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Técnicas de socio-ingeniería para la gestión de aguas pluviales en Ghana considerando las perspectivas de las partes interesadas y las superficies sostenibles.

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DOCTORAL THESIS
Socio-engineering techniques for stormwater management in Ghana considering stakeholders' perspectives and sustainable surface coverings.

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Dedications

My doctoral thesis is dedicated to Fortune Nyame Adom Yiwo, Glory Ekua Assoh Yiwo and Blessing Nyamenim Yiwo.

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Abstract

Flooding is one of the most detrimental global hazards associated with climate change, especially for developing countries where resources to mitigate the menace are limited. In Ghana, flooding has been rising despite actions taken by the government. Here, the views of relevant stakeholders (politicians, citizens, volunteers, technicians and academia) were sampled and analysed using statistical tools. The popular categories of floods in Ghana were highlighted coupled with towns where the stakeholders shared their experiences with flooding. Most participants highlighted the relevance of citizen participation to avert floods, while seeking the alternatives to augment the capacities of conventional drainage systems through permeable surfaces. The politicians were the only group that did not acknowledge the role of surface permeability in terms of flood reduction. In view of this situation, strategic organisations of flood related education, highlighting on the effectiveness of natural drainage systems, is demanding. To this end, the need for nature-based solutions and green infrastructure to build flood resilience can be popular and applicable.

In connection with the outcome of the survey, a laboratory investigation was carried out to create a sustainable engineering technique applicable to flood mitigation in Ghana. The investigation produced pervious concrete pavements (PCPs) with palm kernel shells as aggregates. PCPs were designed by different mix ratios for both control and experimental composites in which PKS were incorporated as aggregates. The percentages of aggregate replacement by PKS were 0%, 25% and 100%. A permeability test was applied to all specimens and the sample with 100% dura PKS recorded higher rates of permeabilities (8.3 m/s), while the samples with no or less (25%) dura PKS recorded very low rates (1.16 m/s and 2.07 m/s). In order to determine the mechanical characterisation, compressive, tensile splitting and flexural tests were carried out. Even though the mechanical properties of the PCPs were relatively low, the average strengths were within the acceptable thresholds.

To improve the representation of the real stakeholders' perception of flooding trajectory in Ghana, future research may focus on stakeholders' locations. Further research may consider focusing on only politicians to validate whether the narrative that suggest they oppose the application of permeable surfaces is throughout the country and a true reflection. To evaluate the application of PCPs, a methodology that incorporates a spatial multi-criteria decision-making would be helpful. A special focus on the design of interconnected natural and permeable surfaces would foster water percolation in case of flooding. The conversion of dura-PKS into other forms like powder or ashes could be an alternative as a binder or additives for sustainable local brick-and-mortar production. The PKS in its raw state without any pre-treatment for such PCPs is highly recommended due to the environmentally usefulness.

Keywords: concrete; data analysis; flood management; laboratory testing; palm kernel shells; permeable pavements; questionnaire; stakeholder perception

Resumen

Las inundaciones son uno de los peligros más perjudiciales asociados con el cambio climático, especialmente para los países en desarrollo, donde los recursos para mitigar la amenaza son limitados. En Ghana, las inundaciones han ido en aumento a pesar de las medidas adoptadas por el gobierno. En esta tesis se recopilaron las opiniones de las partes interesadas (políticos, ciudadanos, voluntarios, técnicos y académicos) en la gestión de inundaciones y se analizaron utilizando herramientas estadísticas. Las partes interesadas compartieron sus experiencias sobre inundaciones según las ciudades en las que vivían. La mayoría de los participantes destacaron la importancia de la participación ciudadana para evitar las inundaciones, enfatizando también la búsqueda de alternativas para aumentar la capacidad de los sistemas de drenaje convencionales a través de superficies permeables. Los políticos fueron el único grupo que no reconoció el papel de la permeabilidad de la superficie en términos de reducción de inundaciones. Ante esta situación, se requiere la organización estratégica de acciones de educación relacionada con las inundaciones para destacar la eficacia de los sistemas de drenaje natural como las soluciones basadas en la naturaleza y la infraestructura verde.

Como resultado de la encuesta, se realizó una investigación de laboratorio para una solución de ingeniería sostenible aplicable a la mitigación de inundaciones en Ghana. La investigación produjo pavimentos de hormigón permeable (PCPs en inglés) con cáscaras de palmiste (PKS en inglés) como parte de los áridos. Los PCPs se diseñaron con diferentes proporciones de mezcla para las probetas de control y las experimentales con PKS como áridos. Las tasas de reemplazo de áridos por PKS fueron 0%, 25% y 100%. La muestra con 100% de PKS registró tasas de permeabilidad más altas (8,3 m/s), mientras que las muestras sin o con menos PKS (25%) alcanzaron tasas muy bajas (1,16 m/s y 2,07 m/s). Para determinar la caracterización mecánica, se llevaron a cabo ensayos de compresión, tracción y flexión. Aunque las propiedades mecánicas de los PCP eran relativamente bajas, las resistencias medias se encontraban dentro de los umbrales aceptables de acuerdo con la normativa vigente.

Para mejorar la representación de la percepción real sobre la trayectoria de las inundaciones en Ghana, las investigaciones futuras pueden centrarse en las ubicaciones de las partes interesadas. También se puede considerar centrarse únicamente en los políticos para validar si la narrativa que sugiere que se oponen a la aplicación de superficies permeables se extiende a todo el país y es un reflejo verdadero. Para evaluar la aplicación de los PCP, sería útil una metodología que incorpore una toma de decisiones multicriterio espacial. La conversión del PKS en otras formas como polvo o cenizas podría ser una alternativa como aglutinante o aditivo para la producción local sostenible de ladrillos y mortero. El PKS en su estado crudo sin ningún tratamiento previo para dichos PCP es muy recomendable debido a su utilidad ambiental.

Palabras clave: análisis de datos; cáscaras de palmiste; cuestionario; ensayos de laboratorio; gestión de inundaciones; hormigón; pavimentos permeables; percepción de las partes interesadas

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1 Introduction

The evolution of the urban landscape, geography, and ecology have collectively escalated due to infrastructural developments, population and the kinds of infrastructure adopted in most metropolitan areas. In this vein, the physical environment gets compromised and countless communities bear the consequences. As part of these dynamics, climate change has become a key character, and climatological hazards, including flooding have been a trending phenomenon. Stakeholders in different parts of the world have applied varying strategies to manage stormwater, which is known to be a major cause of the flood and related menace but the challenges persist. In Ghana, the developmental and population growth rises with incremental flood trajectory. The concept of flood mitigation has been examined from the social, economic, technological, and environmental perspectives. However, there is a need to investigate stormwater management in Ghana from a combined stakeholders' perspective and sustainable surface coverings.

1.1 Background

Natural hazards have roused the awareness of many communities to recognize the significance of building a more nature-based environment. Floods are among the most devastating natural hazards affecting millions of people worldwide [1] as their effects compound and cascade through society. This occurrence sets people and communities into undesirable conditions and vulnerabilities. This effect aggravates people's, societies', and governments' economic health situations and developmental aspirations. Both in developed and developing territories, flooding has been a threatening experience. Nonetheless, certain countries and communities have controlled the flood challenges to a rather more resilient society through research and practical lessons learned. Globally, the frequency and severity of floods are expected to increase due to climate and land-use change [2].

The repetitive occurrences of flooding, with extensive impacts on human comfort, economies, and ecosystems are a global concern and cause for worry [3]. The manifestation becomes overwhelming, especially in areas with improper waste management, poor settlements, and a lack of resources. Considering the low level of preparation, high population growth, and recent approach to land use in sub-Saharan Africa, it is predictable that the region may suffer more from flooding effects [4]. A creative effort is demanded to change the narrative of floods in the sub-region. Hundreds of death counts and destruction of assets worth millions of dollars are attributed to flooding in this region annually [5].

In Ghana, for instance, an incredible regional land coverage is threatened by floods anytime it rains [6,7]. The situation becomes even more concerning in cities with high population growth [8]**.** According to Ahiadze [9], urban flood severely affects the lives of people and properties in the coastal belt of Ghana every year. In a quest for resilience against the menace of floods, it is thoughtful that the urban design and building implementation sequence are carefully examined.

As discharges from the Bagre dam spill out every wet season from north to the coast, the situations in the Savannah, Oti and Volta regions become troubling. Hundreds of people are victimized, and over 200 km^2 of farmlands are destroyed coupled with machinery [10]. This recurrent and unswerving occurrence [11] and the devastating effects are projected to worsen in the future when special care or preparations are not set [9]. A deliberately designed system to fully address this concern is urgently required, especially amid climate change [12].

Even though the government has a responsibility to ensure that the flood risks are reduced, individual preparedness to deal with floods is equally necessary [13]. Behavioral attitudes have indirectly contributed to the increasing records of flood circumstances [14]. Aside from reviewing and implementing designs to mitigate floods, the citizenry's attitude may also influence the desired change [15]. In this regard, a suggested result-oriented approach is for the government to prioritise social interventions that induce behavioural change [16]. Through this, awareness creation amongst the public advances and may contribute to flood risk reduction. In contemporary times, technology plays a role in many discourses and adapting it locally in urban stormwater management can help attenuate the challenges that come with flooding [17].

Human activities like construction, improper waste management, and deforestation overwhelm the natural land cover, which promotes biodiversity and ecological balance. Aside from these physical developmental patterns, irresponsible mining activities popularly known as 'galamsey' are currently and fervently distressing the natural flow paths for water in sub-Saharan Africa [18]. A community can envelope, and external works including components like aprons, pavements, rain gardens, ponds, and bio-retention tanks will significantly contribute to runoff reduction and ecological balance.

For these reasons, it shall be useful for local authorities to establish policies that encourage the sale and use of land, green infrastructure (GI), and vertical building styles, unlike the usual lateral pattern [5]. GI are useful in flood management but the functionality depends on the application of the techniques, and designs that fit to reduce runoffs [19]. Runoffs occur because of rainfall or spillage from a source (river, dam, lake etc.). Depending on the source and flow path, numerous contaminants may be conveyed along causing environmental harm.

A more environmentally friendly way required to capture the discharges and separate possible pollutants is the use of GI. In Ghana, for instance, runoffs are usually collected from the sides of roads by conventional (opened) drains, which accommodate more silt [21]. Meanwhile, with the integration of GI, runoffs are well-trapped, treated and used for agricultural and domestic activities [20]. To actualise communal flood resilience, it is relevant for urban designers to pay attention to the choice of materials used as pavement or covering [22].

A developing country like Ghana may strategically adapt to focusing on investigating resilient solutions using local materials that are readily available [16]. Considering the environmental significance of permeable pavements, particularly if made of concrete, and the conditions suitable for their application, it will be helpful to incorporate them in the built environment as a flood mitigation method in Ghana [23]**.** Acknowledging certain acceptable limits of strengths and rates of permeability, local stakeholders producing concretes and estate developers may adopt GI, using a variety of available materials as aggregates [24].

The approach may target the use of materials that are considered wastes, creating a nuisance to the environment, and even contributing to floods in a way. In this way, floods can be controlled and the physical environment can be sustained, achieving a complete waste management cycle [25]. Natural materials like clay, bamboo and timber are known for their usages and contributions to sustainability in the built environment [26,27]. Among many organic materials, palm kernel shells (PKS) found in parts of Asia and Africa are equally useable for construction considering their rigidity, and harmless effect when interacting with water and soil [26,28,29].

PKS has varying species depending on the oil palm tree (dura, pisifera and tenera species). For instance, the tenera variety has been proven to be applicable in Malaysia and other parts of the world [26,30], whilst less is said about the dura variety that is common in Ghana [31]. Knowing that the dura PKS has thicker shells than the tenera and the pisifera varieties [32], it will be thoughtful to use it as aggregates for pervious concretes [33,34]. This is particularly motivated because the size and shape of aggregates in concrete influence the performance of the concrete.

1.2 Aim and Objectives

This thesis aims to investigate local flood drivers in Ghana and propose alternative sustainable approaches to mitigate flood risks. The research methods comprised gathering and analysing stakeholders' perceptions and a laboratory investigation on pervious concrete pavement using dura PKS as aggregates. This general aim was founded on the following specific objectives:

1. To disseminate a well-designed questionnaire to gather general insights on how stakeholders in Ghana perceive the flood drivers and prospective solutions.
2. To identify the main causes of flooding in Ghana and what solutions stakeholders believe could be more effective in mitigating these floods.
3. To find the trajectory and inclination of the perceptions based on the classifications of diverse stakeholders (e.g., technicians, volunteers, politicians, academics, and citizenry) concerning flood drivers and potential attenuation options.
4. To conduct a laboratory analysis on permeable concrete pavement using limestone as control aggregates and untreated dura-PKS as experimental aggregates.
5. To adapt a mix design with a water-cement ratio 0.33, and coarse aggregate replacement ratios ranging from 0%, 25% and 100%.
6. To determine and compare the experimental specimens' physical and mechanical properties to those of the control and facts from existing literature.

The first three objectives relate to societal aspects, while the fourth to the sixth connect with the engineering aspect of the research.

1.3 Research Questions

The under-listed questions are the main doubts that this investigation seeks to answer:

1. Can the stakeholders' perceptions of flood occurrence and mitigation be captured by questionnaire?
2. Are there any particular trends regarding the main causes of flooding and potential solutions identified by the stakeholders addressed?
3. How different do participants working in different fields and locations perceive about flood drivers and mitigation measures?
4. Can untreated dura-PKS be adapted as aggregates for permeable concrete pavement in a laboratory in relation to limestone as control?
5. How does the adaptation of a mix design with a certain water-cement ratio and various coarse aggregate replacement ratios affect the properties of pervious concrete?

6. Are there significant disparities or similarities in the performance between the control and the experimental permeable concrete specimens in terms of strength and permeability rate?

1.4 Structure of the thesis

The thesis structure comprises an introduction, literature review, methodology, results and discussions, conclusion, recommendations, and a list of references. The introduction entails the background of the study. Here the aim of the research work is outlined with the potential objectives to actualise the aim. The existing literature that concerns the background of the study is then reviewed. Upon reviewing relevant literature and narrowing the narrative to the case study area or situation, the research gap was identified and highlighted. From then on, the research context was set, and the approach suitable for the investigation was derived.

The aspects considered for the review included the tools, sampling techniques, pervious concrete pavements and the application methods for flood management in advanced countries concerning the situation in Ghana. The design of the methods used to carry out the investigation was detailed. The approach combined qualitative and quantitative research methods to obtain the results for discussion. The results obtained were analysed and discussed using comparison techniques. Finally, conclusions and recommendations were made based on the outcomes of the investigations.

2 Literature Review

In this section, past and recent literature on the engineering applications, societal perspectives on flood and the case study area were extracted, put together and appraised. The urban surfaces, green infrastructure (GI), mix designs for pervious concrete pavements (PCPs), characterisation of PCPs, incorporation of additives, aggregate type and their effects on the performances of PCPs, were aligned according to the engineering perspective. The social aspects encompassed the studies on interdisciplinary collaborations, response management techniques and a highlight on adoptable policies that is flood resilience inclined.

Figure 1 summarises the concepts and topics addressed in this section to gain insights into the societal and technical perspectives of floods and the design of engineering solutions for their mitigation using PCPs.

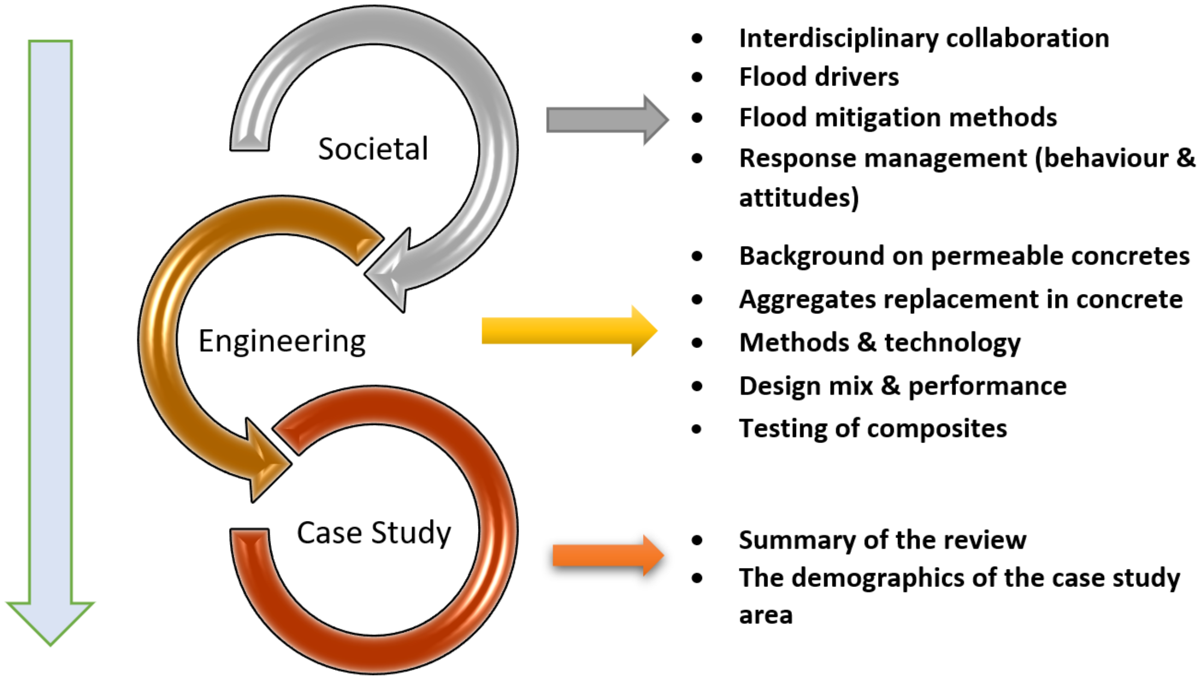


Figure 1. Flowchart of the socio-engineering aspects considered in the literature review

2.1 The societal perspective

2.1.1 Interdisciplinary collaboration

The combination of engineers and social scientists from their various interdisciplinary research projects helps optimise insights and better understand water and society interactions. This can be a path along which applicable solutions to current or future water-related challenges can be actualised. Working with participants like individuals, policymakers, community leaders, and government representatives who may have less technical insights on flood management will amount to solely gathering their apparent views which may not necessarily be facts. Hitherto, it is important to establish the finding with the understanding of persons from across disciplines and not only technical participants.

This is because there may be research points of interest from where results or views will either be divergent or convergent. From this, hypothesis can be established should data from both expertise and social participants be merged. More so, introducing technical terminologies and methodologies to participants with far-distant academic backgrounds will help bridge the gap between the disciplines [35]. Research findings and conclusions are somewhat limited if the method is technically oriented without considering general societal perspectives and observations of the people. It becomes difficult to understand results that are acquired from findings sourced from a closed environment where strict methods were applied [36].

Aside from the technically inclined stakeholders in the study area, understanding the procedure and terminologies makes it difficult for others to contribute. Real-world challenges are addressed through collaborations and considering the combination of perceptions and facts to decide on flood-related challenges is a well-meaning approach. Though hydrology is engineering-biased, water usage and the effect of water-related catastrophes is more socially oriented. That, notwithstanding, very few overlaps in these domains have been considered for research projects in Ghana.

As attested by Bennedict and Hussein, that 'Water is Life' [37], the intersections of these disciplinary perspectives are significant for resolving real global water crises in the future. Even though perspectives look opposing, a critical examination of the two disciplines or methods depicts some elements of commonality and needs to be advocated. Engineering and social sciences are known to be methodologically mismatching. However, they could be more convergent, compatible, and complementary [38]. Rather than assuming the incompatibility of the domains, the focus should be on the research problem.

It is important to affirm that methodological variances are not necessarily obstacles to integrating distant disciplines [39]. Researchers from different backgrounds can cross disciplinary boundaries when similar research objectives drive them. This may contribute to novelties under engagements and debates on challenges and practices. Crossing disciplinary interactions spark interest and that relating to water systems and floods are anticipated as well. Despite the challenges that may be associated, collaborations are needed considering the opportunity to build a common platform, understand and provide a holistic problem-solving approach [40].

2.1.2 Flood drivers & consequences: Local urban perspectives

Flood threatens society in diverse ways when not carefully contained. In Ghana, floods resulting from stormwater discharges affect buildings, agricultural works, transportation, and many more businesses [12]. As a result of unplanned settlements in the cities due to rural-urban migration, the trends of runoff values rise as many premises are covered with impermeable solid concretes. Also, improper management of waste affects the performance of the existing conventional drainage systems [41]. Eventually, this prevailing circumstance becomes a recipe for floods whenever there is a minimum downpour.

The attitudes of the average citizenry directly reflect on the chances of suffering from or sustaining natural disasters like floods. From a sustainable urban design perspective, flood management must incorporate innovative materials in the system from design to implementation stages that enable a complete natural water cycle [42]. The application of GI in many parts of sub-Saharan Africa is somewhat overdue. Despite the need to immensely adapt and apply, governments' unwillingness, limited data records, and lack of public exposure amongst other factors draw back the implementation.

Building green cities is expensive but cannot be compared to the potential cost of the effect of a catastrophe caused by floods. As implemented successfully in China, Australia, and

Europe, developing countries like Ghana can be encouraged to implement similar strategies in certain critical locations of the country. Certainly, the conventional pipe-based flood management systems cannot be resilient to flood challenges looking at the trajectory of climate change trajectories [43]**.** Aside from flood risk reduction, the multi-functionality and synergies associated with GI in terms of urban agriculture, social amenities, environmental features, aesthetical value and sustainable water supply make the option awesome and holistically affordable [43].

According to Keraita [44], wastewater from households joins streams without any form of intermittent treatment in many parts of Ghana[44]. Having farmlands in the low elevation areas following waste and stormwater flow paths makes the circumstance scary. The situation demands strategies to reduce environmental and health risks, especially in the event of floods. The chances of posing health risks to urban and peri-urban agriculture via wastewater-stream contaminations are higher due to improper stormwater control and sanitation systems. Though results from Abass et al [45] suggested otherwise, health risk can be reduced to the bare minimum should a well-designed drainage system be in place.

2.1.3 The government and green infrastructure policy for flood mitigation

Annually, the shoreline of Ghana suffers coastal flooding resulting in tremendous washing away of lands. Popular towns like Keta in the Volta, Esiama in the western, Elmina in the central and La in the Greater Accra regions have predominantly been victimised by the effect of stormwater and flood risks. A policy framework to contain the tragic phenomena and reduce the level of susceptibility was recommended by Boateng [46]. Amongst these were developing storm warning systems, evacuation plans, and building elevated storm surge shelters.

Introducing permeable pavements in various households, and parks along the shoulders of roads, can contribute immensely to flood management [47]. The future is now, and engineering or technological innovation needs to address flood-related challenges in all cities in Africa suffering the effects [48,49]. Globally, GI is advocated for flood control. However, demonstrating this campaign has not manifested much in many parts of developing countries. In the case of Ghana, both the government and the general populace have hesitated to replace the conventional drainage system with PCPs for flood mitigation purposes [50].

Apart from the government's oral posture, which confirms the endorsement of Sustainable Developmental Goals (SDGs), the full arms of government creating a framework for the implementation of PCPs could be considerably proactive. Considering the benefits of GI implementation, prioritising the application of PCPs would be a good decision. Aside from flood control, it will be helpful in air quality improvement, energy savings, and climate change [50,51]. One of the ways that the government may change the narrative as a commitment to practical flood management is to review the construction-related laws, incorporating a minimum percentage of GI on all infrastructural projects.

2.1.4 Response Management Techniques

Flood risk management (FRM) can be more effective when it incorporates participatory methods, involving local communities, stakeholders, and experts. These methods ensure that decisions are informed by real-world knowledge, increase public trust, and eventually enhance resilience. By this approach, the communities have first-hand experience of flood impacts and can provide critical historical insights on flood patterns. Participation raises awareness about the risks, all-inclusiveness and encouraging proactive mechanism from both individuals and groups.

The characteristics of the respondents may vary depending on a questions asked [52]**.** Popular interviewing techniques including face-to-face, telephone, and self-administered responses are applicable for data gathering and analysis. A technique may influence the validity of responses despite the level of threat to the questions indicated [53]. The Marlow-Crowne scale, which has been hyped as a method for identifying persons who distort responses, is shown to be ineffective for that purpose [52].

Over two decades ago, Ramsden asked a question about attitudes to science in his 'Mission impossible?' article [54]. Though, arguable, it is relatively established that attitudes somehow affect data depending on the structure of question [54]. Through discussions, interpretations of responses may be slightly or greatly shifted either by sentiments, emotions, limited content connections or interest of the authors [55,56]. With reference from Fisher and Frey [57], one may relate the teacher and student discourse scenario to the researcher and respondents in qualitative research.

The impression of the investigator often may not be the same as the respondent's. Sometimes, authors are dismayed when many of the respondents give responses contrary to the investigation's anticipation. So, properly structuring questionnaires or interview questions reduces potential erroneous response patterns and helps reduce deviation from the context [53]. Nonetheless, Cycyota and Harrison [58] argued differently, with a highlight on the class of the respondents and their interests. In the view of increasing understandability, creative formative assessments enable researchers to determine what audiences, readers or respondents know, have an interest in, and the level of understanding.

According to Fisher and Frey [57], interactive writing, portfolios, multimedia presentations, and audience response systems influence clarity in communicating a message [57]. Occasionally, information may be gathered through unconventional methods but the data or information may be credible for decision making [59]. Bekoe [60] highlighted that the hasty and improper application of a technique intended to influence understanding is likely to neglect effective and psycho-related domains, which may be of equal importance. In effect, the purpose of research works may not necessarily manifest, depending on how a tool is used.

Due to convenience, verifiability, low-cost delivery and smart feedback systems, researchers are using electronic technologies to disseminate and collect survey responses [61]. Despite the merits, one needs a bit of experience and basic technological skills to be able to command the application holistically. The online survey technique, for instance, does not align with a special category of investigations in certain fields. Both engineering and socially inclined studies are applicable so far as the messaging applications are activated and potential respondents are available on the selected platforms.

The cyber frontier is currently the endorsed option for future research works specifically in the areas of web survey design, sampling, data collection and responses, and publicity [61]. The Delphi technique becomes helpful when anonymity, response sieving, structuring group communication and policy-making are the key characteristics [62]. In the scenario of classified stakeholders as applied in making sense of consensus [63], similar applications will be suitable for gathering perceptions of stakeholders of flood in Ghana.

In the study of climate change responses, Addaney [56] applied quantitative and qualitative techniques to analyze the collected data from the Dormaa West district in Ghana. Here, a random selection of 190 household respondents from five communities and four planning and climate agencies showed evidence of climate change impacts on local livelihood [56]. Yin et al [64] used the protective action decision model to analyse attitudes of persons vulnerable to flood risk. Using the Tobit and binary logistic regression models, it was evident that 60.16% of households were not prepared for flood disasters despite proximity to high flood susceptibility [6].

As established by Yin Q, et al [64], formal education, level of income, introduction of taxes on buildings in flood zones and previous experience and cost implications, influence flood risk management. Similarly, in Pakistan, the flood risk perception index was developed using relevant attributes on a Likert scale and a binary regression model. The influence of socio-economic and institutional factors on rural households' risk perception was examined. Interestingly, it was also determined that flood risk perception is strongly linked to socio-economic variables such as age, education, house ownership, family size, past flood experience, proximity to river source, as well as institutional factors and extreme weather forecast information [65].

Again, the findings detailed that flood risk perception varied among household heads based on education levels, age, and monthly income levels. It is perceived that floods bring about psychological stress and mental distress even though the mechanisms underlying this association remain largely unknown [66]. To assess the link between flood risk perception and psychological distress, the Yamane sampling technique was applied to ascertain the size of samples in rural communities. In this case, combined methods comprising descriptive statistics, chi-square, one-way ANOVA, Pearson's correlation tests, and regression analysis were used to analyse data sampled from 4 flood-prone rural communities of Muzaffargarh in Pakistan [67].

Through 17 interviews and 392 household surveys in Glefe, a suburb in Accra, a data set for better understanding flood perceptions was composed [68]. The data were qualitatively and quantitatively examined and analysed through regression analysis. The findings revealed that fear, flood experience, and coping experience were the major factors influencing residents' flood risk perceptions. The simple but powerful logistic regression tool is useful for understanding the influence of several independent variables on a single dichotomous outcome variable and policy development especially if data is limited [69].

Due to the size, complex and dynamic nature of respondents, there may be the tendency that applying only one research method to certain investigations may fail. This is because the full relationships of responses may be deficient, thus affecting the full understanding of the dynamics of risk situation or perception [45,70].

2.2 The engineering aspects

2.2.1 Background on permeable concrete pavements

The environmental benefits of permeable concrete pavements (PCPs) makes it relevant to implement them in our localities. Few among them are stormwater runoff reduction, underground water quality improvement, heat-island effect mitigation, traffic noise reduction, and skid resistance improvement. However, they have high maintenance requirements due to clogging problems [71]. Also, due to their composition, they have lower density, thermal conductivity, lower drying shrinkage, and high permeability than conventional pavements [72]. Thus, for an appropriate application of PCPs for the use as a supporting part of drainage, the exact development of the infiltration process, the lasting infiltration performance and its dependence on the interacting factors have to be known [73].

By comparing traditional Portland cement concrete (PCC) and Portland cement porous concrete (PCPC), the testing results showed that the surface temperature of PCPC was not as higher as that of PCC under the same thermal conditions as validated by Haselbach and Kevern et al [74,75]. As highlighted by Callejas et al [76], PCPs usually absorb more heat from solar radiation and present higher surface temperatures than those of traditional concrete pavements. According to Wu [77], the surface temperatures of PCPC increased more slowly and decreased faster under windy conditions. This indicates that the thermal evaporation of permeable pavements is the main function in abating their thermal impacts on the environment. The high conductivity of PCPs in both dry and wet conditions helps alleviate the urban heat island effect [78]. The emerging areas of research like nanoscience and nano-engineering may help address its durability.

Due to its high porosity and permeability, PCPs are considered an alternative to traditional impervious hard pavements for controlling stormwater in an economical and friendly environmental way. Permeable concrete is normally made of single-sized aggregate bound together by Portland cement and used restrictedly as a pavement material, because of its insufficient structural strength. The interesting observation is that a lot of waste products from industrial, domestic, and agricultural sectors can be used as aggregates for PCPs [79–81].

In this vein, permeable concrete can be enhanced when attention placed on the sizes and kind of aggregates in the design mix [82]. Pervious concrete is considered lightweight concrete with no or small percentage of fine aggregate. Ordinarily, PCPs have low compressive strength and are prone to clogging, which degrades performance and reduces service life. However, the combination of different sizes of coarse aggregates in the concrete mixtures influence the potential properties such as permeability and porosity.

In spite of the drawbacks associated to the conventional PCPs, there have been developments to overcome their limitations [83]. Eventually, the introduction of permeable concrete with high strength and clogging resistance has been a key factor in recent times. As density can be an effective indicator for predicting compressive strength, and porosity [84], the incorporation of certain aggregates for PCPs can also exhibit impressive resistances for surface splitting and flexural tests [85]. The rate of porosity and permeability of pervious concrete can be improved or decreased depending on the materials adapted as aggregates in the mix [86].

2.2.2 Methods of mix, proportions, and additives

The selected method of mixing directly impacts on the performance of the specimen or composite. This parameter is a very sensitive aspect of concrete production. A lot of assumptions are made by researchers when designing composites. The researcher's interest plays a role in the choice made. The assumptions considered when designing for pervious concrete may not be the same for ordinary or plane concrete. Meanwhile, all assumptions must range with the established limits of the existing standards [87,88]. Sometimes, based on the empirical equations established, a new mixture proportion design method is proposed to achieve a functional target like compressive strength and permeability rate.

Predictive approaches based on multiple regression and reliability theory provide useful information on achieving the sustainable design and practice of permeable concrete with the admixtures [89]. The higher reliability, precision, and adaptability of the result of the design method are validated [90]. The performance of permeable concrete mixed with various alternative construction materials has varied in many situations. For instance, composites with fibres have improved infiltration rates whilst composites with tyre chips as aggregate tend to clog pores and decrease infiltration [89]. The degree of infiltration is reliant upon the geometric configurations of the composites.

2.2.3 Aggregates replacements and effect on the performance of concretes

All ingredients constituting the production of concrete are replaceable. Sometimes, replacement applies either to a binder or coarse or fine aggregates. It is the researcher’s interest to determine the type of replacement and the material to replace [26,85,91]. In certain situations replacements may be singular or combined [92,93]**.** Depending on the inspiration, any material at all may replace a known aggregate. For instance, in the case of Anwar et al [94], where a meta-analysis of the performance of pervious concrete was done using cement and aggregate replacements, up to 40% of replacements for cement and 50% for aggregate were viable, as combined replacements.

The performance of concrete is influenced depending on the material, the percentage of replacement, and the method. The durability of pervious concrete coupled with the applicability of replaced materials acquired from different locations demands further investigation to confirm the trend or dynamics of using replacements versus the durability of the PCPs [94]. Though the coefficient of permeability and porosity of lightweight composites may be high, it is important to achieve appreciating values for mechanical and physical properties. Despite the significance of PCPs to the environment, the economic value is compromised if their resistance to load is insignificant [27].

2.2.4 Design mix consideration for pervious concrete pavements

Considering the materials normally used either as aggregates or binders of PCPs, the design parameters become very sensitive [27,29,95]. Fine aggregates decrease with an increasing rate of permeability and vice versa. On the other hand, increasing fine aggregates increases bonding, consequently increasing strength. According to Yahaya and Kabagire [96], the packing density of the fine aggregates increased to render a positive effect on the strength development of previous concrete although the permeability was on the decline. So, achieving optimal proportions of the aggregates produces functional pervious concrete.

Similarly, this is the case for water-cement ratios in pervious concrete design as confirmed by Ibrahim [27] and Sahdeo et al [97]**.** Generally, water-cement ratio of PCPs ranges from 0.29 to 0.39 [27] but may vary slightly depending on the state of the aggregates being used [24,84,98]. The workability of concrete reduces if the quantity of water is less. However, as Wu [89] and González et al [91] attested, an easily flowing concrete has little or no strength to resist potential loads. Water content increases with decreasing strength but workability improves [77,80,99].

Aside from the contribution resulting from the nature of the material, is the method of batching. Batching by volume or weight for the same materials may produce different results but similar trends. This is because the materials used as aggregates (dense or light in nature) affect the quantity of binder and water-cement ratio. For instance, when a less dense but absorptive material is batched by weight, the volumetric quantities of the composites increase. Zaetang et al [85] replaced natural aggregates with different proportions of palm oil clinker for previous concrete.

Depending on the material used as aggregates, the performance of PCPs will differ relatively. Considering two separate investigations on PCPs where the materials incorporated differed but with the same range of replacements (0-100%) and batching method applied, the performances of the PCPs could not have been the same. Recycled block aggregates (RBA) and recycled concrete aggregates (RCA) were tested for PCPs by Zaetang [72], whilst dolomite and copper slag aggregate were also used in an investigation concerning PCPs by Lori [86] **.** For the combination of RCA at all replacement levels, the surface abrasion resistance improved whilst for RBA, the improvement in surface abrasion resistance was gained with a 20% replacement level only.

For the incorporation of the dolomites and copper slag aggregates, the mechanical properties of the experimental composites with 60% replacement recorded higher strength than the control mix. At this level of replacement, the compressive strength, flexural strength, and splitting tensile strength augmented to 31%, 19% and 18%, respectively [86]. There is a relation between the physical properties and the mechanical properties of concrete depending on the absorptive nature of the materials applied. This is because, water-cement ratio is a key design consideration for all kinds of concrete and the strength of concrete depends on it. Hence, different kinds of materials incorporated at varying levels demonstrate either an increasing or decreasing strengths of the pervious concrete samples.

2.3 Case study area

Ghana, the case study area located in west Africa with geographical boundaries between latitudes 4.5°N and 11.5°N and longitudes 3.5°W and 1.5°E, is bounded by the Gulf of Guinea to the south, Togo to the east, Ivory Coast to the west and Burkina Faso to the north (Figure 2). The country has a tropical monsoon climate with agricultural land accounting for about 65% of the overall land area [100]. As of 2021, Ghana had a population of about 31 million people, of which, about 52% are males and 48% are females [101].

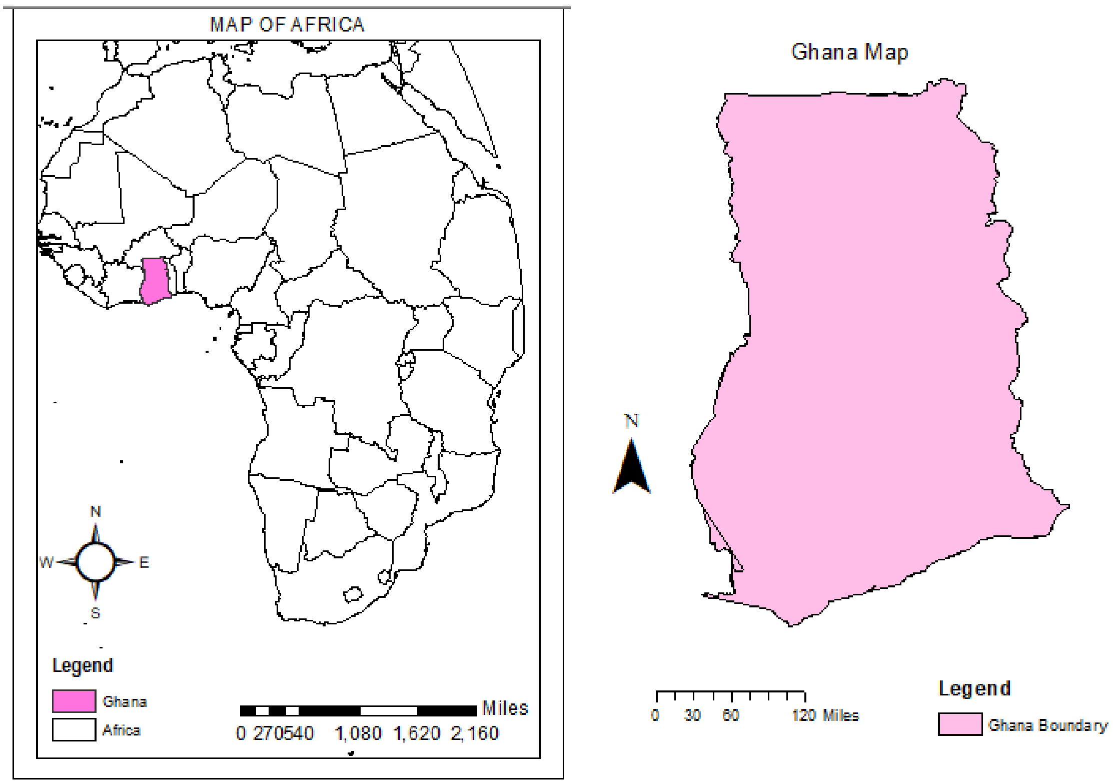


Figure 2. The map of the case study area (Ghana), highlighted on the African map

Generally, the land coverage is categorised into the northern middle and coastal belts. The northern belt is normally dry with a seasonal annual rainfall pattern whilst the middle to the coastal belt is relatively green with more rainfall records. The northern belt comprises Upper West, Upper East, Savannah, Northern and Northern East whilst the coastal belt comprises

Volta, Greater Accra, Central and Western regions. The regions between the northern and the coastal belt represent the middle belt.

2.4 Summary of the review

The social aspect commenced with the significance of cross-disciplinary research, narrowing the scope to social and engineering perspectives. The section delved into the trajectories of flooding from the global perspective to the situation of Ghana, the case study area. Bearing in mind the potential drivers of floods, the perceptions of stakeholders in the case study area were analyzed. Here, insights were acquired through by gathering stakeholder views and suggestions from previous research works. The perceived drivers were exclusively related to the dynamics in similar cases or jurisdictions. Stemming up from that, alternating methods that may be useful in flood attenuations were also explored. Amongst these included a review of local government policies on the introduction of GI and behavioral change of the likely victims of floods. Various researchers have loomed into investigations about flood resilience in Ghana from diverse outlooks and procedures. From questionnaires, workshops, and interviews with key stakeholders, sole and combined participatory tactics have been used to establish findings about flood risk management [3,102,103]. Yet scarcely have they developed a criterion at the national level comprising all relevant parties [5].

Aside from that, the investigations conducted previously have not sufficiently closed the gap that exists relating the advancements to the actual flooding circumstances in the country. For decades, the literature concerning flooding in Ghana has paid more attention on the economic effects and trends coupled with societal dynamics like culture, beliefs, and perceptions implications. Interestingly, no regard has been given to focusing on flood control and mitigation measures. Unlike, other jurisdictions where GI is integrated in infrastructural development for climate adaptation and disaster risk reduction [104,105], the case of Ghana is different. The advocacy for the application of GI and other potential surfaces that are resilient to floods has been diminutive. The disparity is interesting enough to consider an investigation that is oriented to the global interest so far as flood reliance is concerned. Hence, this study seeks to construct awareness about the social and technical drivers and potential solutions for flood risk management in Ghana.

Based on this, the connection between the social and engineering factors needed to improve flood understanding and management in Ghana can be established, while multi-stakeholder perceptions can be analyzed on the role of resilient surfaces for flood attenuation purposes. Furthermore, the analysis can ascertain and possibly address how different actors perceive the different climatic and societal drivers of flooding notwithstanding their role in reducing the risk. This supports the assertion and review of the integration of both social interventions and technical aspects to flood risk reduction in Ghana emphasized by Steen and Ferreira [106]**.** To this end, a questionnaire was designed to assemble feedback from five fronts of the national populace: volunteers, academics, citizens, decision-makers (politicians), and field technicians working in the fields of flood management.

In what concerns the technical side, though conventional drainage systems help the retardation of floods, it is believed that integrating or increasing the application of GI will intensify the course of reducing floods in Ghana. Acknowledging the environmental advantages of GI especially for water management, the application of PCPs can be suitable adaptation for flood control in certain locations, considering the pores within the composites to store runoffs temporary. Focusing on PCPs, their characterization depends on the mixture design, type of aggregates, and percentage replacements, while their performance is influenced by the densities, porosity, strength, permeability, and absorption rates of their constituents.

To the best of my knowledge, many researchers have investigated flood mitigation-related works but have not assessed the performance of PCPs using the dura species of PKS for flood mitigation purposes in the world [24,33,107]. Significantly, similar investigations [30,33] that used other species did not use it without any previous treatment as proposed here. Hence, the distinction or novelty to other related previous investigations is established when carefully compared [81,108,109]. Meanwhile, aside from little usage of the dura-PKS in Ghana for local fuel, the material is largely regarded as waste creating a nuisance to the environment. Moreover, its characteristics predict the chances of substituting it with conventional aggregates for PCPs, which is currently becoming increasingly expensive. To fill these gaps, this thesis aimed to gain insight into the use of raw dura species of PKS by analysing their mechanical and physical properties when used as partial replacement of known aggregates in low-traffic PCPs for flood mitigation purposes.

3 Methods

This chapter highlights on the techniques applied to derive the results discussed in the following section. Primarily, quantitative research methods were applied, where both causal-comparative and experimental approaches were used. The social perspective of flood drivers and contributing factors in Ghana was captured through a survey distributed among relevant stakeholders. Following the conclusions of the perspective survey, an experiment was conducted in the laboratory which investigated into the adoption or application of palm kernel shells (PKS) in the production of pervious concrete pavements (PCPs) as a flood mitigation measure.

Figure 3 shows the flowchart of the methodology adopted for addressing flood management in Ghana. Groups of stakeholders of flood management in Ghana were selected and surveyed through a snowball sampling technique. Based on the conclusions of such survey, PCPs were designed different mix ratios for both control and experimental composites including PKS as aggregates. The percentages of aggregate replacement by PKS were, 0%, 25% and 100%

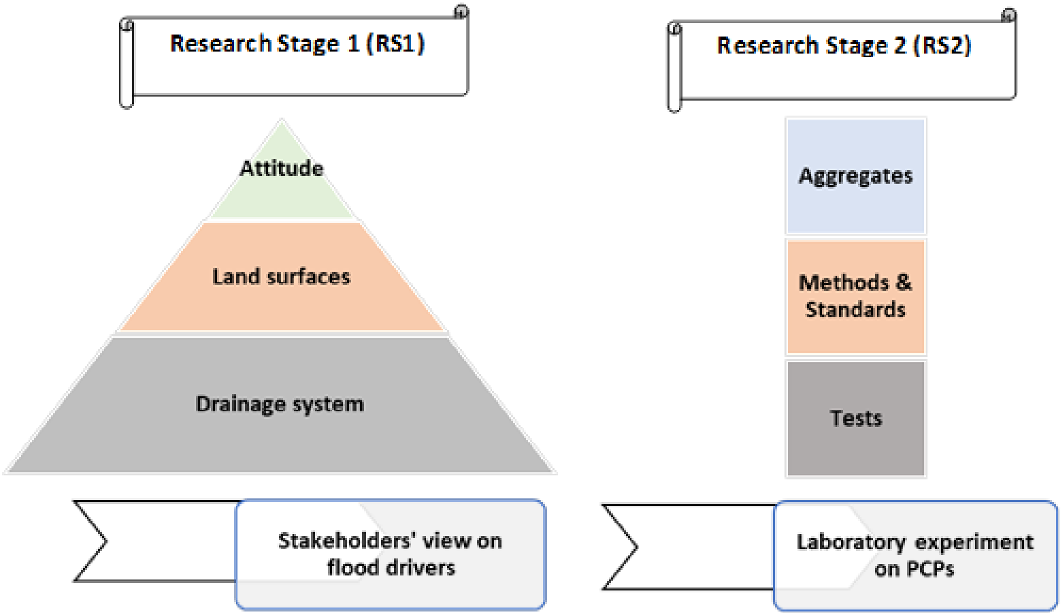


Figure 3. General flowchart of the method applied for the research work

3.1 Stakeholders view on flood drivers

The social and technical perceptions of floods in the case study area were captured through a designed online questionnaire. A brief description of the steps involved in the questionnaire is provided in Figure 4.

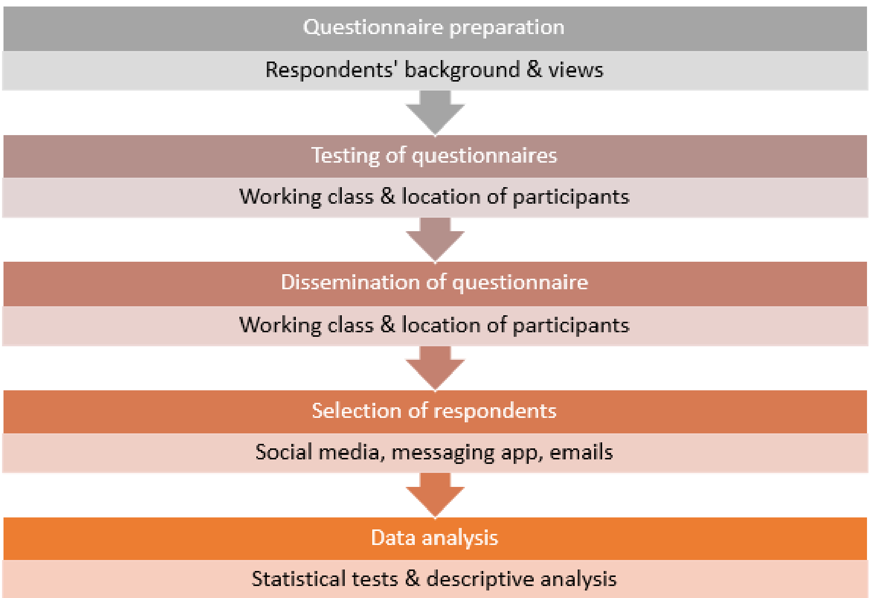


Figure 4. Flowchart showing the main steps taken to gain insight into the perception of flood management in Ghana

3.1.1 Questionnaire preparation

In gaining insight into the role of land cover, urbanisation, resilient surfaces and stakeholder participation in flood risk management in Ghana, questions were asked. The set of questions included personal information of the respondents, social perceptions, designs of the built environment, flood contributing factors, and potential flood mitigation actions. The questions on the personal information were useful as they talked about their academic backgrounds, professional experience with water-related working fields, and their locations.

This information helped to draw conclusions based on knowledge, experience, and location perspectives. Also, as a motivation to gather general assumptions about flood drivers in Ghana and recommendations on alternate management solutions, questions regarding the general observations about flood management were asked (Table 1).

Table 1. Excerpts showing the types of questions included in the online questionnaire.

Question	**Answering options**
2. Which of the following do you think is or is likely to aggravate flooding the most?	a) Rainfall b) Landcover
12. Rate the following according to the situation in your locality so far as a flood-contributing factor is concerned:	Strongly disagree / disagree / undecided / agree / Strongly agree Building in flood-prone areas Bad attitudes
17. Which city or town do you currently live in?	……………………………………..

Importantly, questions were asked about the designs of the built environment to ascertain the relation that exists between the existing drainage system and the flood tendencies. The questions were inspired by the protection motivation theory [110] where the coping-appraisal construct was considered. This seeks to put together beliefs that will be effective in reducing the flood threat by adopting a particular measure. The theory was applied by connecting the perceived efficacy of certain attitudes and measures in mitigating risk as demonstrated by questions 3 to 9 (Table 2).

Excluding the pre-testing items, the questionnaire was formed by 18 mandatory and 3 optional questions. As presented in Table 2, the set of questions included Likert scale, open-ended and multiple-choice questions. The design of the questionnaire was arranged in the order as follows: flooding conceptualization and management, stakeholders and citizens' responsibilities, land cover, urbanization and built environment and personal information.

Table 2. Description and characteristics of the questions sent to address flood perception in Ghana.

Question	Question type	Options
1. What do you think is the main cause of floods?	Open-ended	-
2. Which of the following do you think is or is most likely to aggravate floods?	Multi-select	Rainfall/Land cover/Water table/Poor drainage/Kind of settlements
3. Rate these options in respect of their contribution to attenuating flood risks:	Likert scale	Very low/Low/Medium/High/Very high
4. How do you rate the efficiency of stakeholders like the National Disaster Management Organisation (NADMO) in resolving flood risks?	Likert scale	Poor/Fair/Good/Excellent
5. How would you rate the citizenry's role in resolving flood risks in your community?	Likert scale	Not important at all/Somewhat unimportant/Neither unimportant nor important/Important/Very important
8. Per your experience, should land surfaces be permeable and percolating enough; what will be the flood tendencies?	Likert scale	Lower/Similar/Higher
9. Which of the following works against the natural mechanisms or designs that mitigate flood risks?	Multi-select	Built-up surfaces like concrete floors/Nature-based solutions like pond creation/Porous covers like marble
10a. Do you think that natural mechanisms to prevent flood risks (e.g., soil infiltration) have been altered?	Multiple-choice	Yes/No
10b. If 'Yes' in 10a, how?	Open-ended	-
11a. According to your observation or opinion, are existing drainage systems not resilient enough to mitigate floods in your community?	Multiple-choice	Yes/No
11b. If 'Yes' in 11a, what else do you suggest being done?	Open-ended	-
12. Rate the following according to the situation in your locality so far as flood-contributing factors are concerned:	Likert scale	Strongly disagree/Disagree/Undecided/Agree/Strongl y agree
13a.Do you perceive that certain materials used for construction contribute to flood risk?	Multiple-choice	Yes/No
13b, If 'Yes' in 13a. what material (s) and how?	Open-ended	-
14. Rate the influence that these components have on reducing flooding:	Likert scale	Very low/Low/Medium/High/Very high
15. How do you rate your knowledge level on flood risk management:	Likert scale	Very low/Low/Medium/High/Very high
16. Relationship to flood management:	Multiple-choice	Academic/Worker (technician)/Citizen/Volunteer/Politician (decision-maker)
17. Which city do you currently live in, have lived or are familiar with in Ghana?	Open-ended	–
18. What is the most common type of flooding in your area?	Multiple choice	River flooding / Coastal flooding / Groundwater flooding / Urban flooding
19. How would you rate your understanding and ease as you filled out the questionnaire?	Likert scale	Very low/Low/Medium/High/Very high
20. Specify if you have any suggestions for improving the questionnaire:	Open-ended	-

In the case of the Likert scale questions, the rating was intended to capture the direction and strength of the feelings of the respondents [111]. For instance, as shown in Table 2, questions like 3, 12 and 14 were further grouped into dissimilar choices with respective frequencies that were to be assessed by Likert-scaled options. Meanwhile, the multiple-choice questions were essentially to isolate alternatives based on individual choices. Here, distinct grades of intensity were not emphasised or deprived of.

The open-ended optional questions in nature gave room for respondents to provide more specific answers representing their views about flood experience and mitigation concerns. The optional questions were not mandatory considering the knowledge-based structure of the questions in terms of flood management.

3.1.2 Validation of the questionnaire

To validate the questionnaire and determine the readability, clarity, and understandability of the set of questions, it was pre-tested with five (5) selected persons. Each person corresponded to representatives for the profiles considered in the questionnaire: academic, citizen, decision-maker (politician), volunteer, and worker (field technician). Here, particular emphasis was placed on questions numbered 19 and 20 (Table 2) to gather relevant recommendations or affirm the contextual significance and usability of the questionnaire in terms of structure and content.

A week was initially allocated for the pre-testing of the questionnaire, but it was extended from the 6th of February until the 26th of February 2021. Besides testing it with a reduced number of participants, the internal consistency was also qualitatively evaluated. To this end, control questions were used; for instance, as shown in Table 2, question one (1) was used as a control for questions two (2) and twelve (12). Furthermore, we compared our outcomes with previous research findings to evaluate content validity.

Given time and resource constraints, the verification of the questionnaire's re-test reliability was not done. In effect, we were not able to establish the extent to which individuals' responses to the questionnaire items remained relatively consistent across repeated administration of the same questionnaire. Out of the targeted five 5 respondents, four (4) responses were received. In this regard, three (3) respondents out of the four (4) voted for "high" and one (1) voted for "normal" with respect to the standard of the structure of the questionnaire.

That notwithstanding, only one of the respondents suggested that making the questions more straightforward and self-explanatory could help answer more easily. Counting on the encouraging feedback received from the sampled respondents during the pre-testing phase, the questionnaire was disseminated to 133 potential participants selected based on snowball sampling technique [112,113].

3.1.3 Sharing of questionnaire and gathering of responses

Following the design of the questionnaire and the validation of the set of questions, a list of potential recipients was created to obtain a representative sample in terms of profile and origins of the stakeholders. Then, the questionnaire was disseminated to the shortlisted participants via e-mail or through messaging applications. The snowball sampling technique was useful as we could not have easily contacted all the respondents. Respondents were reached through sampled persons identified through personal contacts and our previous research works.

These people formed a representative sample according to both their profiles concerning flood management and the regions where they lived. The dissemination of the form was carried out throughout March 2021. Once all the expected responses were received, they were obtained as spreadsheets using Google Forms' automated functionalities. From then, the feedback provided by the addressees was ready to undergo a series of analyses in descriptive and statistical terms. The selection and categorization of the respondents were pertinent and strategic because they helped to determine diversified views based on location and experience or exposure to flood-related matters.

3.1.4 Data analysis

Amongst the analytical tools, R 4.1.0 was selected as the suitable application for processing the responses [114–116]. Both text mining and statistical testing were useful in the analytical section. The analyses were constrained by the sample size, which was expected to be diminished. Text mining was applied to the four open-ended questions (Table 1). Question 1 was mandatory, whereas the three others (questions 10b, 11b, and 13b) were discretionary. Considering the multi-stakeholder nature of the assessment, the responses collected were analysed based on the respondent's profile and locality (towns and cities).

The most frequent terminologies in the responses were aggregated and highlighted using word clouds. Hither, at least a word recurrence of three (3) was established as a threshold from which to incorporate them into the clouds. Through correspondence analysis, the frequencies were recorded in tables and the distance between their elements was represented [117]. In addition, Ward's method [118] was applied to cluster the texts hierarchically and the chi-square distance processed [119] between the selected words. The Elbow method [120] was used to determine the optimal number of clusters. For the statistical tests, a comparison was done based on the frequency of the decision selected by the respondents. Considering the small sample size and also to determine whether the population from which the sample is sourced was normal or not, Shapiro-Wilk (S-W) tests were conducted. Upon the application, it was observed that the P-values of the S-W tests were less than 0.005. This implied that the distribution was not normal and hence, there was the need to adapt nonparametric test on the samples.

Now, the Kruskal-Wallis or Mann-Whitney tests, which are nonparametric alternatives to One-way ANOVA on ranks and Student's t test were applied to ascertain whether there were statistically significant differences in the responses provided by different stakeholders [121,122]. Applying one test or another depended on whether the number of groups compared was two (Mann-Whitney test) or greater than two (Kruskal-Wallis test).

Fisher's exact test [123] was applied to complement all inference drawn from the analysis in general. This application helped in the better understanding how the profiles of the respondents and the sizes of the cities they lived (as in questions 16 and 17) induced the flooding concepts from both social and technical perspectives (questions from 3 to 14). More so, the test was particularly applied to questions 16 and 17. This was because they were the questions that alluded to the objectivity of the data concerning the respondents.

To this significance, contingency tables captured the answers to questions 3 to 14 according to the profile of the respondents (Table 3). The effect size of the test was also determined to provide additional justification to the reliability of the results attained statistically [124]. To this end, the effect size was interpreted as large, medium and small in relation to the degree of freedom (df) of the contingency tables as suggested by Cohen [125] (Table 3).

Table 3. The effect size for contingency tables depending on the degrees of freedom (df).

df	**Small**	**Medium**	**Large**
1	0.10	0.30	0.50
2	0.17	0.21	0.35
3	0.06	0.17	0.29
4	0.05	0.15	0.25
5	0.04	0.13	0.22

The size of the locations the participants were familiar with or resided in was categorised into very large, large, medium, and small in terms of their population. From a population greater than 1 million, between 100,000 and 1,000,000 inhabitants and between 20,000 to 100,000 inhabitants were respectively denoted as very large, large, and medium. Locations with less than 20,000 inhabitants were labelled as small locations (towns or cities). This application was replicated given the breakdown proposed by Satterthwaite [126] whereby 2 very large cities, 15 large cities and 63 medium-sized cities were classified.

Again, it is in line with the data collected from the United Nations Population Division and processed by Worldometer [127,128] whereby the circumstances for Ghana at the time of the survey (the year 2020) affirmed the trajectory as participants respectively resided in the very large, large and medium-sized locations (towns or cities). In establishing the statistical significance of the survey given its fact-finding nature, a margin of 0.10 was set as the threshold in conjunction with the argument made by Labovitz, who suggested that large error rates were usually associated with small sample sizes [129,130].

3.2 Experimental sequence

This section adopts experimental work to prepare lightweight concrete specimens. The aggregates were graded and batched with cement and water to prepare control and experimental lightweight concrete specimens, without any pre-treatment or additives. The mechanical and physical properties of the specimens were determined via testing after being kept in a curing chamber for 28 days. Experimental samples containing palm kernel shells (PKS) were scanned with a microscope to gain insight into the cellular nature of these materials. The main stages for the experiment are illustrated in Figure 5.

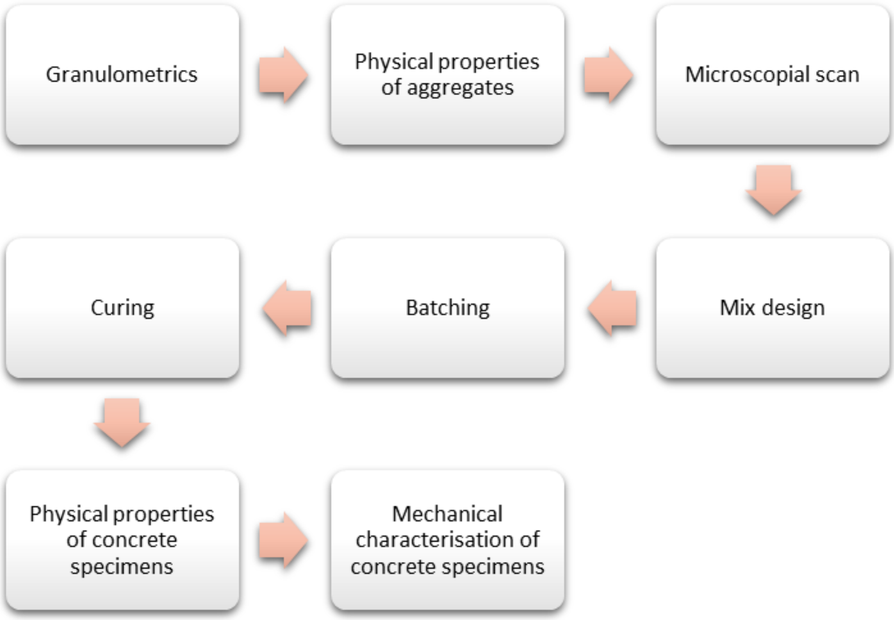


Figure 5. Flowchart showing the main steps considered for the experiment.

3.2.1 The granulometry of the aggregates

3.2.1.1 Particle size gradation

The study adopted limestones and dura-PKS as aggregates. The limestones were used as the aggregates for the control specimens and the dura-PKS as the experimental aggregates. Their particle size distribution and geometrical properties were determined by adopting EN 933:1&2 [131]. The set of UNE sieves (mm) was arranged with the least size at the bottom and increasing order above (0.5 mm to 14 mm). After the aperture was set, the setup was connected to an electric power source to enable vibration in back-and-forth motion which influenced aggregates to pass as soon as possible.

The same procedure and setup were applied to both aggregates separately (Figure 6). Due to the lack of fine particles derived from the permeable nature of the specimens, sieve sizes below 0.5 were not used. Unlike the approach applied by Khankhaje et al., [30], where PKS were pre-treated before used, aggregates were screened here directly without washing, decanting, or fiber removal.

(a) Limestone aggregate

(b) Dura-PKS aggregate

(c) Manual sieving

(d) Aperture setup for sieving

Figure 6. Setup for aperture and evaluation of aggregates.

3.2.1.2 Flakiness Index

The aggregates' geometrical properties were determined by applying EN 933-3 where the flakiness index (FI) test was conducted [132]. Here, a minimum quantity of the aggregates was sampled and sieved using mesh and bar. The accumulated weight was determined after recording the respective weights for each sieve fraction. Aside from recording the accumulated mass in each of the sieves, the aggregate retained between the lower and upper sieve sizes (t_i and T_i, respectively) were also recorded as shown in Table 4. Due to the potential weight variation of the application, a sample of aggregates was prepared according to EN 932-2 [133]. Here, the aggregates were conditioned to a constant temperature of 110±5 °C for 24 hours [134].

Table 4. Correspondence between mesh and bar sieves

Mesh (ti/Ti)	16/20	12.5/16	10/12.5	8/10	6.3/8	5/6.3	4/5
Bars (mm)	10	8	6.3	5	4	3.15	2.5

With the bar sieve approach, per fraction, the weight of aggregates obtained in a flat or planar orientation was recorded (Figure 7). The aggregate particles that recorded dimension (thickness) of less than 0.6 times their mean area was taken out since they were very flaky. More so, for aggregates sizes smaller than 6.3 mm or retained on 63 mm, the test sieve was not applicable. The mass of each granulometric fraction and the mass of non-cubic particles were recorded.

In the case of the bar sieves, a zippy back-and-forth movement was applied until no aggregates passed to the bottom (Figure 7). The data recorded were the weight retained in each t_i/T_i mesh sieve fraction and the weight of the material passing through its corresponding bar sieve. The calculation of the FI (%) for each fraction approximated to the nearest integer was calculated (Eq. (1)).

Figure 7. Illustration of manual sieving by bars.

$$FI\ (\%) = \left(\frac{W_T}{B_T}\right).100 \qquad (1)$$

3.2.1.2 Shape Index

The shape index (SI) of the aggregates was determined by applying UNE-EN 933-4 whereby the geometric properties of the particle shape of aggregates were examined [131]. Accordingly, a handful of aggregates (not less than 100 number of aggregates) were fetched, and the geometric characterization of the aggregates was determined by manually measuring the length (L) and thickness (T) of each particle with the help of a Vernier caliper (Figure 8). The relationship between the L and T dimensions were such that their ratio was more than 3 (L/T>3). To establish a particle's shape index, the quantity of aggregates that are cubic and non-cubic in nature were categorised and compared in terms of weight. The percentage by mass of granulometric fractions less than 10% of the initial mass of the sample was not used. The average quotient between the mass of non-cubic particles (M_2) and the total mass of the aggregate sample (M_1) was deduced in percentage as in Eq. (2).

(a) The length of an aggregate (b) The width of an aggregate

Figure 8. Measurement of the length and thickness of aggregate with a caliper.

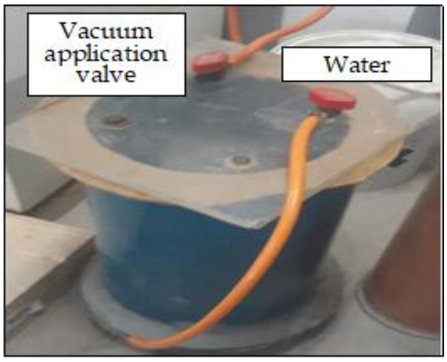
The sample of aggregates was prepared according to EN 932-2 [133] by drying them at 110±5 °C until a constant mass reached [134]. This was relevant because the moisture content of aggregates from the source may compromise the result since SI depends on the mass of aggregates.

$$SI\ (\%) = \left(\frac{M_2}{M_1}\right).100 \tag{2}$$

3.2.2 Physical properties of the aggregates

The physical properties of the aggregates were investigated by considering their densities. Here, apparent specific density, bulk specific density, saturated surface dry density, and set density, water absorption rate, porosity, and permeability rates were the properties explored**.** By the application of the standards EN 1097-3 & 6 [135], the properties were determined. Aggregates were put in an oven at a constant temperature of 100 °C for a day. Following the standards EN 932-1 & 2, the samples of aggregates were dehydrated until a constant weight was ascertained and the dry weight of the aggregates was recorded [133].

The sample was then conditioned to vacuum for the next 24 hours in a compartment such that air was trapped out from both compartments and the accessible pores of aggregates. On the next day (exactly 24 hours), the chamber was filled with water through a water inlet valve with a constant vacuum at a pressure of 5 kPa (Figure 9). Due to the presence of water in the compartment at length, the aggregates became highly saturated with water after the next 24 hours in the water before being removed from the compartment.



(a) Compartment containing the specimen and water

(b) The vacuum pump with valves connecting cells

Figure 9. Detail of the vacuum cell and vacuum pump illustrating the maturation process.

After the three-stage saturation process, the aggregates were removed and with the help of a weak absorbent cloth, they were superficially dried. This was done to eliminate the surface gloss of water from the aggregates, without necessarily drying. Subsequently, the saturated weight with the dry surface (W_{SSD}) was recorded. The apparent volume of the sample (V_a) was then determined from the thrust exerted by the volume of the displaced water according to Archimedes' Principle as illustrated in Figure 10.

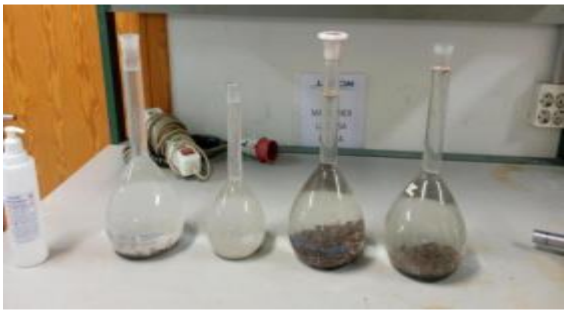


Figure 10. Determination of the mass of the displaced water.

The accessible pore volume (h_a) was deduced and expressed in Eq. (3) as the accessible pore volume, obtained by differences between W_{SSD} and the dry weight of the specimen (W_D).

$$h_a = W_{SSD} - W_D \quad (3)$$

Assuming that the density of water in the laboratory was 1 g/cm^3 and the same units were used, the relative volume (V_r), bulk density (D_b), apparent density (D_a), and specific saturated surface dry densities of the aggregates (D_{ssd}) were obtained using Eqs. (4), (5), (6) and (7), respectively.

$$\text{Relative volume: } V_r = V_a - h_a \quad (4)$$

$$\text{Bulk specific density: } D_b = W_D / V_a \quad (5)$$

$$\text{Apparent specific density: } D_a = W_D / V_r \quad (6)$$

$$\text{Saturated surface dry density: } D_{ssd} = W_{SSD} / V_a \quad (7)$$

Once the accessible porosity and the dry weight were known, the water absorption rate (% wt.) was deduced as formulated in Eq. (8). The ratio between the accessible pore volume and the apparent volume of the sample provided the accessible porosity of the material (% vol.) via Eq. (9). A minimum mass of aggregates (M) for each of the fractions was also determined from the maximum size of the aggregate (D in mm) using the formula labelled in Eq. (10).

$$\text{Absorption (\% wt.)} = {}^{h_a}/_{W_D} \cdot 100 \quad (8)$$

$$\text{Porosity (\% vol.)} = {}^{h_a}/_{V_a} \cdot 100 \quad (9)$$

$$\text{Mass of aggregates (M)} = \left({}^{D}/_{10}\right)^2 \cdot 100 \tag{10}$$

The minimum mass values obtained for each fraction were those shown in Table 5**.** Sieving was done by a back-and-forth motion technique where each application lasted for 2 minutes. The sieves were removed, and the same motion technique was manually applied to sieves (one by one) with aggregates retained until no material could pass through the sieve. Sequentially, the material retained by each of the sieves was weighed separately on a balance of individual weights accumulated (W_c).

Table 5. Minimum weight required for sieving

Fraction (d-D)	0 – 6	6 – 12	12 – 18
Weight (kg)	0.34	1.92	4.34

After the sieving process, the fine material (aggregates that passed through the 0.5 mm sieve) obtained in the bottom sieve was further poured on sieves with sizes below the 0.5mm to the 0.063 mm sieve size. This was done to determine the percentage of fines distributed in the material. The cumulative percentage by weight of the aggregate that passed through each sieve (Cp) expressed in millimetres in Eq. (11) for each fraction.

$$Cp\ (\%) = 100 - (100 \cdot \frac{W_c}{M_1}) \tag{11}$$

where W_c is the cumulated weight of aggregates retained on individual sieve fractions and M_1 represents the total mass of aggregate sample used for the grading test. The filler content (F) was determined by following the indications specified in the UNE-EN 933-3 standard [131] as shown in Eq. (12). The weight of the sample before (w_1) and after (w_2) washing was recorded and the percentage of fines was calculated where these aggregates represented the amount that passed through the 0.063 mm sieve.

$$F(\%) = [(w_1 - w_2) + P] \cdot 100 \tag{12}$$

where P is the amount of sample collected at the bottom of the column of sieves, after carrying out the complete granulometry of the aggregate.

3.2.3 Microscopical scan of dura PKS

The cellular nature of the PKS was diagnosed using a Zeiss scanning electron microscope (SEM). The microscope was equipped with Andor - Oxford Instrument (X-ray detector). For this experiment, the microstructure of the dura-PKS was zoomed in using the model EVO MA15. The three spots of the PKS considered for the scanning were Region 1, 2, and Region

3 (Figure 11). The respective regions represented the very compacted, less compacted, and porous spots.

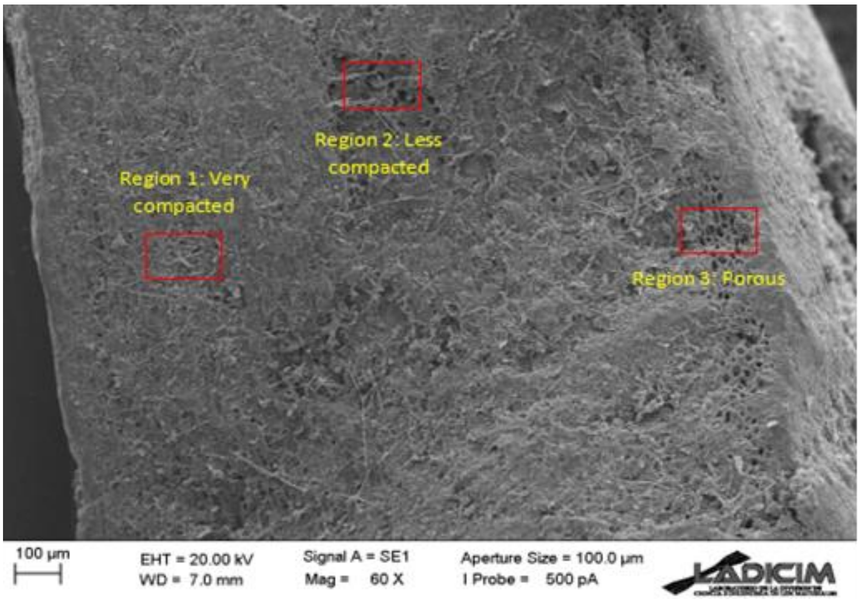


Figure 11. Microscopic analysis of the cellular structure of the dura PKS.

3.2.4 The mix design, batching and curing of concrete specimens

Upon review of the existing scientific literature like Alengaram et al.[33] Khankhaje E. et al [34]. Sonebi et al.[137] and Sriravindrarajah et al.[138] that concern the mix design for permeable concrete, the respective quantities for the concrete constituents (cement, aggregates, and water) were established. A mix design for permeable concrete was designed and three different mixtures were batched as shown in Table 6.

Table 6. The mix design considerations for the pervious concrete under study.

Parameters	**Previously proposed mixes[33,34,137,138])**	**Proposed mix**		
		100% limestone	**100% PKS**	**25% PKS**
Water-cement ratio	0.33	0.37	0.37	0.34
Aggregate-binder ratio	4.17	4.17	4.17	4.17
Aggregates (g)	1,500	1,500	1,500	1,500
Binder (g)	360	360	360	360
Water (g)	119	131.76	131.76	122

With the aid of a metallic recipient with a stirrer integrated as the mixer, the constituents of concrete were contained and batched. The mixer was plugged into an electric energy source which induces the metallic fork-like stirrer to revolve at a constant speed which tends to stir up all the aggregates in the metallic container. For every batch, the required quantity of cement was first deposited in the mix recipient followed by aggregates and water. For the water, the quantity was poured into the containment in bits as the machine stirred up the cement and the aggregates until the last drop.

To ensure workability, the water was poured last and in bits to ensure the composite achieved the needed consistency when tested for the slump. Though a prototype mix design was followed, it was important to determine the actual water-cement ratio since the materials used were not the same as those used in the previous design. The mixing machine was plugged on to mix for 4 minutes and then stopped for a minute. This process was repeated twice to ascertain a complete mix.

Immediately after batching, when the concretes were well set, the molds were removed, and the specimens were placed in the curing chamber where they were conditioned to a constant humidity and temperature of not more than 20 ºC. The concrete specimens were kept in the chamber until the 28-day age, after which they were removed and tested for other characteristics relevant to the study.

3.2.7 Physical properties of concrete composites

Specimens were cured for 28 days of age, and the set of densities was determined together with porosity and absorption rates. Following the method labelled in EN 12390-7 [139] and EN 83980-1[140,141] standards, the set of densities was determined in connection with the accessible porosity, and the water absorption coefficient [140]. Using an electric cutter with a wet diamond disk saw, the standard cylindrical specimens (size 150 mm in diameter and 300 mm in height) were cut into three (3), thus obtaining three samples (approximately 150 mm in diameter and 75 mm in height).

For each specimen, about 37.5 mm was cut off both at the upper and lower ends to ensure an even distribution of pores. The tendency of aggregate segregation usually occurs at the base or apex of concrete which may influence results on permeability rates. Three (3) sub-samples of specimens were obtained per mix from standard cylindrical specimens. A systematic three-stage saturation process was carried out to determine the saturated weight, apparent volume of specimen, and volume of voids or displaced water.

The specimens were dried at a temperature of 110 ± 5 ºC in a ventilated oven until the dry weight of the specimens was recorded. Subsequently, the control and the experimental specimens were allowed to cool at room temperature after they had been placed in a vacuum chamber for 24 hours to extract the air. By the effect of overpressure, water was siphoned into the chamber for the next 24 hours. Upon submerging the specimen in water at atmospheric pressure, they attained a high level of saturation due to the pores present in the concrete specimens.

The concrete specimens were removed, and with the help of a poorly absorbent cloth, the water that superficially covered the specimen was gently wiped. The weights of the specimens were re-measured after the process and the saturated weight was recorded. By the application of the Archimedes principle, the apparent volume was determined from the thrust exerted by the volume of the displaced water. Again, upon establishing the saturated weight, the apparent weight was deduced by the ratio of the initial dry weight to the saturated weight. To do this, a metallic mini basin was filled with water and the mass of the water was measured.

The specimens were then gently suspended in the water with the help of string hooked to an adjustable support above the basin. The displaced water was captured and measured as the displaced. The summary of the process applied to ascertain the various durability indicators and physical properties is illustrated in Figure 12.

Figure 12. Illustration of the procedure applied to determine the physical properties of the composites (specimen).

The method applied to deduce the physical properties of the aggregates was replicated for the composites. Here, porosity, absorption rate, and the set of densities of the composites were determined. Having determined the saturated dry surface and the dry weights of the composite, the accessible pore volume was obtained as the differences between saturated dry surface weight and dry weight of the composites. Taking into consideration that the density of water in the laboratory was 1 g/cm^3, the bulk and apparent specific densities were obtained using Eqs. (3)-(7).

Once the accessible porosity and the dry weight were known, the water absorption was calculated by the expression in Eq. (8). The ratio between the accessible pore volume and the apparent volume of the sample in percent resulted the accessible porosity of the material (Eq. (9)).

3.2.8 The mechanical properties of the concrete

3.2.8.1 Compressive strength

The compressive strength of the concrete samples (cube) was determined by applying a 1,500 kN capacity of a universal servo-hydraulic press with a load application speed of 0.5 MPa/s (Figure 13). After curing the specimens for 28 days, the ultimate compressive strengths of concrete specimens were tested. The strength represented the uniaxial compressive strengths of 5 pieces of concrete cubic specimens. To achieve this, the standard EN 12390-3 was followed where per mix, at least a hardened concrete cubic specimen (100 mm x 100 mm x 100mm) was made available [142].

The specimens (cubes) were carefully placed such that the bottom and the top of each specimen were very plane and similarly even surfaces touched the loads (top & bottom of the cube) during crushing. This was significant since uneven contact could have rendered marginal errors during and after crushing. The compressive strength (C) of cubic specimens of concrete was calculated as expressed in Eq. (13).

$$C = \frac{F}{S} \tag{13}$$

where F represents the maximum load, expressed in N resisted by the specimen and S is the load application surface in mm^2.

(a) Before crushing (b) After crushing

Figure 13. Set-up for the demonstration of compressive test.

3.2.8.2 Tensile splitting strength (Brazilian test)

To determine the tensile splitting test, the standard EN 12390-6 was followed where a pair of cylindrical specimens (150 x 300 cm) was tested at the of age 28 days test [143]. A 2,500 kN capacity of a universal servo-hydraulic press was exerted on the concretes until failure (Figure 14). A constant load speed of 0.5 MPa/s was applied on the specimens per crush. The load was applied homogeneously on the specimens until they failed respectively. Once the test was carried out on the specimens, an average tensile splitting strength was determined by the geometric characterization of the specimens. The indirect tensile strength (f) was calculated as expressed in Eq. (14).

$$f(MPa) = \frac{2 \cdot F}{\pi \cdot L \cdot d} \tag{14}$$

where L is the length of the load application line (mm) and d represents the diameter of the specimen (mm).

(a) (b)

Figure 14.Setup demonstrating the tensile splitting test (a) before split and (b) after split

3.2.8.3 Flexural strength

The flexural strength was determined using a 250 kN capacity of a universal servo-hydraulic press. Six prismatic specimens of sizes 10 x 10 x 40 cm each were sampled for testing the flexural strength after 28 days of curing. Amongst the six specimens, two represented the control, which were with no PKS contents, 100% and 25% PKS replacement, respectively. A 60 mm long metallic hook was applied as the single load roller and placed on each specimen at the midpoint.

The load was laid laterally on each specimen until the limit of distortion was reached for each specimen. After they failed, the resistances were recorded and the average flexural strength was determined accordingly. This test followed the standard EN 12390-5 [144] with the variant of using a single centred load roller (Figure 15).

Figure 15. Setup demonstrating a specimen subjected to the flexural test.

The load application speed (R, N/s) was defined in the standard and calculated by Eq. (15).

$$R = \frac{2Sd_1d_2}{3l} \quad (15)$$

where S denotes the increase in stress (MPa), d_1 and d_2 represent the depth (mm) and the height (mm) of the specimen and l is the distance between the centers of the rollers (mm). Each specimen collapsed within a certain period (in seconds) and the cracking stress was determined.

3.2.8.4 Permeability tests

The permeability test was carried out following the standard EN12697-19 [145]. A falling head permeameter was used at an environmental temperature in a well-sealed and compacted cylindrical pipe. Though there are other options for testing the permeability of the specimen, this method was the most suitable for the investigation considering available materials and equipment. The cylindrical concrete samples in the respective representation as control, 25% and 100% replacements were used.

Thin-impermeable sheet of thickness less than 0.5 mm was wrapped along the perimeter of each concrete specimen. Vaseline was applied on the surface of the sheet covering the concrete specimen as an impermeable compound. This was to avoid potential seepage between the concrete specimen and the pipe since there may be some voids. The cylindrical concrete samples were carefully locked and airtight within the cylindrical metallic pipe which formed the base of the setup. On top of the base a calibrated and transparent cylinder known as the permeameter tube was connected.

The permeameter tube was marked at the top and bottom by a vertical displaceable height of 200 mm. A tube was then connected to the setup from a water source (pipe tap in this case). The tap was opened, and water flowed to fill the transparent and calibrated cylinder to the point marked above. Due to the pervious nature of the specimens, the water displaced from the upper line marked vertically downwards to the lower point marked, and the time spent was recorded.

These marked points are referred to as the hydraulic heads (initial and final). Three specimens were used for the test, and for each specimen, the test was repeated twice. To determine the consistent displacement of water on each specimen the test was repeated twice to have an average record of time used for displacement. The rate of permeability was repetitively evaluated based on the average values recorded for samples of each type of mixture. The setup, materials, and procedure for the permeability tests are as illustrated in Figure 16.

(a) (b)

Figure 16. Setup demonstrating the permeability test (a) Sealing of the base (b) Permeameter - water source connection.

Permeability (k) was measured as the time taken for a specific volume of water to pass through the specimen. More specifically, the time recorded for the water level to be tall between two designated points with a head hydraulic gap of 200 mm inside the permeameter tube. Following Darcy's law, k was determined as shown in Eq. (16).

$$k = \frac{aL}{At} \mathrm{In} \frac{h_1}{h_2} \tag{16}$$

where a is the inside cross-section area of the inlet standpipe, L represents the thickness of the specimen at the base, A stands for the specimen cross-sectional area and h_1 and h_2 denote the initial and final hydraulic heads measured at a time in seconds (t), respectively.

4 Results and discussion

In this section, diverse results gathered from the flood management stakeholders' points of view and a laboratory experimental work were analysed sequentially. Tables, and bar charts were generated from the responses gathered in respect of the stakeholders' management perspectives. On the other hand, microscopic, scanned images of the palm kernel shell (PKS) were done. Here, the physical and mechanical properties of the aggregates and composites were illustrated and explored in the laboratory experiment.

4.1 Flooding stakeholders' management perspectives

The perspective of the Ghanaian stakeholders about flood management was extracted from the questionnaire while examined and discussed separately according to the three themes into which the questionnaire was characterised. These main categories of the questionnaire are flooding conceptualization and management, stakeholders and citizens responsibilities and land cover, urbanization and built environment. The results represented the views of the stakeholders, and were statistically determined and interpreted.

In all, 133 stakeholders were contacted during the dissemination of the questionnaire. Of the whole contacted stakeholders, 105 participants confirmed receiving the invitations. Nonetheless, only 50 participants out of the 105 responded, representing a response rate of 46.3%. Respectively, the academic researchers recorded seventeen participants (n = 17) whilst the citizens recorded fifteen participants (n = 15). Likewise, in the responses regarding the locations of the individual participants, Accra recorded the highest frequency followed by Prestea. As twenty-three numbers (n = 23) were recorded for Accra, six numbers (n = 6) were recorded for Prestea as the outcome of the places referred to as the residing localities of the respondents. Table 7 shows the above-referred personal information about the respondents.

Table 7. Participants' knowledge of flood risk management, their relationship to flood management and the city they are familiar with.

Question	Group	n	%
15. How do you rate your knowledge level on flood risk management:	Very low	3	6
	Low	0	0
	Medium	21	42
	High	16	32
	Very high	10	20
16. Relationship to flood management:	Volunteer	3	6
	Decision-maker (politician)	6	12
	Worker(technician)	9	18
	Citizen	15	30
	Academic	17	34
17. Which city do you currently live, have lived or are familiar with in Ghana?	Accra	23	46
	Prestea	6	12
	Kumasi	5	10
	Other	5	10
	Tarkwa	5	10
	Bogoso	2	4
	Cape-Coast	2	4
	Tamale	2	4

The results of the statistical analyses are provided in Table 8, Table 9 and Table 10, which only show the comparisons that proved to be statistically significant (p-values below the significance level established). On the account of the results presented, those involving all groups were omitted due to their lower interests when compared to those in pairs. Table 8 and Table 10 display the discrepancies in the responses that giving the profile of the participants and the size of their cities with which they lived at the time of the investigation. The collective sample of the participants, and the statements behind the frequency variances considering the number of times an available option in multiple-choice, Likert scale and multi-select questions was chosen by participants are shown in Table 9.

The differences in the statistical evidence depending on the classifications were key and demonstrated across perspectives based on the responses for the questions. The questions targeted the generic relief alternatives, local impression about some potential relief alternatives and influence of some selected components to flood reduction. This helped in ascertaining the dynamics statistically and relationship between distinct or common information of the stakeholders regarding flood occurrence. Questions 3, 12 and 14 have varying interests or focus, as the variables (alternatives) were distinctly oriented.

Table 8. Statistical analysis of the responses using the role of the participants in flood management as categories for comparison. The p-values were obtained by using the Fisher's exact test. Only p-values <0.10 are shown.

Question	Group	Group	P-Value	Effect size
3. Rate these options to contribute to attenuating flood risks: [Research, design, and build flood resilient floors or corridors] (Very low; Low; Medium; High; Very high)	Academics	Citizens Decision-makers	0.040 0.004	0.506 0.782
3. Rate these options in respect of contribution to attenuating flood risks: [Provide more support for victims] (Very low; Low; Medium; High; Very high)	Citizens Decision-makers Decision-makers	Workers Volunteers Workers	0.084 0.055 0.027	0.513 0.683 0.817
5. How would you rate the citizenry's role in resolving flood risks in your community? (Not important at all; Somewhat unimportant; Neither unimportant nor important; Important; Very important)	Decision-makers	Academics Citizens Workers Academics	0.018 0.016 0.082 0.004	0.693 0.714 0.667 0.685
8. Per your experience, should land surfaces be permeable and percolating enough; what will be the flood tendencies? (Lower; Similar; Higher)	Decision-makers	Citizens Workers Academics	0.006 0.041 0.005	0.673 0.600 0.664
9. Which of the following works against the natural mechanisms or designs that mitigate flood risks? (Built-up surfaces; Nature-based solutions; Porous covers; Nature-based solutions, porous covers)	Decision-makers	Citizens Academics	0.045 0.047	0.656 0.653
14. Rate the influence that these components have on reducing flooding: [Natural surfaces] (Very low; Low; Medium; High; Very high)	Decision-makers	Volunteers Workers	0.048 0.042	0.866 0.681

It is important to emphasize that the results of the statistical analyses should be interpreted with care due to the small sample size. There is a link between natural permeability and the landscape though the proportionality may not be direct. Aside from the distinction in the respondents view, the results were largely in line with recent trends that emphasize the necessity for developing adaptation measures at various geographic locations and horizontal planes [141]. By this way, high volumes of surface runoffs is expected to drain downstream and eventually reduced the stresses on the limited drainage structures as demonstrated by Kim and Park [142]. Consequently, these approaches have led to the increasing advocacy of GI [143].

Table 9. statistical analysis of the responses collected based on the frequency with the participants selected options available in the questionnaire. P-values correspond to the outcomes of Mann-Whitney-Wilcoxon tests.

Question Groups	**Groups (frequency)**	**p-value**	**size**
3. Rate these options concerning contribution to attenuating flood risks: [Incorporating green components or nature in urban designs and buildings	Low (3) vs High (14) Low (3) vs Very high Medium (7) vs Very high (26)	0.094 0.031 0.029	0.530 0.684 0.690
3. Rate these options in respect of contribution to attenuating flood risks: [Strictly avoid opened drain construction]	Very low (2) vs Medium (15) Very low (2) vs High (17) Low (4) vs High (17)	0.065 0.010 0.017	0.583 0.286 0.755
3. Rate these options in respect of contribution to attenuating flood risks: [Regularly distil drainage systems]	Very high (36) vs Very low (1) Very high (36) vs Medium (3) Very high (36) vs High (10)	0.010 0.011 0.046	0.818 0.802 0.631
3. Rate these options concerning contribution to attenuating flood risks: [Research, design, and build flood-resilient floors or corridors]	High (14)/Very high (23) vs Very low (1) High (14)/Very high (23) vs Low (2)	0.016 0.029	0.760 0.690
3. Rate these options in respect of contribution to attenuating flood risks: [Evacuate settlements in flood-prone zones]	Very low (1) vs Medium (10) Very low (1) vs High (14) Very low (1) vs Very high (21) Low (4) vs High (14) Low (4) vs Very high (14)	0.042 0.009 0.013 0.053 0.055	0.643 0.823 0.786 0.611 0.606
3. Rate these options in respect of contribution to attenuating flood risks: [Sanction defaulters (both builder & occupiers in flood-prone zones)]	High (11) vs Very low/Low (1) High (11) vs Very high (30) Very high (30) vs Very low/Low (1) Very high (30) vs Medium (7)	0.019 0.089 0.010 0.043	0.740 0.538 0.818 0.639
5. How would you rate the citizenry's role in resolving flood risks in your community?	Very important (27) vs Not important at all (3)/ Somewhat unimportant (3) Very important vs Neither unimportant nor important (3)	0.026 0.023	0.704 0.718
7. Is flood history and trend related to land cover?	Yes (44) vs No (6)	0.012	0.797
8. Per your experience, should land surfaces be permeable and percolating enough; what will be the flood tendencies?	Lower (34) vs Higher (4)	0.054	0.609
9. Which of the following works against the natural mechanisms or designs that mitigate flood risks?	Built-up surfaces (30) vs Nature-based solutions, Porous covers (3) Built-up surfaces (30) / Nature-based solutions, Porous covers (3) vs porous covers (8)	0.031 0.075	0.681 0.564
10a. Do you think that natural mechanisms to prevent flood risks (e.g., soil infiltration) have been altered?	Yes (37) vs No (13)	0.059	0.598
12. Rate the following according to the situation in your locality so far as flood-contributing factors are concerned: [Building in flood-prone zones]	Strongly agree (27) vs Disagree (5) Strongly agree (27) vs Undecided (2) Strongly agree (27) vs Agree (6)	0.052 0.018 0.087	0.615 0.745 0.542
12. Rate the following according to the situation in your locality so far as flood-contributing factors are concerned: [Ineffective urban planning]	Strongly agree (28) vs Strongly disagree (9) Strongly agree (28) vs Disagree (3) Strongly agree (28) vs Undecided (3) Strongly agree (28) vs Agree (7)	0.092 0.011 0.015 0.035	0.533 0.805 0.771 0.667
18. What is the most common type of flooding in your area?	Urban (38) vs Groundwater (5) Urban (38) vs River (7)	0.011 0.012	0.802 0.797

Table 10. Statistical analysis of the responses using the city of belonging of the participants as categories for comparison. The p-values were obtained by using the Fisher's exact test. Only p-values <0.10 are shown.

Question	Group	Group	P-Value	Effect size
3. Rate these options with respect to contribution to attenuating flood risks: [Incorporating green components or nature in urban designs and buildings]	Medium	Large Very Large	0.013 0.012	0.737 0.516
8. Per your experience; should land surfaces be permeable and percolating enough; what will be the flood tendencies? (Lower; Similar; Higher)	Large	Medium Small Very large	0.015 0.071 0.004	0.675 0.817 0.590
9. Which of the following works against the natural mechanisms or designs that mitigate flood risks? (Built-up surfaces; Nature-based solutions; Porous covers; porous covers).	Medium	Large small	0.005 0.034	0.781 0.691
14. Rate the influence that these components have on reducing flooding: [Covered drains] (Very low; Low; Medium; High; Very high)	Medium	Very large	0.068	0.476

In general, respondents shared a highly varying responses considering their distinct backgrounds or profiles. Though stakeholders have relations to flood management, their perspectives are likely to be based on diverse experiences which can either be associated to personal observations, theoretical and/or practical orientations. As the technicians perceive that emphasis be placed on the selected suitable land covers and reduce impermeable membranes, the politicians did not share similar understanding. Unlike other stakeholders, the politicians had a limited understanding of the contents of the questionnaire. The variance found in the responses provided by the participants depicts how their distinct profile and the size of their cities influenced the data. By this way the statistical significance of the variations can be affirmed considering the respondents' views across the questions based on the classifications.

4.1.1 Flooding conceptualization and management

Aside from the fact that rainfall is a natural cause of floods, poor drainage systems and improper planning was also noted as the most common causes of floods in Ghana (Figure 17). Though natural phenomenon like rainfall contribute to floods, the behavioural and attitudinal indiscipline set the grounds for floods to escalate. In the case of many parts of Ghana, the factors are significantly geared towards the attitudes of the citizenry than natural occurrence.

Figure 17. Word cloud responses on question 1 - main factors that contribute to the increase of floods in Ghana.

The internal consistency in the responses to questions 1 and 2 were admissible. Based on these results, it was necessary to deal with the most frequent flood drivers by generating new approaches to enhance an efficient drainage system. This might incorporate an extensive range of practices consisting of merging the design of early warning systems to discover flood-prone areas with the implementation of pervious surfaces close to the flooding sources regarding certain strategic locations.

The responses on the account of the perceived factors causing floods were further analysed by counting the number each option has been selected by the participants (Figure 18). The main factors that aggravate floods in the respective locations of the participants were water table, rainfall, poor drainage systems, and impermeable land coverings. Amongst the perceived factors, poor drainage was the leading factor followed by unplanned settlements causing slums. The selected lowland areas and basins could be protected and preserved for the accommodation of discharges during downpours instead of occupying such areas with settlements.

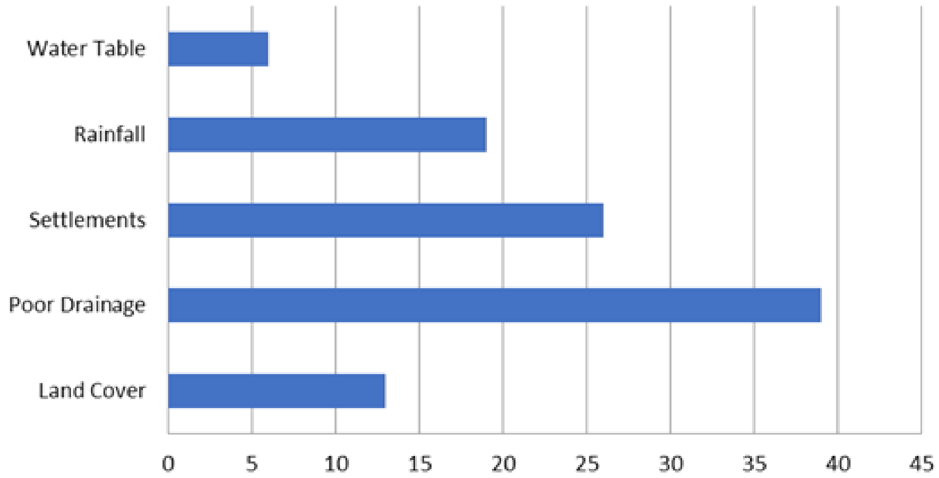


Figure 18. Categorised flood causative conditions according to responses from Question 2.

This implies that focusing more on a prudent urban planning system would tremendously reduce the occurrence of floods despite any potential rainfall intensity and the dynamic of the soil available. In this case, the participants categorised as citizens agreed with the general inclination as presented in Figure 17 and Figure 18 as pointed out the general terms such as poor drainage or the lack of it. As a substitute, the most relevant cluster for academics was more particular considering their deeper expertise in the subject matter understudy.

Multiple options were deemed relevant in the account of the contribution of several actions to flood management. The outcomes pointed out the complexity of building flood resilience, highlighting how it cannot be addressed using unconnected adaptation actions but relatively resorting to an amalgamation of preparedness, adaptation, absorption, response, and recovery actions [144].

4.1.2 Stakeholders and citizens' responsibilities

Knowing the effect of floods on the citizenry, it was important to ascertain their contribution to mitigating the challenge. Over 72% of the respondents agreed that the citizenry has a role to play in resolving the risks associated with floods (Figure 19a). That notwithstanding, the attitudes of the citizenry have not been helpful. Of the 50 participants, 42% were of the view that the current citizens' attitudes were not helpful at all in managing flood occurrences (Figure 19b). Only 12% subscribed that the attitudes of the citizenry were most helpful.

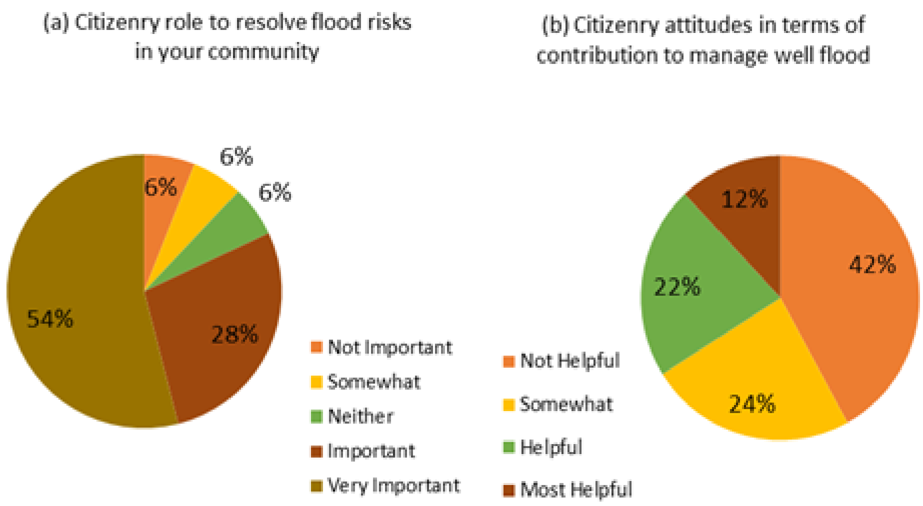


Figure 19. (a) Question 5: How would you rate the citizenry's role in resolving flood risks in your community? (b) Question 6: How would you rate the citizenry's attitudes in terms of contribution to managing flood occurrence in your community? (n = 50).

This implies that there is a need to design a holistic national campaign on attitudinal change aside from the option of sanctioning defaulters. It has been highlighted in recent studies [145,146] that creating educational initiatives aimed at educating and encouraging community involvement in disaster management is a promising course of action for disaster prevention. This incongruity between the responses to these two questions emphasizes that there is a need and chance to improve the citizenry's participation in flood management in Ghana. Concerning the differences between diverse stakeholder types, it was realised that only the decision-makers category did not rate the role played by citizens as principally important or very important (Table 10).

4.1.3 Land cover, urbanization, and the built environment

Only 13 participants (12%) declared that land cover tends to aggravate flood risk (question 2, Figure 17). By inference, these results suggest that the type of question (multi-select) may distort this factor's importance, especially as most respondents (88%) answered that flood is historically related to land cover. The answers to question 7 (Table 9) highlighted that the trajectory of a flood depends on the land cover type. With 44 participants choosing ‘YES’ against 6 choosing ‘NO’, implies an overwhelming endorsement to the point that nature of the land matters to flood tendencies.

Again, the answers to question 8 validates the assumption that rate of flooding in a locality depends on the nature of the land cover. If the land is percolative enough, the chances of flood reduce as 34 participants chose lower while only 4 participants chose the option that flooding could be higher even though land cover may be permeable. Among the respondents, 68% (n = 34) indicating a majority contended that flood trends would be lower should land surfaces be permeable enough.

Similarly, in this regard, 30 participants representing 56% declared that built-up surfaces work against flood attenuation by answering question 9. Respectively, NBS and porous covers like marbles were followed by 9 and 8 participants in the percentage representation of 18% and 16%. These assumptions imply that flood tendencies somewhat depend on the type of land covering. It is globally accepted that urbanization has a negative impact on flood reduction [147,148].

In this vein, the responses to the question 9 brings to bare further evidence to that assumption that urbanisation increases built up surfaces and consequently influence flooding and it is especially critical situation in Sub-Saharan Africa. This is because resources are limited in many rural areas which makes people highly susceptible and consequently influences urbanisation [149]. As displayed in Figure 20, the word cloud obtained for the open-ended optional questions 10b, 11b and 13b concerned the effect of altering natural flood mitigation mechanism to artificial impermeable coverings.

Figure 20. Word cloud showing natural and artificial mechanisms for flood mitigation (questions 10b, 11a and 13b).

The resilience of existing drainage systems depends on the construction materials used because some material may be permeable or not. By implication, the trend or rate of artificialization increases with high chances of flooding or burdens society with the cost components for constructing buoyant drainage facility which could unnecessarily be on the high if high runoffs are anticipated compared to composite that are partially percolative.

Paradoxically, in this case, the decision-makers demonstrated to discount the relationship between permeability and flood occurrence by the discourse that flood trends would be similar in the case of having permeable surfaces. Per the stance of the politicians, the alteration of the hydrological cycle is not through the increased sealing of natural surfaces. This choice was against the general trend observed in question 8, whereby almost 70% of the addressees believed that flood trends would decrease with the use of permeable surfaces.

In addition to this, the existing institutional bodies, can work on extensive stakeholders engagements, and epistemic lock-ins resulting from continuing antique practices can further coerce the implementation of alternative solutions for building flood resilience [150] in the localities. Given varying surfaces, the rate of flood tendencies differs and this implied that the increasing replacement of natural covers by built-up surfaces hinders runoff infiltration and consequently floods up an area after a minimum precipitation.

It is therefore necessary to carefully consider contribution of the selected materials to flood risk reduction when designing a proper drainage system in a community. These attributes to question 12, whose statistical consequence points out to a significantly high number of respondents which allows the predominant impact of urban developments to increase flood risk (Table 9). As illustrated in Figure 20, key roots including ‘Preservation’, ‘Paths’, ‘River’, ‘Basin’, ‘Streams’, and ‘Soils’ confirm that chances of flooding would reduce if the natural water ways are not obstructed by human activities.

Alternatively, roots like ‘Reclamation’, ‘Code’, ‘Use’, ‘Vegetations’, ‘Wetlands’, and ‘Zoning’ emphasized that, in a situation whereby the existing water ways have been partly tempered with, the land can be reclaimed and replanting of vegetations and the use of coding to zone selected areas as buffer enclave. The responses gathered in this regard, affirmed to the globally established sequence that green spaces essentially help to control floods whilst paved surfaces accelerate flood occurrence [151,152]. Nonetheless, it was intriguing to learn that, in contrast to covered and opened drains, surfaces featuring marbles and marbles in sand-bed in a way reduce floods.

Again, the chart showed that the difference in contribution for covered and opened drains was narrow which conflicted with the perception of regularly distilling drains (Table 9 and Table 10). The disparaging positions of the decision-makers and the outstanding categories reflected in the responses underline the need to build collaborative learning systems among all pertinent stakeholders. Such modalities can contribute to producing holistic and sustainable strategies to advance flood resilience [153]. This can help conquer the scepticism and enhance the sense of ownership among concerned players [154].

Again, it was realised that the city of belongingness of the addressees produced statistically significant differences in the responses related to 4 questions (Table 7). In terms of population, 80% of the responses were related to medium and very large cities. Here, the results achieved were conditioned by the irregular distribution of the participants across the groups. The reduced sample size of the large group could be the reason behind its discrepancies, especially as the responses provided by the respective categories conflicted with each other in varying situations.

For instance, respondents valued the role of green infrastructure to be a proactive measure which enhances flood risk reduction as it was answered in question 3 (Table 10). Nevertheless, the responses regarding question 9 exposed a direct relationship between surfaces and flood tendencies. Otherwise, questions 3 and 14 in Table 8 and Table 9 pointed out the increased awareness observed in very large cities concerning the flood control potential of either green infrastructure or covered drains. The higher degree of development of these populated cities could justify why their inhabitants allocate more worth to the effectiveness of natural drainage systems, although the prevailing is artificial.

Largely, most participants across the locations of Ghana, thought that the reactional interventions to flood management have not been helpful and there was the need to be more proactive with mitigation measures. In this regard, the popular suggestions were that, instead of providing relief items to victims, the interventions should rather concentrate on the regular distilling of drainage systems, sanctioning of defaulters and incorporation of green elements (Figure 21). While, adapting to a more proactive approach to dealing with attitudes that do not encourage flood risk reduction, placing emphasis on research works on flood resilient surfaces will augment the cause of action as the stakeholders in the academia highlighted on that option despite the citizens and decision makers thinking otherwise. A medium to very large groups advocated for the application of the mitigation options that seeks to incorporate green components in infrastructure design. Many were the cases that mitigation actions addressed recorded diverse magnitude of emphasis to question 3.

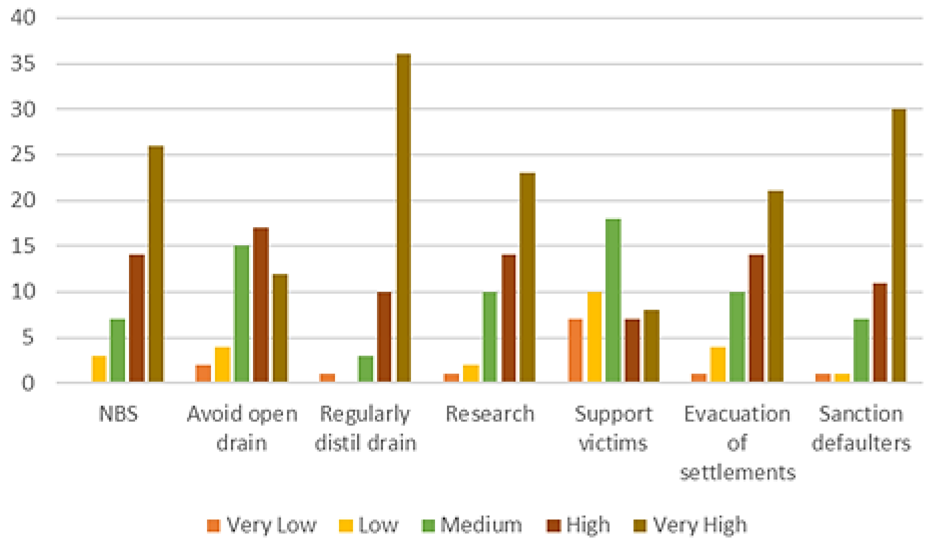


Figure 21. Perception of the participants on the contribution of different measures to attenuating flood risks(n=50)

Depending on the category of the participants, opinions on the significant approach in terms of flood attenuation options were different. It was realised that the participants who were academics believed that the provision of support for flood victims was negligible because according to them has a very low influence on attenuating flood risks (Figure 21). In contrast, other profile like citizens, believed that the reactionary measure of providing relief items were of a high influence (Table 7 and Figure 21). More so, according to the size of the city the participant is familiar with, a statistically considerable variation was also found.

For instance, for question 3, 'incorporating green components or nature in urban designs and buildings' recorded a varying effect or significance. The academic respondents believed and highlighted the awareness that implementing flood-resilient floors and corridors (Table 7) will cause a positive change to the flood mitigation endeavour.

For this motivation, the contribution rated by academics on the application of resilient floors and corridors as an attenuation mechanism was very high in most situations. This, however, conflicts with the views of other categorised participants like citizens, workers and, especially, decision-makers. This trend of results is in line with and validates the preceding illustration (Figure 19, Figure 20 and Figure 21) since it emphasizes that decision-makers (politicians) focus on taking action after the occurrence of floods instead of promoting the adoption of aprioristic measures.

Based on the account by respondents on question 11(a) which signified that the capacities and functioning of the existing drainage systems were limited, an open question was followed as question 11(b). This question opened up pool of suggestions that participants perceive to potentially augment the flood resilience. The key terms of the suggestions made by participants in answering question 11(b) were outlined and put together in the word cloud form (Figure 22). These words recorded varying frequencies base on the number of times they appeared in respective suggestion or statement. The keywords that recorded the highest frequencies were 'flood', 'existing', and 'structures', and 'Waste. In a descending order, others like 'Plastic', 'management', 'proper', 'waterways' 'avoidance', 'drain', 'building', etc., followed. The sequence of the result affirmed the notion that the existing hydraulic structures were stressed and incapable of accommodating both water and plastic wastes. As a result of the situation renders the locality vulnerable to floods.

Figure 22. Word cloud showing the perception of participants on actions to augment flood resilience

Per the survey, the responses from different localities generally attest that many variables directly affect flood occurrences (Figure 23). Variables such as 'ineffective urban planning' and 'building in flood-prone zones' were strongly perceived to be the most influential. To address this, the community planners can re-zone the settlements such that certain areas like lowland areas close to water paths can be designated for recreational and buffer purposes whilst buildings and settlements are strictly positioned distant from the lowlands. By this approach, the water tables patterns will be stable, since filling of low-lands with foreign materials is unfriendly to the groundwater quality and system [155,156]. In resolving this, a confirmation is being established about the need to advance the application of nature-based solutions in Ghana whereby permeable spaces act as buffers along the water courses.

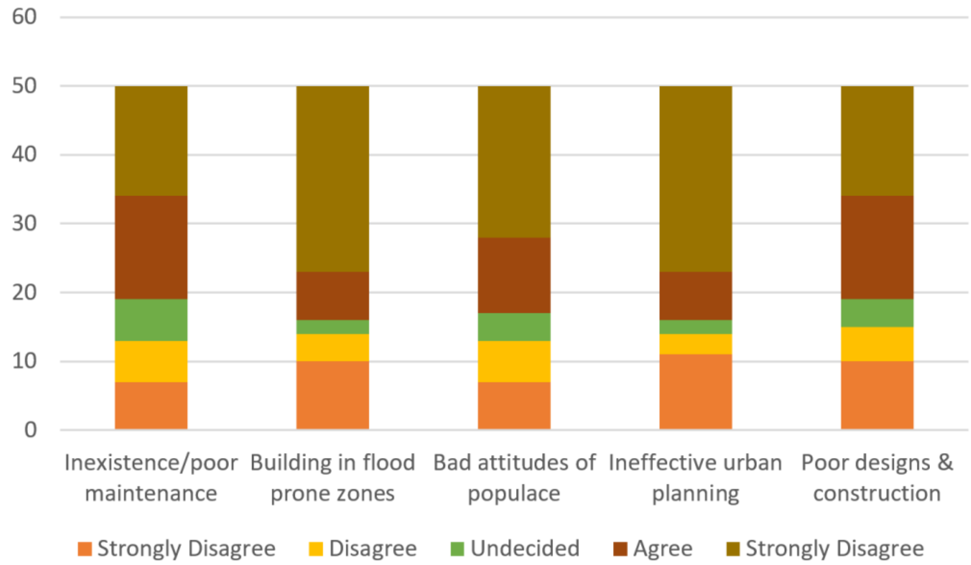


Figure 23. Question 12: Rate the following according to the flood situation in your locality regarding flood contributing factors

Natural land surfaces play a significant role in to flood risk management, especially because they allow discharges to seep in and thereby restore the natural water cycle. This is due to the pores present in the natural land surfaces. To this hypothesis, questions 8, 9 and 14 were asked as shown in Table 8 and most emphasis was placed on the challenges found in some respondents from small to large cities.

The result created an impression that supported that natural lands are permeable and hence can play a role in flood management. This fact stresses the need to assess the usefulness of implementing alternative drainage designs that make use of composites and /or natural and or permeable materials [157,158]. Once more, one of the primary causes of flood risks in modern societies have been the progressive replacement of the natural landscape than synthetic covering. In this regard, 'what is the main form of flood in Ghana?' the answers to question 18, demonstrated that the primary type of flood is caused by urban runoff accumulation.

In other to harmonise the urban runoff according to the results gathered concerning land covering, the adoption of GI and NBS into the urban designs to improve urban drainage and quality of discharge with augmented liveability and socio-economic sustainability [159]. In the same vein, the notions of decision-makers in terms of which surfaces work against flood mitigation diverged from the remaining groups by pointing out porous covers instead of built-up surfaces (question 9).

This was further validated by question 14, which revealed that decision-makers significantly differed from the academics, volunteers, or workers in what concerns the influence of natural surfaces on flood reduction (Figure 20). The latter largely rated this impact as high or very high, whilst the preferred option for the former was medium. These and previous results concerning the group of decision-makers confirmed the main barrier traditionally found to implementing different drainage measures to pact with increasing flood trends, which concerns the cynicism and unusualness about the effectiveness of solutions intended at representing the natural hydrological cycle [160,161].

4.1.4 The flood perception in Ghana and Implications for other developing countries

Though the results achieved in this study were limited to Ghana, the findings may have an impact on how people throughout the continent of Africa view flood risk management. The focus is to attenuate the frequency of floods by utilizing factors like land cover, how floods are conceptualized, and stakeholders' responsibility. The line of investigation adopted was braced by the commendations made by Anthony [162], who reasoned that the triangulation of findings from diverse outlooks can afford an improved understanding of the water and flood-related challenges the population must deal with.

The multi-stakeholder technique used in this study may have helped to corroborate the results of earlier research conducted in African nations as in the case of Mucova et al. [55]. In the circumstance where well-designed interviews were steered to determine the attitudes of community respondents from Mozambique towards adaptation strategies to climate change hazards. Conversely, these authors categorized their respondents in line with demography, education, or religion, without paying attention to their role in managing such schemes.

Likewise, their suggested strategies emphasized how people adjusted to floods through various situation such as moving, rather than the technological fixes anticipated to deal with the experiences at the source. As stressed by Subbarao et al. [163], applicable response planning is vital to dealing with floods for the reason of the frequency and consequences of these events. Particularly, the application suits developing countries bearing in mind the fact that their susceptibility to flood manifestations owing to low adaptive capacity and resources [164].

It is thus, principal to intentionally center the design of participatory processes around the source of pertinent data regarding the perspectives of the various stakeholders involved in flood management. Given that it is common and can be rationalised for the entire continent, the multi-stakeholder labelling projected in this consideration is symbolic and adjustable across Africa. With regards to plans to deal with floods, readily available is a development driven by the protection of people from these hazards. For example, the study performed by Ahmad and Afzal [165] in Pakistan assessed a series of measures mostly involving augmenting the resilience of buildings through strengthened foundations, reinforced materials, and others.

According to the count, poor planning and land use are the main causes of for floods, which corresponds with the eminence laid by Du et al. [51] on how permeable surfaces can adapt to increasing levels of pluvial flooding in developing countries. Again, this aligns with the discoveries of Dhiman et al. [166], who pointed out the non-existence of proper drainage as an advocate of flood risk across India. Statistical systems like the ones employed here have been studied and found to be useful for scientists, and water managers as those used in this examination have been explored and were apposite for scientists, water managers, and decision-makers in studies on disaster risk reduction in Africa.

Concurrently, the patterns observed in this output aligned with the research conducted by Oyekale and Oyekale [167] and Bossa et al. [168], who used frequency analyses to assess the effect of climate hazards like floods on agricultural sustainability across diverse African countries. Largely, the position taken in this investigation can be featured in other investigations in developing countries, where floods have been argued to be often poorly understood and understudied [169].

Hence, more understanding of the perspectives of the key players in flood control can be obtained, particularly regarding how they see the role that land permeability plays. The knowledge gathered from this study can be useful in better preparing for flood events in the future. For instance, local urban planners and building inspectors may consider a design that incorporate voids in the drainage structures is a key mitigation measure. Furthermore, merging these findings with the numerical models created by people such as Adedeji et al. [170], Chukwudum and Nadarajah [171] for Nigeria, will help actualise comprehensive concepts to design flood early warning strategies.

4.2 The experimental sequence

4.2.1 Physical properties of limestone and dura-PKS aggregates

For the grading test, a common sieve size range was set for both the control aggregate (limestone) and the PKS. The distribution of the particle sizes in terms of the percentage remaining on the sieve was determined after both aggregates had been sieved (Figure 24). Thereafter, it was observed that a small quantity of PKS passed through the 1 mm to 2 mm sieves, whilst the minimum sieve size for the limestone was 2.5 mm. The volume of PKS particles was more than that of limestones due to their lightweight nature compared to the limestone.

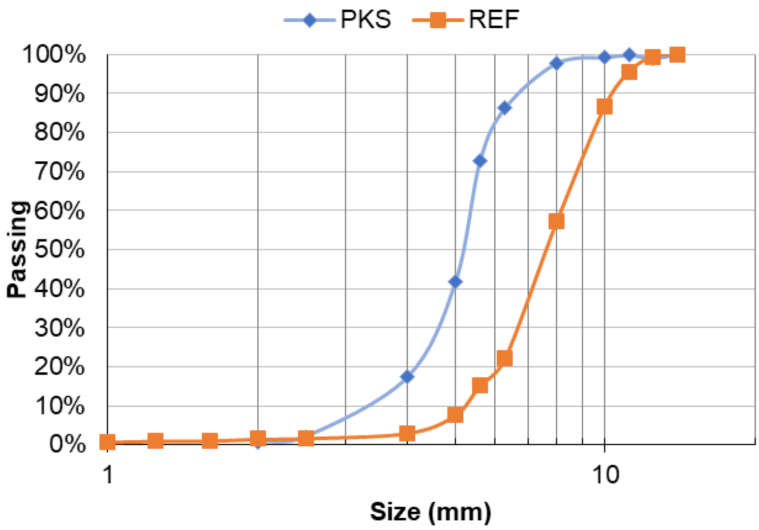


Figure 24. The grading curve for dura-PKS and limestone.

Aside from the fact that both aggregate sizes ranged between the limits of 1 mm and 14 mm, the PKS particles were coarser and flakier but slightly finer with a lower flakiness index were the granulitic nature of the limestone. The form of the dura-PKS aggregate was kept unchanged even upon exposure to both extreme cold (deep freezer) and hot (oven) conditions. The dura-PKS is not as tough as limestone yet the strength of the dura-PKS did not change as it did for natural rocks and related aggregates [172] after incessant dry and wet conditions for three consecutive days.

As the densities recorded for the limestones were higher, those of the dura-PKS were lower. The trend changed when tested for flakiness, humidity, porosity, and absorption (Table 11). Nonetheless, in the case of the humidity of the dura-PKS, it varied based on the temperature. The humidity of the PKS increased with increasing temperature.

Table 11. Physical properties of the aggregates

Property	**Flakiness index (%)**	**Shape Index (%)**	**Humidity (dry at 80°C) (%)**	**Humidity (dry at 100 °C) (%)**	**Apparent Density (Kg/cm³)**	**Relative Density (Kg/cm³)**	**Saturated Density (Kg/cm³)**	**Porosity (%g/cm³)**	**Absorption (% gram)**
Limestone	6-7	0.29	0.3	0	2.68	2.74	2.7	2.16	0.8
PKS	33.4	7.92	13.43	59.4	1.46	2.15	1.78	32.06	22

Bestowing to international references such as the South African National Standard 1083:2006 [173], the limit of FI of coarse aggregates is 35%. Again, according to the British Standard 12620: A1:2008 [174], the limit the FI of coarse aggregates is 50%. Additionally, according to Tam and Tam [175], the combined FI for their 11 samples was lower than 40%. Hence, the FI of 33.4 % is less and within the thresholds of the standards compared to the values reached in similar investigations [33,176].

Despite the qualification of the FI value for the dura PKS, there is still a magnificent difference compared to other species of the PKS or PKS from different locations [24]. Considering the wide variation in the FI values of PKS, it would be helpful for further research to evaluate samples of the aggregates, and clarify and highlight the disparity in the originality, source, and species of the PKS (dura, pacifier or tenera).

After the scan test of the sample of the PKS, it was observed that the pore distribution varied depending on the area of the shell examined. Depending on the region of the PKS, the level of compactness or porosity may vary. Again, the pore openings in the interior and exterior parts of the PKS were different. Thus, the R-1 region characterized the part that had negligible pores whilst the R-2 and R-3 represented those parts of the PKS having fewer pores and the porous parts (many pores) respectively, as shown in Figure 25. Mostly, the structure of a typical pore of the PKS is conical or funnel-like as it widens at one end and narrows at the other end. This revelation by the microscopic test and analysis, it calls for the need for further investigation in the future to focus on the placement of the aggregates in the concrete when used for lightweight pervious concrete.

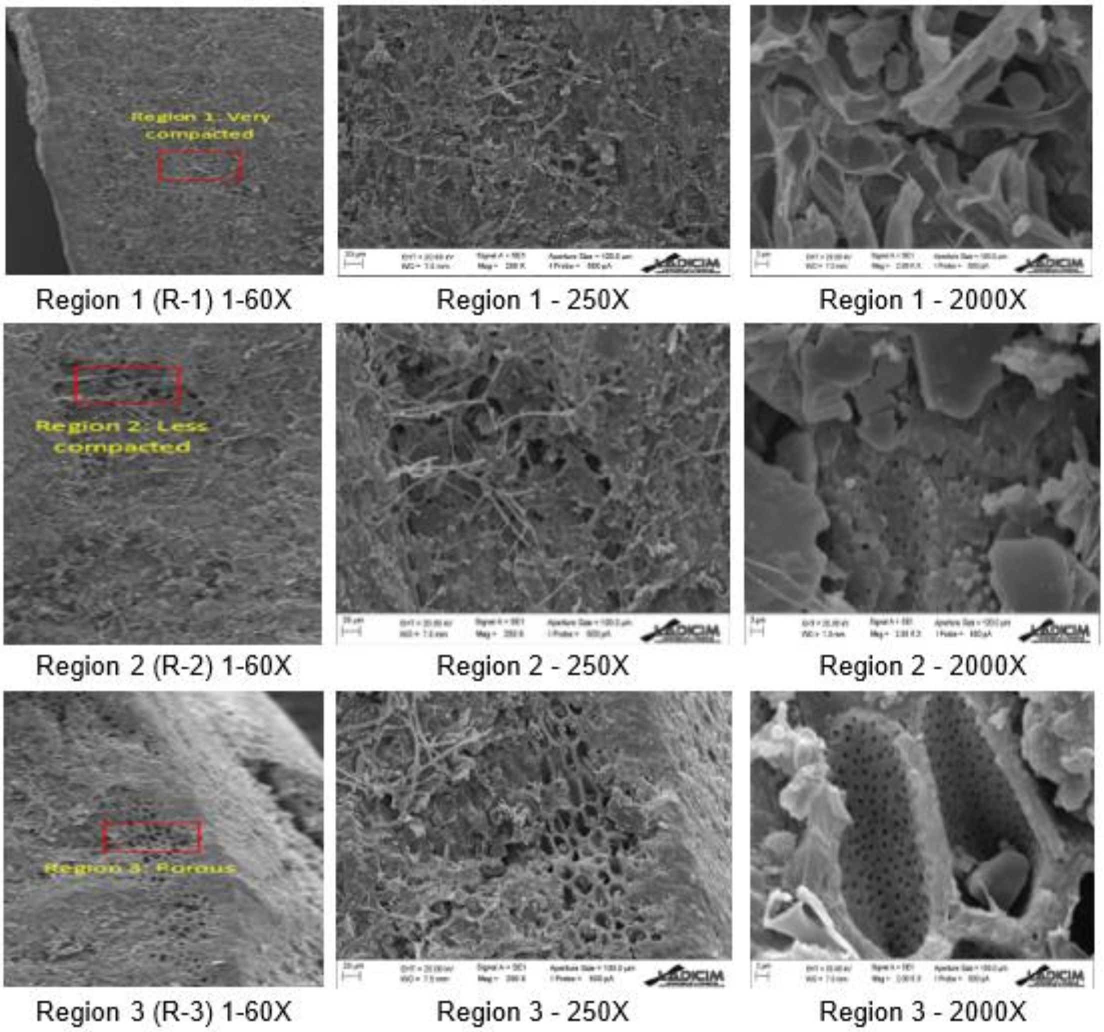


Figure 25. Microscopic analysis of the cellular nature of Palm Kernel Shells (PKS) with a zoom 250X and 2000X Region 1 (R-1) Region 2 (R-2) & Region 3 (R-3).

4.2.2 Physical properties of concretes

The densities recorded for the concrete with the PKS were low due to the lightweight nature of the PKS aggregates integrated as depicted in Table 12. The rate of decline of the densities depended on the proportions of the PKS incorporated. In the same vein, the porosity of concrete increased when a portion of the aggregate was replaced by PKS. The highly porous and absorptive nature of the PKS influenced the composites to increase their porosity and absorption rates depending on the replacement quantity.

Table 12. Physical properties of the permeable concrete mix under study.

Property	**Control**	**100% dura-PKS (% variation compared to control)**	**25 % dura-PKS (% variation compared to control)**
Apparent density (g/m^3)	2.18	1.13 (-48.2%)	1.89 (-13.3%)
Relative density (g/m^3)	2.53	1.62 (-36.0%)	2.29 (-9.5%)
Saturated density (g/m^3)	2.32	1.43 (-38.4%)	2.07 (-10.8%)
Porosity (g/m^2)	13.38	30.15 (+125.3%)	17.38 (+29.9%)
Absorption (%)	6.27	26.65 (+20.4%)	9.19 (+2.9%)

The uneven performance of the experimental mixtures was worth highlighting and this physical characterisation was as a result of the amount of PKS aggregates present in the composite. With minimal manual compression, the composite with 100% dura-PKS became abortive after 72 hours (3 days) of exposure to drying conditions (100 ^oC) followed by 6 weeks of conditioning in water.

As an alternative, the composites with 25% dura-PKS remained physically firm when the same test was applied. This shows that the durability of mixtures with very high contents of dura-PKS is unpredictable when subjected to thorough dry–humid environments. The recorded densities for the control concrete conform with the literature [177]. Similarly, as already recognized by Alengaram et al. [33], the composites with both 100% and 25% of dura - PKS as aggregates recorded densities in the range of 1600 - 1900 kg/m^3. This characterisation was due to the presence of the PKS being light in nature.

The experimental composites were induced and consequently recorded lower densities as labelled in Table 12. The densities of the composites with 100% PKS recorded a consistent decline in the apparent, relative, and saturated densities in relation to the control. Respectively, a reduction by 48%, 36% and 38%. For the composite with 25% dura-PKS in the mixture, the trend followed as 13% for apparent density, about 10% for relative density and approximately 11% for saturated density. On the same background, the rate of water absorption and porosity rate within 24 h tremendously increased. That of the 100% dura-PKS recorded an absorption rate of 20% whilst the mixture with 25% dura-PKS recorded a variation of 3%. For porosity, as the mixture with 100% recorded an increase to 125%, that of the 25% incorporated with dura-PKS recorded 30%.

4.2.3 Mechanical properties of concretes

4.2.3.1 Compressive strength of the tested composites

Given an average compressive strength of 4.6 MPa, 11.2 MPa and 27.5 MPa for the concrete mixtures with 100%, 25% dura-PKS and the control respectively, the strength of the mixtures with 25% and 100% of dura-PKS at 28 days were far low relative to the control. However, in principle, the compressive strengths recorded for the experimental concrete mixtures in this investigation (Figure 26) are within the range of values obtained in related works [24,178].

Again, the results are validated considering that pervious concrete with a density of around 1800 kg/m^3 normally yields compressive strength within 5.7 MPa to 10.1 MPa [179]. Though in this case, the compressive strength was reduced by the increasing contents of the dura-PKS, the minimum compressive strength of 4.6 MPa is higher than the average compressive strength obtained in related works where mixtures did not have fines [34,89,180].

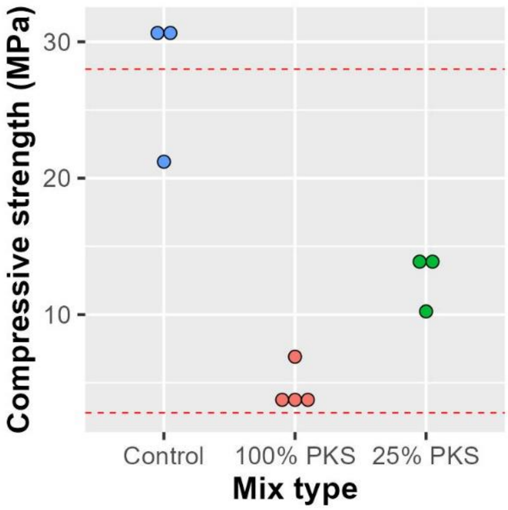


Figure 26. Compressive strengths of concrete base on mix type. The red dashed lines indicate the lower and upper acceptable limits suggested for permeable concrete.

The variation of the mechanical properties of the composites was characterised by the percentage of dura-PKS content in the mixture. As the control produced a high strength, the strengths yielded by the experimental concretes with dura-PKS fully or partially incorporated were relatively low (Figure 26). Typically, the high voids present in pervious concretes, affect the ability of the concrete to resist loads of compressive in nature [24,34]. In this vein, it is normal that the average compressive strength recorded for the experimental concrete was lower as compared to the control due to the incorporation of the PKS.

Though, the strength recorded for the experimental composites were relatively low, these strengths were not below the acceptable range as far as lightweight concretes are concerned [24,34]. Considering the report from the American Concrete Institute (ACI) the minimum stress when a Pervious Concrete is under compression is 2.8 MPa [85]. In this respect, it can be concluded that, all the three concrete mixtures satisfied the condition for compression at least. This was met even for the composite with 100% of dura-PKS aggregates which yielded the least strength of 4.6 MPa (Figure 26).

4.2.3.2 Tensile strengths of the tested composites

Generally, the results for the pervious lightweight concretes were lower than anticipated, as similar previous research works on pervious lightweight concretes conducted by Khankhaje et al. [24], recorded a higher tensile stresses. Though, the sequence followed as it was for compressive where the control was higher followed by the concrete mixture with 25% and 100% PKS, they all fell below the acceptable limits. The control, concrete mixture with 25% and 100% PKS produced a strength of 1.3 MPa, 0.71 MPa and 0.38 MPa respectively (Figure 27). This implies that the aggregates that constituted the mixtures have negligible tensile characterisations. Again, comparing the result to the case of Khankhaje et al. [24], the control specimen, recorded an extra tensile resistance of 47% (2.47 MPa) than the control for this study.

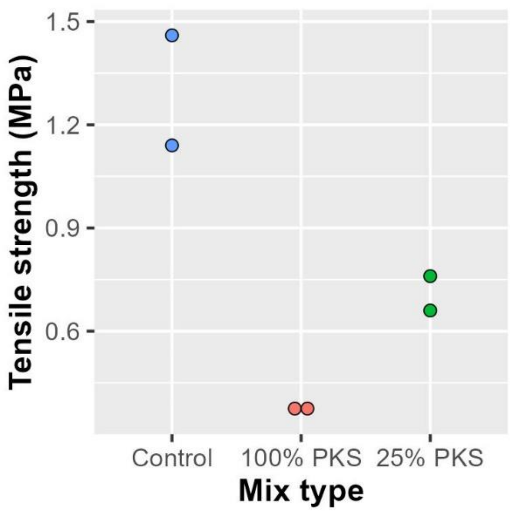


Figure 27. Tensile strengths of permeable concrete base on mix type.

Aside the control, the minimum tensile strength achieved by Khankhaje et al. [24] is 10% more than the average tensile recorded for specimen with the 25% dura-PKS. This is an indication that the tensile stresses yielded by composites incorporated with dura-PKS are not encouraging. Therefore, such composites may not be useful for applications where tensile loads may be significant.

4.2.3.3 Flexural strengths of the tested composites

This investigation seeks to determine a permeable pavement for lightweight vehicles. On this background, the flexural strengths for the concretes with varying mixture are deemed to be determined since it is a property critical for the design performance of pavement as anticipated for this research [181]. Per this experiment, the composite with 25% dura-PKS incorporated yielded an average stress of 2.93 MPa which is 39% declination of the corresponding flexural strength of the control which was 4.81 MPa (Figure 28).

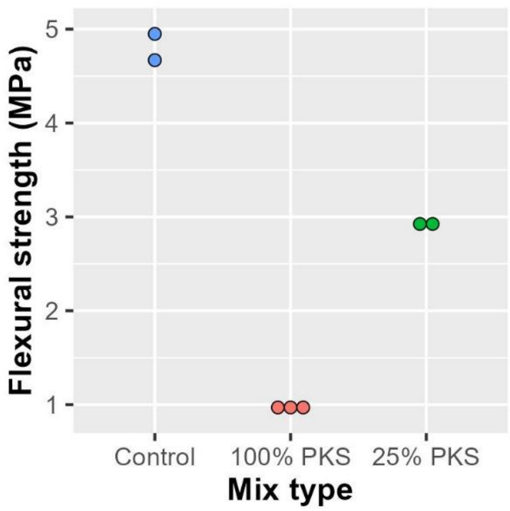


Figure 28. Flexural strengths of permeable concrete base on mix type

The mixture with 100% recorded a flexural strength of 0.9 MPa, representing about 80% of a reduced strength of the control. Though the flexural strength gained by the experimental composites were relatively low, the mixture with 25% dura-PKS exhibited an improvement considering fact that the maximum stress in the report by Ibrahim et al [182] is 1.32 MPa. Again, according to Alshareedah et al. [181,178], for a concrete to achieve a flexural strength that is equivalent to 10% to 20% of their corresponding compressive strengths implies a significant indication to meet the minimum flexural strength especially as it has been the trend in related literature.

That notwithstanding, the result obtained in this investigation is even more validated and satisfactory considering the flexural strength range of 1.5 - 3.2 MPa established by Chandrappa and Biligiri [86]. Furthermore, it is imperative and positive for the experimental composites with 25% of dura-PKS incorporated in the mix having more than 50% of the flexural resistance of the control in the investigation by Fatima E, Jhamb A, Kumar R. [183] . It is therefore assuring that, the mixture with 25% of dura-PKS can function as alternative for lightweight pavement [180,184].

4.2.4 Permeability of concrete

The pores on the PKS influenced the high absorption, porosity, and permeability rates of the composites with PKS compared to that of the control [135,137, 188]. A continuous network of voids in concrete was vital to ascertain the appreciable rate of water permeability. It was not surprising that the average rate of permeability for the control was low due to relatively high compact nature. But in the case of the experimental concretes, substantial rate of permeability were recorded [188].

Bearing in mind the minimum water permeability rate required according to related literature [94,185,189], the results obtained in this research proved that the values attained by the falling head test for all mixtures were more satisfactory. The high permeability rate in line with the increasing quantity of PKS introduced in the mixes displayed that the material was naturally absorptive [30,34,180]. The recorded high rate of permeability of the experimental composites was believed to have been influenced by the pores in the PKS aggregates compared to that of the control [185,186] as displayed in (Figure 29).

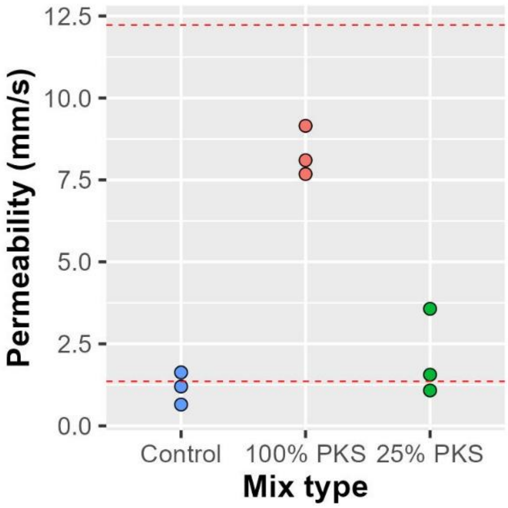


Figure 29. Permeability rates of permeable concrete base on mix type. The red dashed lines indicate the lower and upper acceptable limits suggested for permeable concrete.

Correspondingly, the rates of permeability for the mixtures with 25% and 100% dura-PKS were 78.4% and 61.5% higher than that of the control. The values obtained for the 100% dura-PKS samples demonstrated an outstanding increase in permeability compared with previous works using lower replacement ratios [26]. The porous and absorptive nature of the dura-PKS influenced the high permeability rates of the composites with an increasing amount of PKS introduced in the mixtures [24,34,185,186].

Considering the minimum water permeability rate required according to previous research [177,185,189], the results obtained for this investigation based on the falling head test were more satisfactory for all mixtures (Figure 29). Furthermore, with respect to the report by Powers [190], the drainage potential of such aggregates (dura-PKS) is very helpful when incorporated into permeable concrete mixtures. The application of the dura-PKS as an aggregate for flood control composites can be suitable considering the characterisation of high porosity and absorption rates.

The fact that dura-PKS are naturally lighter, the partial replacement of PKS affected the densities of the block of ordinary concrete. In the same vein, the porosity of concrete enhanced when a portion of the aggregate was replaced by PKS. PKS are highly porous and absorptive; consequently, they tend to induce the ordinary concrete to increase its porosity and absorption rates upon partial replacement.

5 Conclusion

This chapter gathers relevant findings about flood drivers in Ghana and accordingly aggregates them into perspectives. The thesis approaches to flood risk management in the perspectives of social and engineering dimensions. The conclusion accounted the diverse contributions of the flood phenomena and suggested some practical lines of actions needed to minimize the trajectory of flooding and the effect accompanying the occurrences. It encompasses the summary of the findings that resulted from both dimensions and their implications in the scientific community as well as potential mitigation measures for flood risk reduction that may be applicable in Ghana, the case study area. The conclusion chapter involves a series of sections that deal with the general conclusion, specific conclusions, limitations, future lines of investigation, and impact of the study.

5.1 General conclusion

The results achieved throughout this study shed light on stakeholders' perceptions of flood drivers and conducting investigations into alternatives to deal with these drivers as mitigation options. Since the essential part of the flood drivers perceived by stakeholders were associated with the horizontal surfaces or land coverings, the choice of the materials to be used as a cover on the land in the course of developmental projects requires careful consideration. The absorptive nature of material potentially influences water permeability, which can positively influence flood risk reduction.

More so, the stakeholders, especially the politicians and citizenry have contributions to aid in achieving a flood resilient community. This is because the attitudes and posture of these classes of participants upon the understanding on flood management can influence flood risk reduction indirectly. In order to achieve the aim of the thesis, it was necessary to conduct the investigation mainly according to both social and technical dimensions. On the account of the social dimension, a flood resilience-based questionnaire was designed and disseminated to selected participants.

Qualitative and quantitative analyses were carried out on the responses gathered from the participants. Questions were particularly asked with the intention of revealing the socio-technical drivers and potential solutions for flood risk management in Ghana. The participants representing the stakeholders for flood management included, academics, citizens, decision-makers (politicians), volunteers, and workers (technicians). Consequently, the mitigation measures from the social perspective were determined after analysing the responses from the main stakeholders involved.

Considering the fact that runoff accumulation on the land coverings result in flooding, it was necessary to present pervious pavements which seek to accommodate essential volume of runoffs in the pores as a means of reducing flooding. On this basis, which is more inclined in the engineering perspective, a laboratory investigation was conducted into lightweight permeable pavement where dura-PKS was used as the experimental aggregates in comparison to the limestone as the aggregate for the control.

In this study, the emphasis was on the water-cement ratio, mixture, rate of permeability, densities and acceptable limits of mechanical properties of the composites including flexural, tensile splitting and compressive tests. Three concrete mixtures were applied for which included that of the control (no dura-PKS aggregate present), 25% dura PKS, and 100% dura-PKS. The results in terms of densities, permeability and the mechanical properties were compared to each other in line with standards and related literature. More specific conclusions are presented in both social and engineering (technical) dimensions of the study in the next sub section of the chapter.

5.2 Specific conclusions

5.2.1 Stakeholders' responses on flood management

The concerns were isolated and addressed in terms of both physical structural elements (built surfaces) and non-structural measures. In what concerns non-structural measures, a statistically significant number of the participants from distinct backgrounds utilised the opportunity to contribute their individual concerns and perceptions regarding flood occurrence and potential resolution channels. This served to answer the first research question posed in the introduction section of the thesis. This is because their contribution representing their perceptions had formally been collected or extracted and analysed for a decision. Most of the participants popularly highlighted a notion that signify the relevance of the participation of citizenry in flood preventive activities. Hence, an insight has been gained following the flood resilience based-questionnaire from which a sustainable approach to flood mitigation has been proposed. The set of questions set out in the questionnaire exposed the varying causative agents of flooding and the associated dynamics to the phenomena. Upon examination of the responses addressed by the participants, it was realised that the trends and main causes of flooding in Ghana are embodied both in the social and engineering perspectives. The social perspective includes attitudes of the citizenry leading to runoff accumulation and the existing impervious land cover types, resulting in flood due to obstruction of water supposed to percolate downstream. The trends can be categorised into horizontal and vertical water flow obstructions. The social perspective includes poor waste management, improper positioning of building blocks in areas prone to floods which obstructed water ways and resulted in runoff accumulation. For the engineering aspect, one key influence has been urbanisation. As most people migrate to locate in the urban areas, this induces more built-up surfaces which interfere in vertical flow of water or runoffs, therefore causing flooding. Among the actions of the citizenry that contribute to flood risks is urbanisation and the rate of artificializing the horizontal planes which compromise downstream percolation. This could be reduced by the application of the green and or grey coverings.

This answers the second research question which sought to identify trends of actions causing flooding. This recommendation was based on the validation of the efficiency of the measure voted by a significant number of respondents. Accordingly, conclusion is drawn that there is a need for designing hybrid drainage systems consisting of both nature-based solutions and conventional or traditional applications. This integrated system has the capability to deal with the increasing drainage demands posed by climate and land cover changes. Again, this is in line with the responses that established that the alteration of natural surfaces through increased urbanization is a key factor in exacerbating flood risk in Ghana.

Holistically, these dimensions of the flooding causative trends or dynamics can be associated to the limited awareness or knowledge gap between the participants concerning flood risk management. And this provides answer to the third research question. In view of this conflicting perspectives, participants suggested that the most effective approach to curbing the menace is by adapting a systemic national campaign on flood resilience even more targeting the politicians. By this, they will appreciate the principles behind flooding and mitigation measures could easily be implemented. Fostering flood awareness is key to strengthening the extent of preparedness towards flood resilience. In this vein, it is relevant to work on schemes that would awaken individuals to consciously empower them to strive against acts that contribute to flood occurrences.

These schemes may comprise training, media sensitization, organisation of flood related workshops for opinion leaders, introduction of the flood mitigation concepts in basic schools and other recognisable social units. Indeed, individuals have roles to play considering the fact that their actions and inactions will determine the threat threshold for floods in their country.

The backgrounds of the stakeholders influenced the perspective of flood risks drivers. Regarding the surface coverings and relations to flood risks, it was only the politicians' class who did not see the need in the implementation of green and permeable areas. The responses to several questions consistently admit and encourage the merits of applying permeable surfaces to attenuate flood risks except the political class (decision-makers).

Again, this answers the third research question of the introduction of the thesis, as it validates hypothesis that participants working in different fields and locations perceive differently about flood drivers and mitigation measures. The perceptions of flooding in Ghana are somewhat believed to have been based on the classifications of diverse stakeholders (e.g., technicians, volunteers, politicians, academics, and citizenry). The politicians and a majority of the citizenry do not agree with other stakeholders like the volunteers, technicians and academia that flood drivers concern the type and nature of material covering the land surface.

Therefore, potential attenuation options are perceived differently. By inference, it can be established that the decision-makers are unwilling to adopt an alternative drainage system aside from the traditional one. It is unfortunate that the posture of the political group may hinder the implementation of the measures suggested. It is therefore important to advance the know-how of the politicians with respect to the effectiveness of these measures. Taking this action can pact with this investigation's main constraint. This recommendation relates to the private and non-collaborative format applied to gain insight into the perception on flood management in Ghana.

5.2.2 Experimental works on permeable concrete pavements for flood mitigation

In spite of the disparaging perceptions among stakeholders' concerning the nature of land covering and the influence on flooding, a laboratory investigation was conducted on permeable concrete pavement as an alternative FRR measure. The conclusion drawn from the experimental works addresses the last three research question (4 to 6) asked in the introduction.

Limestone was used as control aggregates and untreated dura-PKS as experimental aggregates with a water-cement ratio of 0.33. After the analysis, the mixture with 100% untreated dura-PKS was found to be highly permeable but could not withstand the anticipated minimum loads for pavements. However, the mixture with 25% dura-PKS is suitable considering its optimum rate of permeability and the satisfactory mechanical characteristics when tested for flexural and compressive stresses. This confirms that the amount of replacement of limestone with the untreated dura-PKS aggregates has influence on the mechanical and physical properties. This answers the fifth research question, since the adaptation of the mix design with a water-cement ratio of 0.33, and coarse aggregate replacement ratios ranging from 0%, and 25% of the untreated dura-PKS affected all the hydraulic and mechanical properties.

The 0% of dura-PKS represent the control and the 25% dura-PKS became the newly established mixture proven to be implementable after comparing its physical and mechanical properties to those of the control and facts from existing literature. The answer to the fourth research question is 'yes', but depending on the percentage replacement. The untreated dura-PKS can be applied as aggregates for permeable concrete pavement in a laboratory when partially mixed with the limestone or similar aggregates. However, using the 100% untreated dura-PKS is not feasible due to low resistance to loads except when the ratio of replacement is adjusted to increase the mechanical properties.

The rates of permeability ascertained for mixtures with 100% and 25% dura-PKS recorded were 8.3 m/s, and 2.07 m/s, respectively, while the control recorded an average rate of permeability of 1.16 m/s. The sequence changed for the mechanical properties as the concrete mixtures with 100%, 25% dura-PKS and the control recorded an average compressive strength of 4.6 MPa, 11.2 MPa and 27.5 MPa, respectively. Again, for the flexural strength, the maximum average strength of 4.81 MPa was gained by the control whilst the concrete mixtures with 100% and 25% dura-PKS recorded average strengths of 0.96 MPa and 2.93 MPa. Similarly, for tensile splitting test, the control attained the highest strength of 1.3 MPa, whilst the concrete with mixtures of 100% and 25% dura-PKS produced corresponding average strength of 0.38 MPa and 0.71 MPa.

For pervious concrete, it is usual for the hydraulic characterisation to incline whilst the strength to counter potential loads declines. This answers the sixth research question as there are disparity in the performance between the control and the experimental composites specimens. As the control increases in strength, the experimental samples decline and vice versa for the rates of permeability. In this situation, the performances of the composites were generally very low for the tensile stresses. However, the resistance in terms of compression and flexural strengths is satisfactory for the intended applications of the composites as lightweight PCP.

Particularly, the resulting permeable lightweight concrete is effective for flood control purposes by integrating 25% of untreated dura-PKS into known aggregates. This further confirms the answer to the fourth research question, since the untreated dura-PKS can be adapted as aggregates for permeable concrete pavement when compared to the existing literature. The mechanical properties of the composites were not influenced by the higher flakiness index of the dura-PKS as relatively lower indices were recorded of other species of PKS.

5.3 Limitations of the study

The research work was constrained with some conditions that limited the output of the findings obtained. The underlisted constraints have been carefully noted for a satisfactory and more reliable information for further future research works and development:

1. Acquiring responses from less than half of the targeted respondents (46.3%) may not have represented the real situation in Ghana, though the respondents had variable backgrounds and profiles. Future investigation could consider in-person interview with all the targeted participants since some participant hesitated in responding to questions via emails and messaging apps, especially if the participant does not know or recognise the researcher personally.
2. Due to limited resources, including logistics, personnel and time constraints, many potential tests, processes and analytical tools could not be applied. For instance, the tests to determine the chemical composition of the dura-PKS and the abrasion resistance of the aggregates were not carried out. The chemical characterisation of the dura-PKS could have been ascertained to determine the risk associated with the implementation of the composite with 25% dura-PKS.
3. Also, the percentage replacement of the experimental aggregates was limited to 25 and 100% due to time limitations. Other ratios such as 50% and 75% could have been included to ascertain the characterisation of the dura-PKS more closely.

5.4 Future lines of investigation

The future lines of study have been enumerated below, as the first and second relate the social perspectives of the flooding dynamics and looking into the most effective way of mitigating the occurrence. The last two proposals fall in line with the implementation of laboratory experimental works that seek to extend the investigation by practicalizing the hypothesis in this thesis for the purpose of flood resilience and beyond:

1. To better represent the real stakeholders' perception of flooding trajectories in Ghana, it will be important to conduct a similar survey but focus on stakeholders' locations. For future research, the same categories of stakeholders, and same number of participants (stakeholders) should be involved from all the regions, since the participants who responded to the questionnaire in this thesis were limited and not same in terms of numbers per group and region. This proposed future research line will either validate or challenge the conclusions made in this thesis concerning stakeholders' perceptions on flood drivers in Ghana. Should the result be similar to

the conclusion in this thesis, then it means the perceptions about flooding in Ghana is constant regardless of the location and the number of respondents.

2. From the antagonistic posture of the political class as against the other stakeholders in this research concerning permeable surfaces, it would be interesting to delve into this hypothesis to ascertain if this trend remains or has changed due to flood related education schemes. By this motivation, further research may consider disseminating the same sets of questions to only politicians across the regions of Ghana.
3. To actualise the usefulness of the implementations of dura-PKS-based permeable pavements, it is expected that further investigation be conducted in the future to design a methodology to evaluate their application via a spatial multi-criteria decision-making approach. In the future, management strategies should put special weight on the design of interconnected natural and permeable surfaces to enable water percolation in case of flooding.
4. More so, in the future, researchers may investigate the effect of using ashes of dura-PKS as a binder in mixtures with clay for brick-and-mortar production for local construction works in Ghana. This may help reduce the demand on cement and the environmental effect of cement as the ashes of PKS could be a sustainable option for cementitious material.

5.5 The impact of the study

The findings of the research conducted relates to social, environmental, and local economic benefits. The part related to the society includes insight gained through training and workshops. Stakeholders such as decision makers, citizens and volunteers can benefit from the recommended training or workshop sessions for better applications of the alternate drainage systems. Regarding the environmental significance, using PKS in their raw state without any pre-treatment for PCPs is environmentally useful. Especially, for the parts of the region where the material (PKS) is excessively available and regarded as waste, the prevailing environmental nuisance will be reduced significantly.

Counting on the re-use of the PKS, the value of the shells is expected to rise, given chance to local industry and individual suppliers to benefit. This application is in line with the re-use of waste material (i.e., waste management) which will enhance and complete the supply-chain cycle. Also, by the affirmation and implementation of the outcomes of the investigation, the economic value of dura-PKS will be on the rise instead of causing a nuisance on the physical environment.

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