Selection

The selection of criteria used in identifying target areas for NBS implementation was based on the spatial factors that are subject to surface runoffs and inundation. Factors on surface runoffs and inundation were obtained from literature by search in Scopus, using the keywords "surface runoff" and "inundation"; eighty-eight (88) studies were identified. These studies were limited to four (4) based on the subject area of "environmental science" and indicator-based studies. This was to aid in extracting relatable criteria relevant to this study's context. The studies included Dash and Sar (2020); Nardi et al. (2018); Park et al. (2014), and Zhou et al. (2013). These studies basically focus on the physical and meteorological characteristics that cause changes in runoff and inundation in cities. From these studies, nine relevant criteria were identified. These nine criteria included LULC, wetlands or distance to rivers, slope, soil texture, elevation, groundwater depth, existing drains capacity, temperature, wind and humidity. However, the nine criteria were reduced to five upon checks for data availability. Hence a total of five criteria were finally chosen to identify target areas relatable to worse and better off in terms of runoff and inundation, thus areas in need of NBS implementation. These included the LULC (Fig. 3a), distance to rivers (Fig. 3b), soil texture (Fig. 3c), elevation (Fig. 3d), and slope (Fig. 3e). The criteria description and their justification are presented in Table 4.

Standardization of Criteria

The five criteria maps were reclassified into four or five classes, depending on the criterion (see Table 5). Specifically, the LULC and soil texture maps were reclassified into four classes while the distance to rivers, slope and elevation maps were reclassified into five classes. This reclassification was adapted for understanding and minimization of information loss. The reclassification was done to clearly delineate the variations in each criterion in terms of "worse off" and "better off" conditions for runoff and inundation. The distance to river criterion map was obtained from the river network data using the Euclidean distance tool in ArcGIS 10.8 and afterwards resampled to a resolution of 30 m. Pixels in the criteria maps (30 m by 30 m) were considered suitable spatial units for this analysis because, in Ghana, the average residential plot size is 900m^2 (UN-HABITAT, 2011). Hence, 30 m by 30 m will be adequate to capture the runoff and inundation dynamics of at least an average building and its surroundings.

The classes were standardized using a rescaling approach by Cutter et al. (2010) to ensure an accurate comparison of the criteria. Rescaling converts criteria values into identical ranges. The study defined a range between 0 and 1, with values nearing 0 being better off areas in terms of runoff and inundation and values nearing 1 being worse off areas in terms of runoff and inundation. The study adopted the rescaling (R) formula used by Cutter et al. (2010) in the following way.
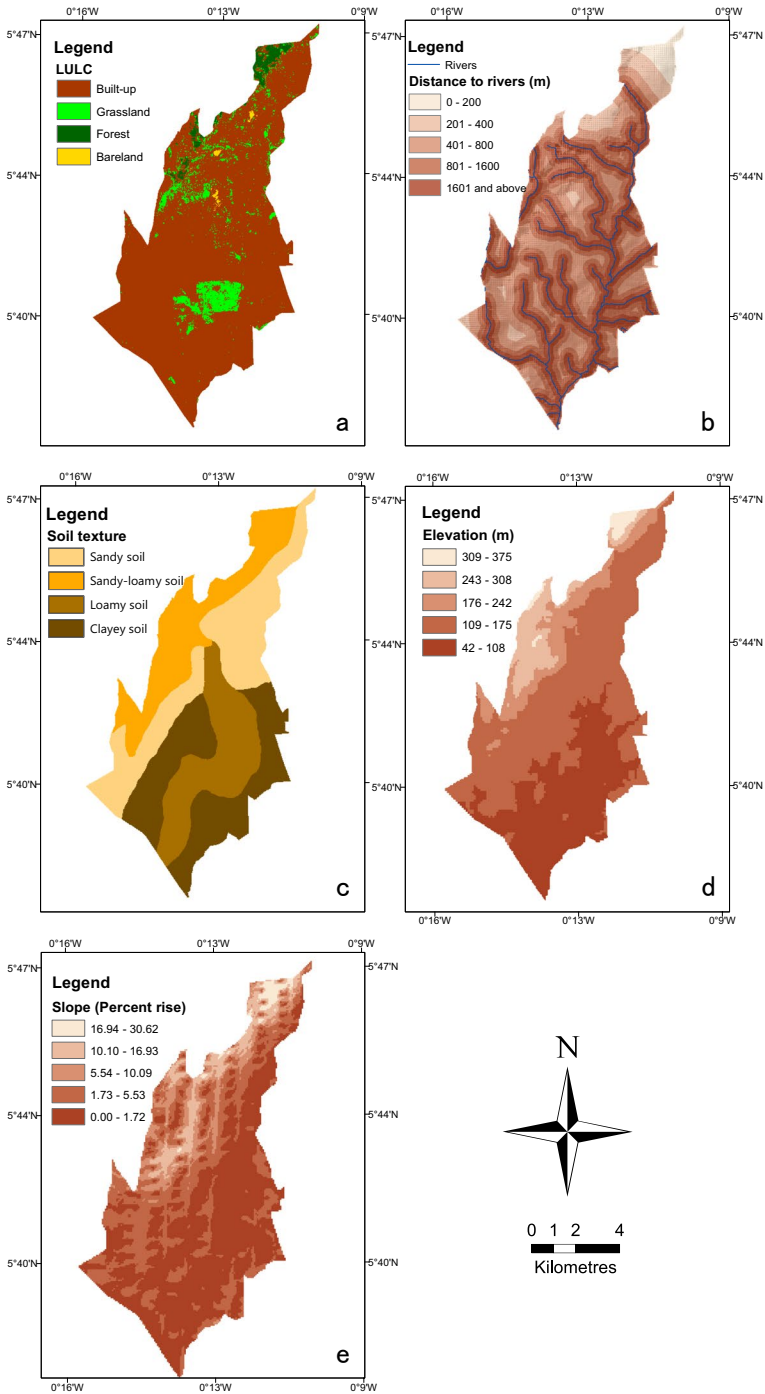
$$R = \frac{Xi - Xmin}{Xmax - Xmin} \qquad (1)$$

Fig. 3 LULC (**a**), Distance to rivers (**b**), Soil texture (**c**), Elevation (**d**), and Slope (**e**). Source: (see Table 2)

Table 4 Description of selected criteria

Criteria	Description	Rationalization
LULC	Areas in the municipality that have been covered with hard surfaces, including roads, pavements, and buildings	Built-up areas are generally sealed, and the probability of water penetrating is low (Lee et al., 2018a, 2018b). Hence, built-up land cover areas are largely worse off in terms of surface runoff and inundation and will therefore need specific NBS interventions that will be effective to minimize urban floods
Distance to rivers	Areas that have proximity to rivers or areas that fall within river buffers	Areas that are very close to rivers and waterways have a high probability of being flooded anytime there is a heavy storm (Rubarenzya Meire, & Willems, 2009), and they are worse off in terms of inundation. This is because these areas mostly have shallow water tables and experience river overflows (Rubarenzya Meire, & Willems, 2009)
Soil texture	The nature and texture (size) of soil particles present in an area	There is a higher infiltration capacity in larger soil particles than in smaller particles. Hence, areas characterised by tiny soil particles like clay soils are likely to be flooded by a heavy storm if the slope and other parameters are not favourable (Amoako, 2012). Therefore, soils with fine texture, for instance, are worse off in terms of surface runoff and inundation and may also require specific NBS interventions
Elevation	Highland and lowland area	Floods, according to several studies, mainly affect lowland areas. Hence, lowland areas are worse off in terms of runoff and inundation. Since water moves typically from highland areas and accumulates in lowland areas (Manfreda, Di Leo, & Sole, 2011), specific NBS measures should be applied in different elevation areas to help mitigate urban floods
Slope	The steepness of landforms in an area	The steepness of a slope determines the water carrying capacity. Typically, water flows quickly in steeper areas and accumulates or is stagnant in relatively gentle and flat areas (Zhang et al., 2019). Hence, horizontal sloped areas are worse off in terms of inundation

Table 5 Classified criteria values before standardization

Criteria	Original value/ description	Classified value
LULC	Forest	1
	Grassland	2
	Bare land	3
	Built-up	4
Distance to rivers	1601 Above	1
	801—1600	2
	401—800	3
	201—400	4
	0—200	5
Soil texture	Sandy	1
	Sandy-loamy	2
	Loamy	3
	Clay	4
Elevation	309—375	1
	243—308	2
	176—242	3
	109 – 175	4
	42—108	5
Slope (Percentage rise)	16.94 Above	1
	10.10 – 16.93	2
	5.54 – 10.09	3
	1.73 – 5.53	4
	0.00 – 1.72	5

where *Xi* is the criteria value, *Xmin* is the minimum criteria value, and *Xmax* is the maximum criteria value.

Determining Weight for the Criteria

Since the criteria for identifying target areas for NBS implementation (i.e., areas subjected to direct runoff and inundation) are not equally important, different weights were assigned. These were calculated using the Pairwise Comparison Matrix (PWCM) of the Analytical Hierarchy Process (AHP) as applied by Jalao (2013). We calculated PWCM based on the opinion of ten urban flood management experts, specifically, planners, engineers, and technical officers working in flood management institutions; they indicated how important each criterion is in identifying areas that are subject to runoff and inundation happenings. This weighting method provides a consistent and efficient approach to determining the importance of multiple options, reduces decision-making bias (Ramík, 2017), and assigns a fair share of the weight. Applying PWCM may sometimes present inconsistencies

Table 6 Average criteria importance rank obtained from urban flood management experts

Criteria	Average rank of importance
LULC	3
Distance to rivers	3
Soil texture	1.4
Elevation	4.2
Slope	4.6

Table 7 Pairwise Comparison Matrix (PWCM) based on urban flood management experts

Criteria	LULC	Distance to rivers	Soil texture	Elevation	Slope	Final weight	Rank
LULC	1	1	3	0.75	0.60	0.19	w_3
Distance to rivers	1	1	3	0.75	0.60	0.19	w_3
Soil texture	0.33	0.33	1	0.25	0.20	0.06	w_5
Elevation	1.33	1.33	4	1	0.80	0.25	w_2
Slope	1.67	1.67	5	1.25	1	0.31	w_1

in decision-making (Lin and Lu 2012). However, limiting the number of experts reduces inconsistencies (Karlsson et al., 2017) and provides clear structuring and weighting problems or options (Aliyu et al., 2015). Therefore, ten urban flood management experts were interviewed.

Table 6 presents the average importance of each criterion obtained from the ten experts, used for the PWCM to determine each criterion's final weight. The criterion importance range was from 1 to 5 where 1 is least important and 5 is most important.

The PWCM was then used in determining each criterion's final weight. The criteria were then evaluated against each other regarding their relative importance. Based on the PWCM, each value in the matrix was divided by the sum of its column. The new values in the matrix were used to determine the final weight of each criterion. This was done by calculating the mean of each row which is the final weight for each criterion that adds up to 1. Table 7 below presents the PWCM and the final determined weight.

Evaluation of the Matrix Consistency

The value extracted from the PWCM was based on subjective judgment, and there are possibilities of errors in the derived results. Hence, an evaluation was done to assess the consistency in the PWCM. With this, a consistency ratio (CR) was calculated. The CR shows the ratio Consistency Index (*CI*) to the average Random Consistency Index (*RI*). Equation 2, adapted from Liang et al. (2017), was then used to calculate the CR.

Table 8 Values of average random consistency index

Number of criteria	2	3	4	5	6	7	8	9
Random Index	0	0.52	0.9	1.12	1.24	1.32	1.41	1.45

Source: (Saaty, 1987)

Table 9 Classification of TAI values into types

TAI Values	Type	Interpretation
0 – 0.20	1	Better off
0.21 – 0.40	2	Intermediate (better)
0.41 – 0.60	3	Intermediate
0.61 – 0.80	4	Intermediate (worse)
0.81 – 1.00	5	Worse off

$$CR = \frac{CI}{RI} \tag{2}$$

The *RI* value was acquired from Table 8, which was developed by Saaty (1987) on the value of an *RI* with respect to several criteria.

The CI was calculated using Eq. 3 from Liang et al. (2017).

$$CI = \frac{\lambda max - n}{n - 1} \tag{3}$$

where *n* is the dimension of the matrix and λ_{max} is the maximal eigenvalue of the matrix. With the maximum eigenvalue of 5.00, the matrix's consistency index (CI) was 0.0025. Also, using an RI of 1.12, the CR for the matrix was 0.022. According to Saaty (1987), the CR value derived means the values for the PWCM are consistent.

Computing the Target Area Index (TAI)

The five criteria maps were used to calculate the TAI for the NBS implementation. The standardized criteria maps were combined using the raster calculator tool in ArcGIS 10.8. The determined criteria weights were multiplied by the respective criteria scores (see Eq. 4) to generate the final TAI ranging from 0 to 1.

$$\begin{aligned} TargetAreaIndex = &(Landcover * w_3) + (Closenesstorivers * w_3) + (Soiltexture * w_5) \\ &+ (Elevation * w_2) + (slope * w_1) \end{aligned} \tag{4}$$

where *w* is the determined weight of a criterion.

The index results were further categorised into five classes using equal intervals (see Table 9). The equal interval used ensures an easy understanding and interpretation of results (Zimmer, 2011).

Type 1 and areas with TAI value approaching 0 were considered "better off" areas in terms of surface runoff and inundation. In contrast, Type 5 and areas with TAI values approaching 1 were considered "worse off" areas. Additionally, individual physical geographical elements and each target area type's land use/ land cover characteristics were outlined for the comparative analysis.

Validation of TAI result

Quantitative validation was conducted by developing a receiver operating characteristic (ROC) curve to validate the TAI results. The ROC is determined by calculating the true-positive and false-positive rate for all possible happenings of an event (in relation to this study, urban floods) against a model result (in relation to this study, the TAI) (Haghizadeh et al., 2017; Lin et al., 2019). In the absence of historical spatial flood data for the municipality, the GPS locations of areas/neighbourhoods that experience frequent flood events in the Ga East Municipality, as given by flood management professionals was obtained from Google Earth and used as validation test points (see Fig. 5) to develop the ROC curve. Regarding the ROC curve, there is the area under curve (AUC), which assesses the dominance of the true-positive, and an acceptable AUC should be more than 70% (Haghizadeh et al., 2017).

Comparative Analysis

A qualitative comparative analysis was used to identify the appropriate NBS measures (green roofs, vegetated swales, rain gardens, rainwater harvesting, detention basins, and porous pavements) suitable for the different target areas. This method has been used in several studies in explaining, for example, why some interventions work or not (Simister, 2017). Also, this analysis facilitates matching features of different phenomena (Pickvance, 2005), thereby, employed to know which NBS measure would work well in the different target areas identified.

Therefore, the land use and physical geographical characteristics of the identified target area types were compared to the design conditions of the specific urban flood-related NBS measures to determine which measure is best for which target area. A matrix table was then developed using the two sets of characteristics. Figure 4 shows the entire methodological flowchart.

Results

Target Areas for NBS Implementation

The SMCA identified different target areas where urban flood-related NBS measures can be implemented. The map in Fig. 5, depicts the spatial distribution of the categorized TAI outcome (Type 1,2, 3, 4, and 5 target areas), with Type 1 and 2 areas mainly occupying the northern part of the municipality and Type 3, 4 and 5 areas occupying the central to the southern parts. The map also shows the neighbourhoods
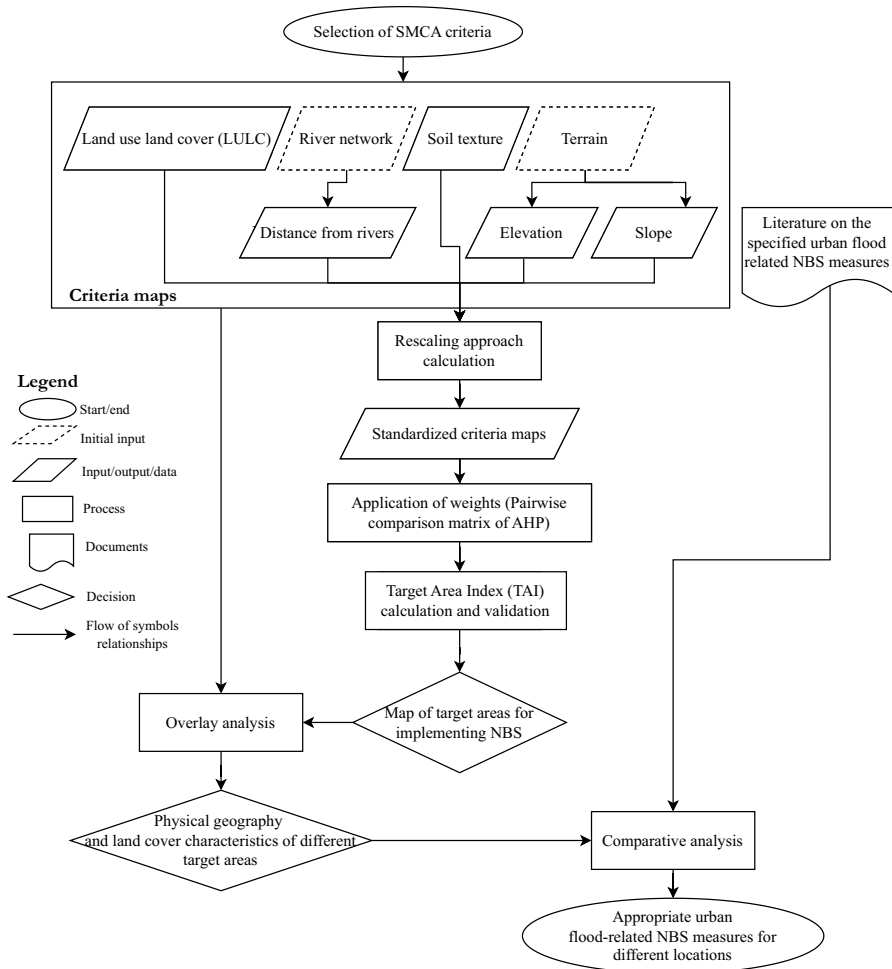
Fig. 4 Methods flowchart of the study

that fall within the respective target areas which are also presented in Table 10. Regarding the ROC curve, we obtained 74.4% for the AUC (see Fig. 6), which establishes the accuracy of the TAI results.

Figure 7 also shows the coverage statistics of the target area types. Types 4 and 5 occupy a greater percentage of the study area's total land area with 38% (31.86 km^2) and 29% (24.62 km^2), respectively. Type 3 covers about 16% of the study area's total land, approximately 13.34 km^2. Additionally, Type 1 and 2 areas occupy smaller portions of the study area's total land, about 4% (3.01 km^2) and 13% (10.66km^2), respectively.
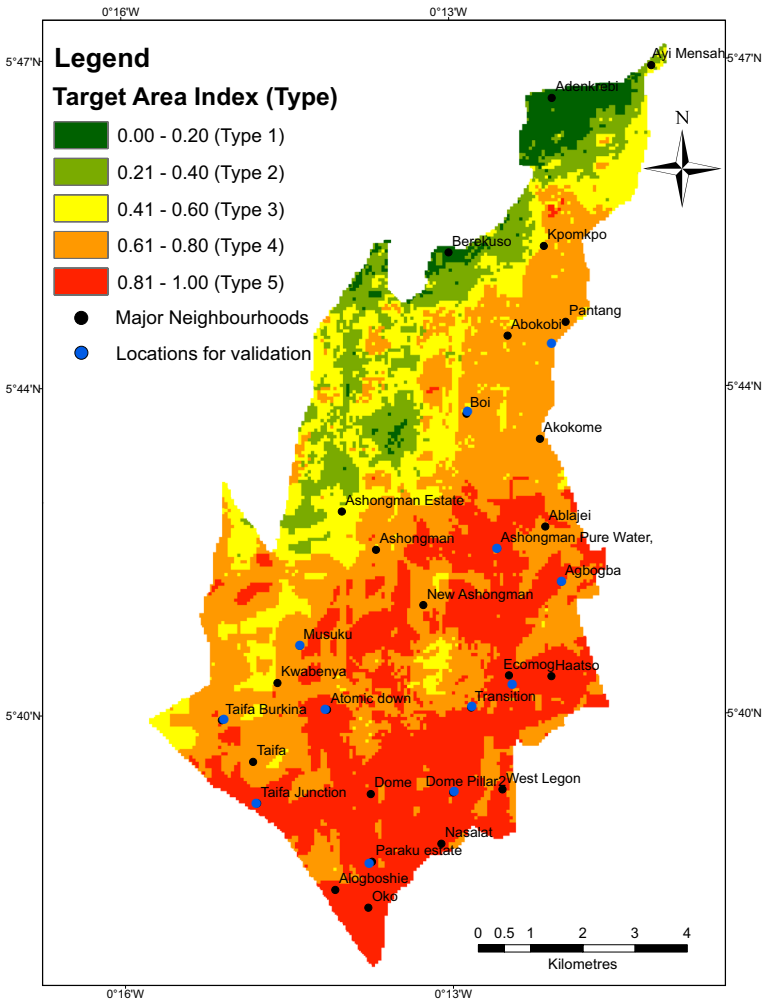
Fig. 5 Map showing the spatial distribution of Target Area Index, classified into Type 1–5

Target Areas Characteristics

Overlay analysis of the target areas with the criteria maps revealed an additional spatial pattern of the identified target areas, as shown in Table 10 and Fig. 8. Type 1 target areas are generally steep slopes and mainly highland areas. They are also characterised by sandy-loamy soil. They are further away from rivers and waterways and predominantly forest and grassland areas. Type 2 target areas are generally steep slope areas, intermediate highland, and lowland areas characterized by sandy and sandy-loamy soils. The areas are also further away from rivers and waterways and are predominantly built-up areas. Type 3 areas are generally

Table 10 Characteristics of the different target areas

Target area	Characteristics						
	LULC	Distance to rivers	Soil	Elevation	Slope	Total area (km²)	Neighbourhoods
Type 1	Made up of 70% forest and grassland, 30% built-up	93% of the area is outside a buffer of 400 m to the nearest river	Made up of 89.2% sandy-loamy soil	Made up of 70% moderate to high elevation areas	80% of the area falls within high slopes	3.01	Adenkrebi, Berekuso,
Type 2	Made up of 72% built-up	60% of the area is outside a buffer of 400 m to the nearest river	98% sandy and sandy-loamy soils	Made up of 75.7% moderate to high elevation areas	Made up of 80% high slope areas	10.66	Ayi Mensah
Type 3	82.9% of this area is built-up	48% of the area is outside a buffer of 400 m to the nearest river	Made up of 86.4% sandy and sandy-loamy soils	About 60.4% of low elevation areas	Made up of 64.5% low slope areas	13.34	Ashongman Estates
Type 4	The area is 92% built-up	73% of the area is within a buffer of 400 m close to rivers	More than 70% of the area is made up of sandy and loamy soils	96% of the area is relatively low land	98% of these areas are generally low slope	31.86	Boi, Abokobi, Pantang, Akokome Kpomkpo, Ashongman, Musuku, Kwabenya, Taifa, Taifa Burkina, and Ablajei
Type 5	The area is made up of about 98% built-up	92% of areas also fall within a buffer of 400 m to the nearest river	58% percent of the area is clayey soil	The entire area is characterized by low land	The entire area is characterized by horizontal slopes	24.62	Taifa junction area, Dome, Dome Pillar 2, Alogboshie, Oko, Paraku Estate, Nasalat, West Legon, Haatso, Haatso Ecomog and Ashongman Pure Water

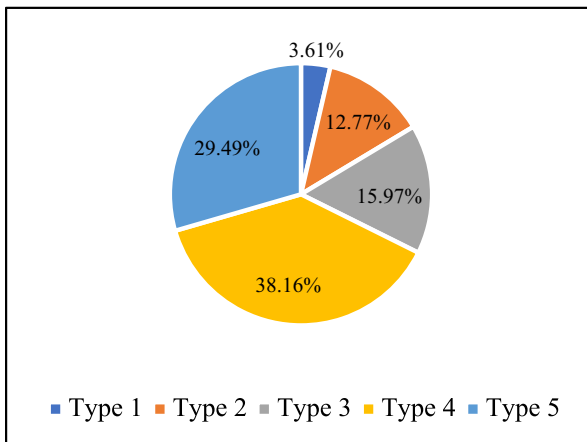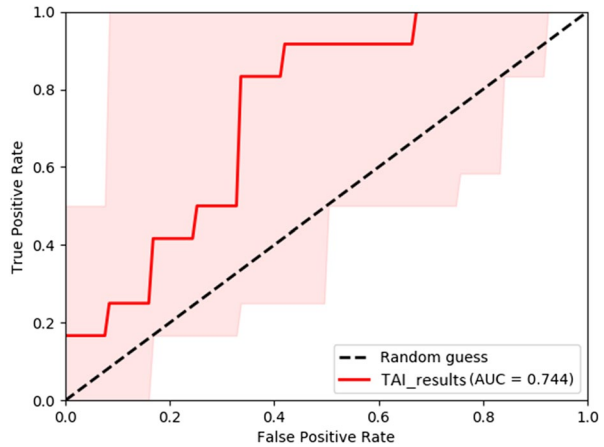**Fig. 6** ROC curve for the quantitative validation

Fig. 7 The area coverage per each target area type

gently sloped, intermediate between highland and lowland areas, and comprised of sandy and sandy-loamy soil areas. The areas are moderately close to rivers and mainly built-up. Type 4 target areas are flat/horizontally sloped areas. They are mainly lowland areas characterised by both clayey and sandy soils. They are also moderately close to rivers and primarily built-up areas. Type 5 target areas are also flat/horizontally sloped, mainly lowland areas, characterised by clayey soils, and the areas are very close to rivers and highly built-up.

Moreover, since all suburbs in the municipality are broadly classified as residential (LUSPA, 2017), the detailed land uses present in the different target areas are mainly residential developments. However, other detailed land uses such as educational, commercial, industrial, civic and cultural, among others, make up the residential developments and suburbs.
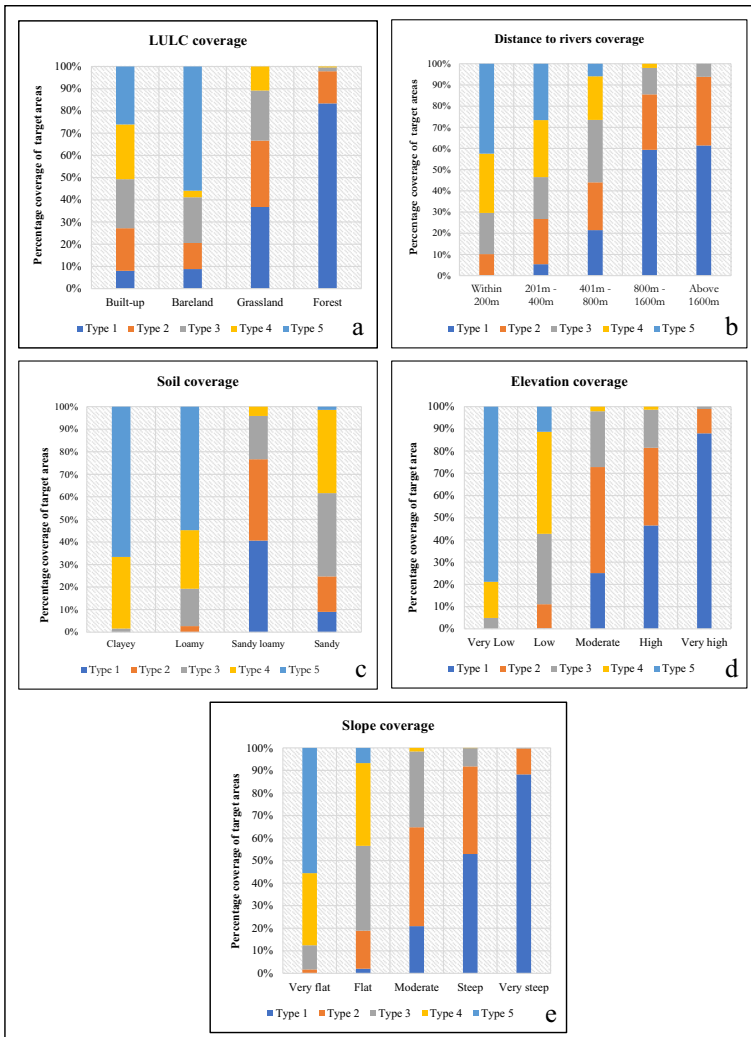
Fig. 8 Distribution of LULC (**a**), distance to rivers (**b**), soil (**c**), elevation (**d**) and slope (**e**) per target area

Sensitivity Analysis

A sensitivity analysis was performed to assess the robustness of the identified target areas and ascertain how the change in the criteria weights used in the SMCA could affect the location of the different NBS target areas in the municipality. A sensitivity analysis was done by applying equal weights to the criteria used and generating another target area map for the municipality using the same equal interval in delineating the different target areas (see Fig. 9).

Comparing Fig. 9 (TAI from equal weight) and Fig. 5 (TAI from relative weights), there was more coverage of Type 5 target areas (38.79%) in Fig. 9 than the
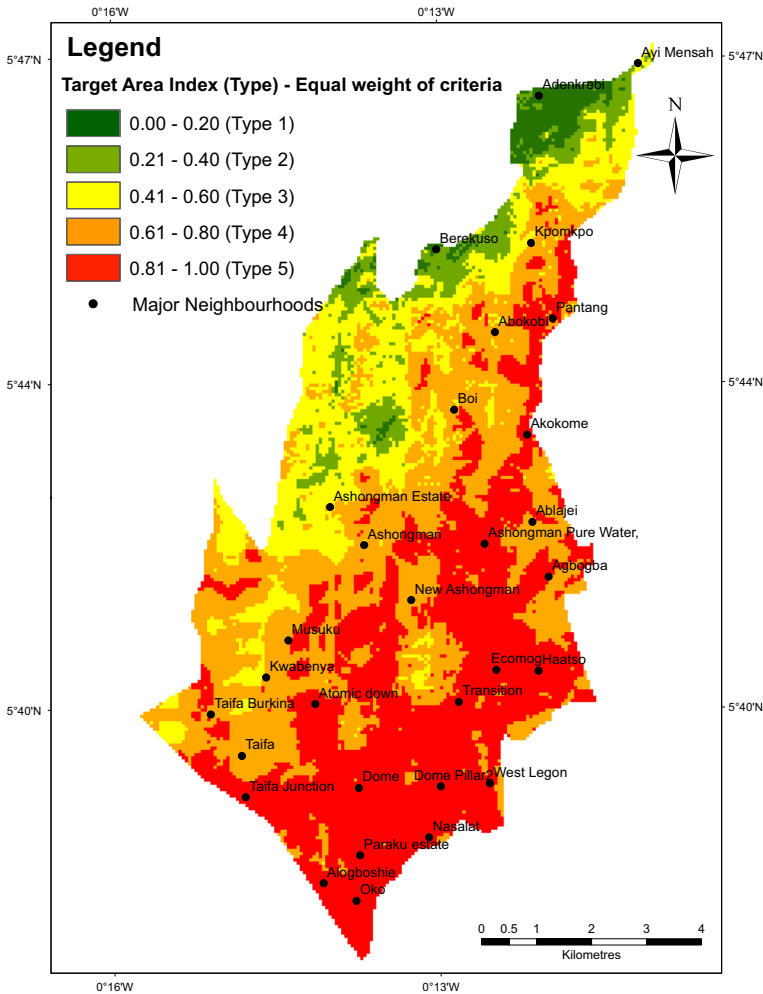
Fig. 9 NBS target areas using equal weights

coverage of type 5 areas (29.49%) in Fig. 5. Also, there was significant coverage of Type 5 areas in relatively upstream areas in Fig. 9, which does not clearly describe a "worse off" area in terms of runoff and inundation. On the other hand, the comparison of the locations and coverage of Type 1 and 2 target areas were very similar in the two maps. Hence, the difference in the Type 5 target areas and change in weight assigned to criteria could lead to different outcomes, which could also affect decision-making on appropriate NBS that will be very effective in the area.

Applying the equal weighting means each of the criteria used in calculating the TAI was given equal importance. This implies all the criteria used are subjected equally (Raghunathan, 2020) to surface runoff and inundation in the study area. From the hydrological perspective, applying equal weights may lead to untrue

reflection, foul analysis, designing and implementing specific NBS measures, and other urban flood management projects (Mohamed Elmoustafa, 2012). Accordingly, in the TAI results shown in Fig. 5, experts gave the lowest weight to the soil criterion and the highest to the slope criterion. The given relative weights to the mentioned criteria are attributed to the highly built-up characteristics of the study area. Therefore, considering the two maps, Type 5 target areas were overestimated when equal weights were used.

Appropriate Urban Flood-Related NBS Measures for the Identified Target Areas

Table 11 compares the characteristics of the target area types to the design conditions of the specific NBS measures. The comparison assumes that an NBS measure is compatible with a target area if more than 50% coverage of a particular target area characteristic is in line with the stated design condition of a specific NBS measure. The 50% or more threshold was used based on the assumption that more than 50% coverage of criteria characteristics dominates the nature of the criteria and suffices decision making. Another assumption is that NBS measures can be applied in all built-up areas since the entire municipality is mainly covered with hard surfaces. An annotated map of the different target areas with the associated appropriate urban flood-related NBS measures is shown in Fig. 10.

Green roofs are generally implemented on buildings with proper roof typology and do not require a specific landform characteristic for their effectiveness (Cascone, 2019). Therefore, green roofs can be applied in all the target area types, and thus also in all neighbourhoods within the municipality.

The conditions of vegetated swales match the physical geographical characteristics of Type 3 target areas. Hence, vegetated swales will be very effective when implemented in neighbourhoods within Type 3 areas. However, there could be a possibility to also implement vegetated swales in Type 4 and 5 target areas but this may not be entirely effective due to the nature of soil characteristics in these areas, which is predominantly clayey.

The comparison also highlighted that rain gardens could be best implemented in Type 2 target areas. The areas are generally moderately sloped, made up of sandy and sandy-loamy soils, relatively highland areas, and farther away from waterways. Neighbourhoods, including Ayi Mensah, can also be targeted to build rain gardens. There may also be a possibility to implement rain gardens in type 1 target areas, but the nature of the slope, which is steep, will affect its effectiveness.

Furthermore, the analysis revealed that rainwater harvesting would be best implemented in Type 2 target areas. Their physical geographical characteristics conform to all the key design conditions of rainwater harvesting. Hence, rainwater harvesting will also be very effective in the type 2 target areas to mitigate urban floods.

Detention basins will be very effective in Type 3, 4, and 5 target areas. Their physical geographical characteristics are generally lowland, close to water bodies, and soil characteristics that are rarely sandy (see Table 10). Therefore, implementing detention basins in the Ga East Municipality should target the respective neighbourhoods within the target area.

Table 11 Matrix of target area types and NBS design conditions

NBS measures key design conditions	Target areas				
	Type 1	Type 2	Type 3	Type 4	Type 5
Green roofs					
Suitable for both horizontal, gentle, and steep-sloped areas	✓	✓	✓	✓	✓
It can be used in high and low land areas	✓	✓	✓	✓	✓
It is suitable for any built-up land use, be it residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Vegetated swales					
Suitable for horizontal and gentle sloped areas	✗	✓	✓	✓	✓
Practically best applied in low land areas	✗	✗	✓	✓	✓
Good for sandy-loamy areas	✓	✓	✓	✗	✗
Suitable for all land use areas, including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Rain gardens					
Suitable for horizontal and gentle sloped areas	✗	✓	✓	✓	✓
Suitable for loamy and sandy-loamy soil areas	✓	✓	✓	✗	✗
They are best applied in highland areas	✓	✓	✗	✗	✗
Not ideal for areas with a shallow water table and close to water bodies	✓	✓	✗	✗	✗
Suitable for all land use areas, including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Rainwater harvesting					
Suitable for gently sloped areas	✗	✓	✓	✓	✗
Effective in highland areas	✓	✓	✗	✗	✗
Suitable for medium-textured soils (Sandy-loamy and loamy) – not ideal for heavy clay soils	✓	✓	✓	✓	✓
Not ideal for areas with a shallow water table and close to water bodies	✓	✓	✗	✗	✗
Suitable for all land use areas, including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Detention basins (ponds)					
Practically best for lowland areas	✗	✗	✓	✓	✓

Table 11 (continued)

NBS measures key design conditions	Target areas				
	Type 1	Type 2	Type 3	Type 4	Type 5
Not suitable for sandy soil areas	✓	✓	✓	✓	✓
Ideal for areas close to water bodies, especially areas near the outlet of a watershed	✗	✗	✓	✓	✓
Suitable for all land use areas, including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
Porous pavement					
Suitable for both gentle and steep-sloped areas	✓	✓	✓	✓	✗
Suitable for both highland and lowland areas	✓	✓	✓	✓	✓
Suitable for moderately infiltrated soils (sandy-loamy and loamy soil areas)	✓	✓	✓	✗	✗
Suitable for areas with a relatively deep water table (HGIC, 2013)	✓	✓	✓	✗	✗
Suitable for all land use areas, including residential, commercial, industrial, etc	✓	✓	✓	✓	✓
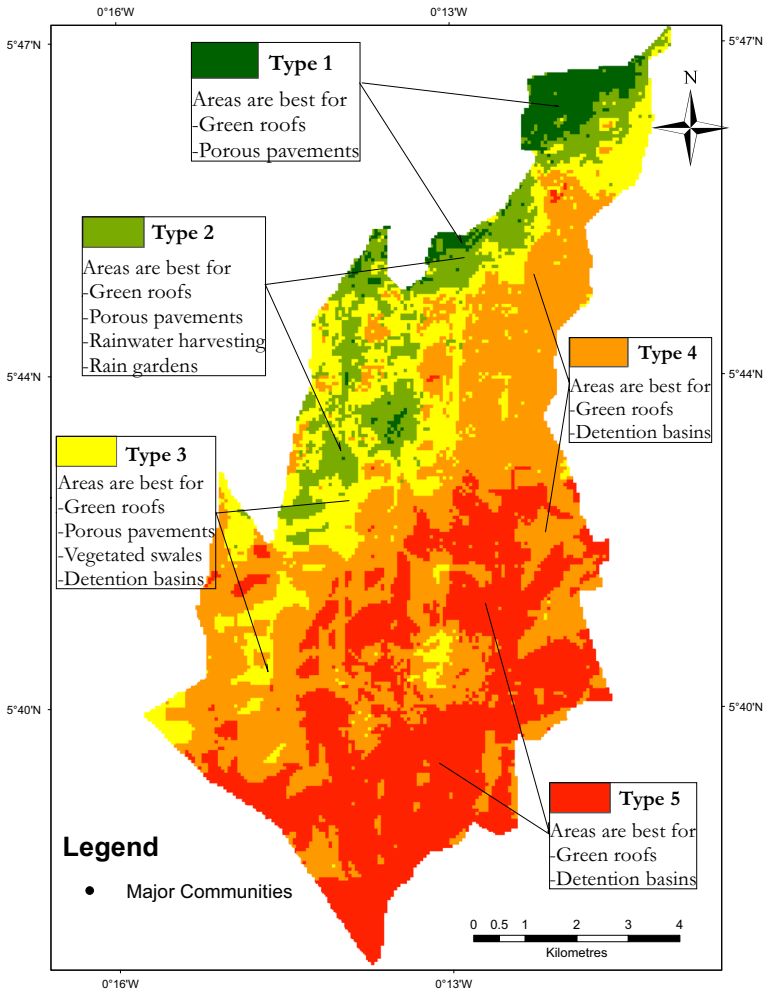
Fig. 10 Target area types with the appropriate NBS measures to be applied

On porous pavements, they are best implemented in Type 1, 2, and 3 areas characterised by soil types with good infiltration capacities. Thelen and Howe (2011) highlighted porous pavements could be implemented at any location where traditional pavements can be laid in the urban area. However, in Type 4 and 5 target areas, clayey soil is practically not ideal for porous pavement (Thelen & Howe, 2011).

In general, Type 2 and 3 areas tend to have physical geographical characteristics that fit most of the specific urban flood-related design conditions of NBS measures, including green roofs, vegetated swales, rain gardens, rainwater harvesting, and porous pavements. These two target areas are relatively upstream, and their land use characteristics indicate an average of 78% built-up.

Implementing the different kinds of NBS measures will help improve the infil-
tration capacity of these areas and reduce runoff volumes that could accumulate
in downstream areas, which will eventually help minimize flood occurrence in
the Ga East municipality.

Discussion

Using SMCA, the study revealed different areas in the Ga East municipality
where specific urban flood-related NBS measures can be implemented to pre-
vent and mitigate urban floods. The developed SMCA methodology integrated
expert views to consider the local context, specifically in operationalizing NBS
usage. Experts' local knowledge also helped capture the physical geography and
land use setting that influence runoff and inundation for a particular jurisdiction.
Therefore, in the context of the Ga East Municipality, the slope was considered
the most important factor in runoff and inundation processes due to the higher
coverage of built-up in the locality. In contrast, other studies, including Dahan
and Al-Komaim (2017), consider soil most important due to the less coverage
of built-up areas. Accordingly, localized expert knowledge provides the basis for
understanding the locational suitability of areas for different NBS measures in
the context of the Ga East Municipality. This affirms Stagakis et al. (2019) call to
implement area-specific NBS. The study also revealed that using equal weights
leads to an overestimation of certain types, specifically Type 5.

The SMCA identified five areas to be targeted in the municipality to imple-
ment specific urban flood-related NBS measures labelled as Type 1 being better
off areas in terms of runoff and inundation and Type 5 being worse off in terms
of the runoff and inundation. The Type 1 areas being better off in terms of runoff
and inundation means surfaces are highly sensitive to water. As Marhaento et al.
(2019) described, high water sensitivity indicates a high probability of surfaces
absorbing water. These areas had sandy, loamy soils with their landcover mainly
grassland and forest, not forgetting the generally upstream nature of the areas.
Considering the better-off nature of Type 1 areas suggests that they might not
necessarily need urban flood-related NBS measures. On the other hand, Type 5
target areas being worse off in terms of runoff and inundation means the areas
have very low water sensitivity. According to Marhaento et al. (2019), low water
sensitivity also indicates poor water absorption capacity of surfaces. The type
5 areas had their main soil characteristics as clayey, with its landform generally
downstream. This study's findings align with Lee et al., (2018a, 2018b) conclu-
sions that high water sensitivity and upstream as well as low water sensitivity and
downstream areas were seen as low and high physical flood vulnerability areas
respectively in Gwanghwamun-hyoja District in Seoul, South Korea. Through the
SMCA, these areas can be elicited.

The study also identified appropriate NBS measures that have the potential to reduce
urban floods effectively for specific locations in the municipality. Relating the different
target areas with the design conditions of the specific NBS measures, it was found
that not all NBS measures will be very effective at all locations in the municipality.

Specific NBS measures can only be functional at certain locations with certain characteristics. This finding means different strategies must be employed for different locations to operationalize NBS measures to fight urban floods in cities. Additionally, this study also showed most of the urban flood-related NBS measures would be very effective in Type 2 and 3 target areas, which are relatively marked to be upstream. Vallecillo et al. (2020) gave a similar assertion and concluded that fighting urban floods in most EU cities should focus on increasing ecosystem contribution closely related to NBS measures in upstream areas. Hence, using specific urban flood-related NBS in the upstream areas will increase the infiltration capacity of these areas and reduce the amount of runoffs that would end up in the downstream and flood-prone areas.

Moreover, exploring the locational suitability of areas for different NBS measures led to specifically matching porous pavements to Type 1, 2, and 3 target areas. This was due to the high infiltration abilities of the areas. Lee et al., (2018a, 2018b) used empirical data to ascertain the application of specific green strategies that could reduce surface water floods in Seoul. Lee et al., (2018a, 2018b) measurements and findings proposed using measures like green roofs and porous pavements, among other measures, for areas with natural soils that can infiltrate stormwater which is similar to what this study found. Lee et al., (2018a, 2018b) also proposed using detention ponds, rain barrels, greens roofs for highly built-up areas, and poor drainage natural soil ability. Hence the usage of the rain barrels will be stationed beneath the parking lots of residential areas. Lee et al., (2018a, 2018b) proposal partly aligns with this study's finding on using green roofs and detention basins in the aforementioned area characteristics. This research revealed green roofs and detention basins as the NBS measures that will be very effective when implemented in Type 3, 4, and 5 areas due to the poor infiltration characteristic of the areas. However, as Lee et al., (2018a, 2018b) specified, the usage of rain barrels, similar to rainwater harvesting, contradicts this research's findings. This may be attributed to the design of the rain barrels, which may be different from the aspects of the rainwater harvesting approach adopted in this study.

In summary, the SMCA approach effectively structures and analyses a spatial problem and makes an assessment that can inform the spatial decision to avert the problem if applied appropriately. It served to explore the locational suitability of areas for different urban flood-related NBS measures to ensure an effective urban flood minimization approach in the Ga East Municipality, Accra.

Conclusion

This study aimed to develop and use SMCA to identify different target areas where urban flood-related NBS measures can be implemented and determine the appropriate measures that will effectively mitigate urban floods in the target areas. The SMCA focused on the PWCM of AHP, which was based on expert knowledge. The results revealed five different target area types in the Ga East Municipality where NBS measures can be implemented. Type 1 target areas were generally characterised as better-off areas, while Type 5 were described as the worst-off areas in terms of runoff and inundation, each requiring specific NBS measures to help mitigate urban floods. Other

target area types were intermediate, also requiring specific NBS. The comparative analysis, therefore, showed that different areas require specific urban flood-related NBS to minimize urban floods effectively in the Ga East Municipality. The study outcome revealed green roofs could be implemented in all locations since their implementation will be on buildings. Vegetated swales were also best implemented in Type 3 target areas. Considering the makeup of Type 2 areas, it was also the best area to implement rain gardens and rainwater harvesting. Furthermore, Type 3, 4, and 5 target areas were also the best to apply detention basins since these areas were generally low land areas with poor soil infiltration capacity. Also, due to mainly soil characteristics, Type 1, 2, and 3 target areas were the best fit to implement porous pavement. Considerably, SMCA could be a useful tool to maximize the functionality of NBS measures for urban flood mitigation and other climate and spatial-related problems in cities.

As the engineering flood management approaches in Ghana and other low-to-medium income countries have been unsuccessful (Ogie et al., 2020; Tengan & Aigbavboa, 2016), and there is not much use for NBS (Kumar et al., 2020), this study outcome could serve as the basis to stimulate an effective usage of NBS in tackling urban floods in the mentioned areas. Specifically, elaborations are given on the locational dynamics possible for specific NBS measures to be suitable and practically effective in a medium-income area. Substantially, the complementation of specific NBS to engineering solutions in downstream as well as applying other NBS in upstream locations have the potential to collectively minimize surface runoffs and inundation.

This study, therefore, unearths and provides locational knowledge in relation to flood management studies on the effective functioning of specific NBS for urban flood reduction. Additionally, the study outcome can serve as a tool for urban flood management institutions in Ghana in their quest to introduce and operationalize NBS to minimize urban flood occurrence rates. Hence, National Disaster Management Organisation (NADMO), among other flood management institutions in Ghana, could consider the target areas identified and their associated neighbourhoods to appropriately register the location of flood management projects, especially the NBS-related ones. In summary, SMCA can support the planning for areas to build and implement urban flood projects, including NBS. The approach applied in this study can be replicated in other contexts in identifying sites to roll out multiple NBS measures. In relation to this study, it is possible to use NBS to buttress engineering approaches in urban flood mitigation. However, since there is limited knowledge on NBS usage in low-to-medium income countries (Kumar et al., 2020), there may be implementation challenges, especially considering the areas' spatial development setting. Therefore, future research can focus on possible ways of integrating NBS into the spatial development of cities for urban flood mitigation.

The study encountered some level of limitations. One limitation was omitting some criteria such as groundwater depth, existing drains capacity, temperature, wind and humidity in the SMCA due to data unavailability. The mentioned criteria addition would have offered a deeper description of the identified target areas. Another limitation of the study is generalizing the target area characteristics and the above 50% threshold in assigning the appropriate NBS measures. There could be locations within a particular NBS target area with different characteristics than what was generalized. Hence, the generalization might affect the identification of appropriate NBS measures that will practically be effective for the respective target areas.

Declarations

References

Acheampong, R. A., & Ibrahim, A. (2016). One Nation, Two Planning Systems? Spatial Planning and Multi-Level Policy Integration in Ghana: Mechanisms, Challenges and the Way Forward. *Urban Forum, 27*(1), 1–18. https://doi.org/10.1007/s12132-015-9269-1

Ackom, E. K., Adjei, K. A., & Odai, S. N. (2020). Monitoring land-use and land-cover changes due to extensive urbanization in the Odaw River Basin of Accra, Ghana, 1991–2030. *Modeling Earth Systems and Environment, 6*(2), 1131–1143. https://doi.org/10.1007/s40808-020-00746-5

Ahiablame, L., & Shakya, R. (2016). Modeling flood reduction effects of low impact development at a watershed scale. *Journal of Environmental Management, 171*, 81–91. https://doi.org/10.1016/j.jenvman.2016.01.036

Al-doski, J., Mansor, S. B., Zulhaidi, H., & Shafri, M. (2013). Image Classification in Remote Sensing. *Environment and Earth Science*, *3*(10), 141–148. Retrieved from https://core.ac.uk/download/pdf/234663192.pdf

Aliyu, M., Bn, A. N., & Ludin, M. (2015). A Review of Spatial Multi Criteria Analysis (SMCA) Methods for Sustainable Land Use Planning (SLUP). *Journal of Multidisciplinary Engineering Science and Technology*, *2*(9), 3159–40. Retrieved from http://www.jmest.org/wp-content/uploads/JMESTN42351081.pdf

Amfo Otu, R., Omari, S., & Boakye Dede, E. (2012). Assessment of Physico-chemical Quality of Groundwater Sources in Ga East Municipality of Ghana. *Environment and Natural Resources Research, 2*(3). https://doi.org/10.5539/enrr.v2n3p19

Ammar, A., Riksen, M., Ouessar, M., & Ritsema, C. (2016). Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. *International Soil and Water Conservation Research, 4*(2), 108–120. https://doi.org/10.1016/j.iswcr.2016.03.001

Amoako, C., & Boamah, E. F. (2014). The three-dimensional causes of flooding in Accra , Ghana. *International Journal of Urban Sustainable Development*, (December 2014), 37–41. https://doi.org/10.1080/19463138.2014.984720

Amoako, C. (2012). Emerging issues in urban flooding in African cities -The Case of Accra, Ghana Clifford Amoako Monash University. *35th AFSAAP Annual Conference Proceedings*, (January), 1–12.

Retrieved from https://www.researchgate.net/publication/271020568_Emerging_issues_in_urban_flooding_in_African_cities_-The_Case_of_Accra_Ghana_Clifford_Amoako_Monash_University/link/54bc9b2b0cf253b50e2d3faf/download

APFM. (2012). Urban flood management in a changing climate. *Integrated Flood Management Tools Series*, (february), 54. Retrieved from https://library.wmo.int/index.php?lvl=notice_display&id=16346#.YNw4n2gzaHs

Bray, B., Gedge, D., Grant, G., & Leuthvilay, L. (2011). *RAIN GARDEN GUIDE*. Retrieved from https://raingardens.info/wp-content/uploads/2012/07/UKRainGarden-Guide.pdf

Cascone, S. (2019). Green roof design: State of the art on technology and materials. *Sustainability (Switzerland), 11*(11), 3020. https://doi.org/10.3390/su11113020

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology, 11*(1), 100. https://doi.org/10.1186/1471-2288-11-100

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management*, *7*(1). https://doi.org/10.2202/1547-7355.1732

Dahan, M., & Al-Komaim, A. (2017). Site Suitability Analysis for Different Indigenous Rainwater Harvesting Systems-A Case Study of Sana'a Water Basin, Republic of Yemen. *Master's Thesis*. Retrieved from http://dspace.library.uu.nl/handle/1874/371105

Dash, P., & Sar, J. (2020). Identification and validation of potential flood hazard area using GIS-based multi-criteria analysis and satellite data-derived water index. *Journal of Flood Risk Management*, Vol. 13. https://doi.org/10.1111/jfr3.12620

European Commission. (2015). *Nature-Based Solutions & Re-Naturing Cities*. https://doi.org/10.2777/765301

European Commission. (2020). *Nature-based solutions: State of the art in EU-funded projects*. https://doi.org/10.2777/236007

Ghana Statistical Service. (2013). 2010 Population & Housing Census National Analytical Report. In *Ghana Statistical Service*. Retrieved from https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/2010_PHC_National_Analytical_Report.pdf

Ghana Statistical Service. (2014). *Ga East Municipality*. Retrieved from https://www2.statsghana.gov.gh/docfiles/2010_District_Report/Greater%20Accra/GA%20EAST.pdf

Gonzalez, A., & Enríquez-De-Salamanca, Á. (2018). Spatial Multi-Criteria Analysis in Environmental Assessment: A Review and Reflection on Benefits and Limitations. *Journal of Environmental Assessment Policy and Management, 20*(3), 1–24. https://doi.org/10.1142/S146433321840001X

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S., & Seto, K. C. (2018). Urbanization in Africa: Challenges and opportunities for conservation. *Environmental Research Letters, 13*(1), 015002. https://doi.org/10.1088/1748-9326/aa94fe

Haghizadeh, A., Siahkamari, S., Haghiabi, A. H., & Rahmati, O. (2017). Forecasting flood-prone areas using Shannon's entropy model. *Journal of Earth System Science*, *126*(3). https://doi.org/10.1007/s12040-017-0819-x

HGIC. (2013). An Introduction to Porous Pavement | Home & Garden Information Center. Retrieved May 18, 2021, from https://hgic.clemson.edu/factsheet/an-introduction-to-porous-pavement/

IRICE. (2006). Rain Water Harvesting. Retrieved from https://sswm.info/sites/default/files/reference_attachments/IRICEN 2006 Rainwater Harvesting.pdf

Jalao, E. R. L. (2013). A pairwise comparison matrix framework for large-scale decision making. *ProQuest Dissertations and Theses*, (May), 131. Retrieved from http://search.proquest.com/docview/1346194884?accountid=14745%5Cnhttp://sfx.fcla.edu/usf?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:dissertation&genre=dissertations+&+theses&sid=ProQ:ProQuest+Dissertations+&+Theses+Full+Text&atitle=&title=A+pair

Jha, A., Lamond, J., Bloch, R., Bhattacharya, N., Lopez, A., Papchristodoulou, N., … Barker, R. (2011). Five Feet High and Rising: Cities and Flooding in the 21st Century. *Policy Research Working Paper*, (May 2011), 1–68. Retrieved from https://elibrary.worldbank.org/doi/abs/https://doi.org/10.1596/1813-9450-5648

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., … Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, *21*(2). https://doi.org/10.5751/ES-08373-210239

Kumar, P., Debele, S. E., Sahani, J., Aragão, L., Barisani, F., Basu, B., & Zieher, T. (2020). Towards an operationalisation of nature-based solutions for natural hazards. *Science of the Total Environment, 731*, 138855. https://doi.org/10.1016/j.scitotenv.2020.138855

Lee, E. S., Lee, D. K., Kim, S. H., & Lee, K. C. (2018). Design strategies to reduce surface water flooding in a historical district. *Journal of Flood Risk Management, 11*(September 2017), S838–S854. https://doi.org/10.1111/jfr3.12268

Lee, E. S., Lee, D. K., Kim, S. H., & Lee, K. C. (2018b). Design strategies to reduce surface water flooding in a historical district. *Journal of Flood Risk Management, 11*, S838–S854. https://doi.org/10.1111/jfr3.12268

Lin, L., Wu, Z., & Liang, Q. (2019). Urban flood susceptibility analysis using a GIS-based multi-criteria analysis framework. *Natural Hazards, 97*(2), 455–475. https://doi.org/10.1007/s11069-019-03615-2

Liu, H. Y., Jay, M., & Chen, X. (2021). The role of nature-based solutions for improving environmental quality, health and well-being. *Sustainability (switzerland), 13*(19), 1–56. https://doi.org/10.3390/su131910950

Longobardi, A., D'Ambrosio, R., & Mobilia, M. (2019). Predicting stormwater retention capacity of green roofs: An experimental study of the roles of climate, substrate soil moisture, and drainage layer properties. *Sustainability (Switzerland), 11*(24). https://doi.org/10.3390/su11246956

LUSPA. (2017). *Greater Accra Regional Spatial Development Framework: Regional Spatial Development Framework Strategies and Policies Report* (Vol. 2). Retrieved from http://www.luspa.gov.gh/files/GARSDF Vol 2.pdf

Magill, J. D., Midden, K., Groninger, J., & Therrell, M. (2011). A History and Definition of Green Roof Technology with Recommendations for\nFuture Research. *Department of Plant, Soil, and Agricultural Systems in the Graduate School, Master of*, 62. Retrieved from https://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1132&context=gs_rp

Magliocchetti, M., & Fasolino, I. (2021). Small rivers and landscape nbs to mitigate flood risk. *Sustainable Mediterranean Construction*, 32–36. Retrieved from http://www.sustainablemediterraneanconstruction.eu/SMC/Special Issue n.5_files/032_Small Rivers and Landscape. Nature-based solutions to mitigate flood risk.pdf

Malczewski, J., & Jankowski, P. (2020). Emerging trends and research frontiers in spatial multicriteria analysis. *International Journal of Geographical Information Science, 34*(7), 1257–1282. https://doi.org/10.1080/13658816.2020.1712403

Marinetti, C., Martens, E., Lexy, N. M., & Arntz, R. (2016). *Methodology Urban Flood Risk Assessment*. Retrieved from https://repository.tudelft.nl/islandora/object/uuid:14c432e0-4eba-49b1-be50-8e4577ae1058/datastream/OBJ

Medrano, O. A. A. (2019). *Measuring the benefits of urban nature-based solutions through quantitative assessment tools (Master's thesis)*. Universiteit Utrecht. Retrieved from https://dspace.library.uu.nl/handle/1874/383347

Ministry of Environment, S., Innovation, T., And, M. of L. G., & Development, G. of G. (2017). Enhancing Urban Resilience in the Greater Accra Metropolitan Area. *Enhancing Urban Resilience in the Greater Accra Metropolitan Area*, (May). https://doi.org/10.1596/27516

Mohamed Elmoustafa, A. (2012). Weighted normalized risk factor for floods risk assessment. *Ain Shams Engineering Journal, 3*(4), 327–332. https://doi.org/10.1016/j.asej.2012.04.001

Nardi, F., Annis, A., & Biscarini, C. (2018). On the impact of urbanization on flood hydrology of small ungauged basins: The case study of the Tiber river tributary network within the city of Rome. *Journal of Flood Risk Management, 11*(1975), S594–S603. https://doi.org/10.1111/jfr3.12186

Oduro, C. Y., Adamtey, R., & Ocloo, K. (2015). Urban Growth and Livelihood Transformations on the Fringes of African Cities: A Case Study of Changing Livelihoods in Peri-Urban Accra. *Environment and Natural Resources Research, 5*(2). https://doi.org/10.5539/enrr.v5n2p81

Ogie, R. I., Adam, C., & Perez, P. (2020). A review of structural approach to flood management in coastal megacities of developing nations: Current research and future directions. *Journal of Environmental Planning and Management, 63*(2), 127–147. https://doi.org/10.1080/09640568.2018.1547693

Oregon Sea Grant. (2011). *Porous Pavement*. 98. Retrieved from https://seagrant.oregonstate.edu/sgpubs/porous-pavement

Park, I. H., Lee, J. Y., Lee, J. H., & Ha, S. R. (2014). Evaluation of the causes of inundation in a repeatedly flooded zone in the city of Cheongju, Korea, using a 1D/2D model. *Water Science and Technology, 69*(11), 2175–2183. https://doi.org/10.2166/wst.2014.077

Pennsylvania DEP. (2006). *PENNSYLVANIA Stormwater BMP Manual*. Retrieved from https://pecpa.org/wp-content/uploads/Stormwater-BMP-Manual.pdf

Pickvance, C. (2005). The four varieties of comparative analysis: the case of environmental regulation. *Paper for Conference on Small and Large-N Comparative Solutions, University of Sussex*,

(September), 22–23. Retrieved from https://www.researchgate.net/publication/279472109_The_four_varieties_of_comparative_analysis_the_case_of_environmental_regulation

Raghunathan, T. (2020). Weighting Methods. *Missing Data Analysis in Practice, 19*(2), 48–71. https://doi.org/10.1201/b19428-5

Ruangpan, L., Vojinovic, Z., Di Sabatino, S., Sandra Leo, L., Capobianco, V., Oen, A. M. P., & Lopez-Gunn, E. (2020). Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review of the research area. *Natural Hazards and Earth System Sciences, 20*(1), 243–270. https://doi.org/10.5194/nhess-20-243-2020

Saaty, R. W. (1987). The analytic hierarchy process-what it is and how it is used. *Mathematical Modelling, 9*(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Santiago-Ramos, J., & Hurtado-Rodríguez, C. (2022). Assessing Ecosystem Services Provision as a Support for Metropolitan Green Infrastructure Planning: the Case of Three Spanish Metropolitan Areas. *Applied Spatial Analysis and Policy*, (0123456789). https://doi.org/10.1007/s12061-022-09441-7

Service, G. S. (2014). *2010 Population and Housing cencus: Accra Metropolitan*. Retrieved from https://new-ndpc-static1.s3.amazonaws.com/CACHES/PUBLICATIONS/2016/06/06/AMA.pdf

Simister, N. V. S. (2017). Qualitative Comparative Analysis (QCA). *In Intrac for Civil Society*. https://doi.org/10.4324/9781315651453

Soz, Watson, & Stanton-Geddes. (2016). Solutions in Urban Flood Risk Management. *Urban Flood Community of Practice*. Retrieved from https://openknowledge.worldbank.org/handle/10986/25112

Stagakis, S., Somarakis, G., & Chrysoulakis, N. (2019). ThinkNature Nature Based Solutions Handbook. *ThinkNature Project Funded by the EU Horizon 2020 Research and Innovation Programme*, (730338), 1–226. Retrieved from https://gib-foundation.org/wp-content/uploads/2019/12/ThinkNature_Handbook_20190913.pdf

Stow, D. A., Weeks, J. R., Shih, H. C., Coulter, L. L., Johnson, H., Tsai, Y. H., … Mensah, F. (2016). Inter-regional pattern of urbanization in southern Ghana in the first decade of the new millennium. *Applied Geography*, *71*, 32–43. https://doi.org/10.1016/j.apgeog.2016.04.006

Tengan, C., & Aigbavboa, C. O. (2016). Addressing Flood Challenges in Ghana: a Case of the Accra Metropolis. *International Conference on Infrastructure Development in Africa*, (June 2015), 498–504. Retrieved from https://www.researchgate.net/publication/316093848_addressing_flood_challenges_in_ghana_a_case_of_the_accra_metropolis/link/58f021d6aca27289c20fde72/download.

The World Bank. (2015). *Rising through Cities in Ghana: Ghana urbanization review overview report*. 1–54. Retrieved from https://openknowledge.worldbank.org/handle/10986/22020

Thelen, E., & Howe, L. F. (2011). *Porous Pavement fact sheet*. 98. Retrieved from https://www.washtenaw.org/DocumentCenter/View/15222/Pervious-Pavement

UNCT Humanitarian Support Unit, G. (2015). *Ghana – Floods Situation Report*. https://doi.org/10.3923/ijss.2017.32.38

UN-HABITAT. (2011). *Ghana Housing Profile: UN-HABITAT. (Volume): 978–92–1–132416–7*. Retrieved from http://www.unhabitat.org

Vallecillo, S., Kakoulaki, G., La Notte, A., Feyen, L., Dottori, F., & Maes, J. (2020). Accounting for changes in flood control delivered by ecosystems at the EU level. *Ecosystem Services, 44*(July), 101142. https://doi.org/10.1016/j.ecoser.2020.101142

Yiran, G. A. B., Ablo, A. D., Asem, F. E., & Owusu, G. (2020). Urban Sprawl in sub-Saharan Africa: A review of the literature in selected countries. *Ghana Journal of Geography, 12*(1), 1–28. https://doi.org/10.4314/gjg.v12i1.1

Zhang, H., Cheng, X., Jin, L., Zhao, D., Feng, T., & Zheng, K. (2019). A method for estimating urban flood-carrying capacity using the VIS-W underlying surface model: A case study from Wuhan. *China. Water (Switzerland), 11*(11), 2345. https://doi.org/10.3390/w11112345

Zhou, Y., Shi, C., Du, J., & Fan, X. (2013). Characteristics and causes of changes in annual runoff of the Wuding River in 1956–2009. *Environmental Earth Sciences, 69*(1), 225–234. https://doi.org/10.1007/s12665-012-1949-8

Zimmer, W. (2011). Classification methods. *Passive Acoustic Monitoring of Cetaceans*, 164–197. https://doi.org/10.1017/cbo9780511977107.008

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