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Sustainable drainage systems (SuDS) for rainwater harvesting and stormwater management in temporary humanitarian settlements

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A B S T R A C T

Effective management of stormwater runoff is crucial in refugee camps and temporary shelters. Across the Africa, this is vital especially with the intense rainfalls due to the climate effect. Sustainable Drainage Systems (SuDS) can be implemented to provide potential sources of water resources across refugee camps and internally displaced people (IDPs). The performance of two SuDS (engineered wetlands and biofilters) was evaluated to assess their effectiveness at reducing levels of pollutants in harvested rainwater and stormwater under simulated environmental conditions of an IDP camp. The SuDS comprised a matrix of sub-surface bedding materials and filter media. Stormwater quality analysis aligned with the WHO and CIRIA standards was carried out over 61 weeks simulating environmental conditions. The SuDS significantly reduced nutrients and organics loading from the influent stormwater. The Constructed Stormwater Treatment System S1-a had an overall high performance in removing impurities (BOD – 60 %, COD – 70 %, Turbidity – 70 %, Colour – 72 %, Phosphates – 63 %, Ammonium – 57 % and Nitrates – 57 %). In addition, the Refugee Camp Engineered Stormwater Treatment System S2-d has overall well-performed impurities removal (TDS – 52 %, COD – 100 %, Turbidity – 100 %, Colour – 41 %, Phosphates – 96 %, Ammonium – 98 % and Nitrates – 88 %). The outflow samples from these SuDS found the concentrations are with high standards. However, it is recommended that the treated stormwater be reused for non-potable sources in these conditions. The implementations of this research findings can be further incorporated into the United Nations sustainable developmental goals of good health and wellbeing (SDG 3) clean water and sanitation (SDG 6), and Peace, justice and strong institutions (SDG 16).

1. Introduction

Rainwater Harvesting (RWH) is described as the interception and collection of rainwater and stormwater runoff for use [1–4]. Implementing RWH systems across Temporary Humanitarian Settlements (THS), such as refugees and internally displaced people (IDPs) camps, can improve the quantity and quality of available water resources, minimise stormwater runoff volumes and reduce the costs of providing water [2,5,6]. Other benefits of implementing RWH systems across THS include a reduction in volume of attenuation storage required to prevent flooding and the delivery of sustainability and climate resilience across the settlements [1,2,7,8]. Stormwater runoff collected from roofs and other impermeable areas can be stored, treated, and then used as a source of water supply for domestic and non-domestic uses across the THS [9]. Many studies have been conducted on the implementation of RWH and stormwater management systems in permanent settlements at both town (settlements of 200 to approximately 5000 people) and cities (populations > 30,000) or >1500 inhabitants per km^2; on an urbanisation scale [1,5,10–12]. However, persistent problems of either insufficient available water resources or both, potable water supply and/or flooding in temporary humanitarian settlements, IDP or refugee camps confirms the need to develop integrated RWH and sustainable

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stormwater management systems. These developments will provide safe water and sanitation facilities, resulting several health benefits for the refugees and the host communities. The potential for harvesting is influenced by the proposed use of the water, the extent of pollution and the treatment provided [13–15]. It is appreciated from engineers and practitioners working in disaster zones, that harvested water can generally be used for a range of non-potable domestic purposes such as sanitation, laundry and for non-domestic uses such as irrigation [2,16,17]. However, adequate treatment of harvested rainwater and stormwater is required to reduce the pollutants load to acceptable levels that meet potable water standards, typically using approaches such as recognised Sustainable Drainage Systems (SuDS) and associated technologies such as permeable pavements, green roofs, bioretention systems, infiltration trenches and basins, swales and bioswales, retention and detention ponds, and constructed wetlands ([18]&b; [15–17]). This is because harvested rainwater and stormwater can become a significant source of health risks as a result of contamination during conveyance and storage [16,19,20]. In addition, SuDS provides effective surface water drainage, flood risk protection and erosion control benefits [4,16]. It is appreciated (engineers and practitioners operating in disaster zones) that the early stages of an emergency or humanitarian crisis may be served by rapid response water and sanitation systems. Nevertheless, first responders should also appreciate the advantages of moving rapidly to establish more substantial and potentially reliable treatment systems which use SuDS technologies, including gravity biofilters and constructed wetlands, which can also be configured to minimise the severe flooding problems often experienced in refugee and IDP camps' environment (Tota-Maharaj et al. 2024; [16,21,22]). In addition, the health risks presented by ponding and flooding in camps' environments are numerous [23,24]. The local control offered by an integrated water harvesting and stormwater management capacity could offer significant health benefits, particularly if "best practice" polices are adopted. Examples of temporary settlements where implementation of integrated 'relief plus SuDS' approaches are required include refugee and internally displaced persons (IDPs) camps across Africa. Hence, we select Lietchour refugee camp in Gambella region of Ethiopia and proposed a SuDS that can be environmentally beneficial while improving the quality of the water usage and sanitation resulting significant health benefit to the occupant as well as the surrounding residents.

Fig. 1 below illustrates a flooding event in Lietchuor refugee camp in the Gambella region of Ethiopia. This study links the actual conditions of rainfall events, precipitation patterns, mimicking similar soil and

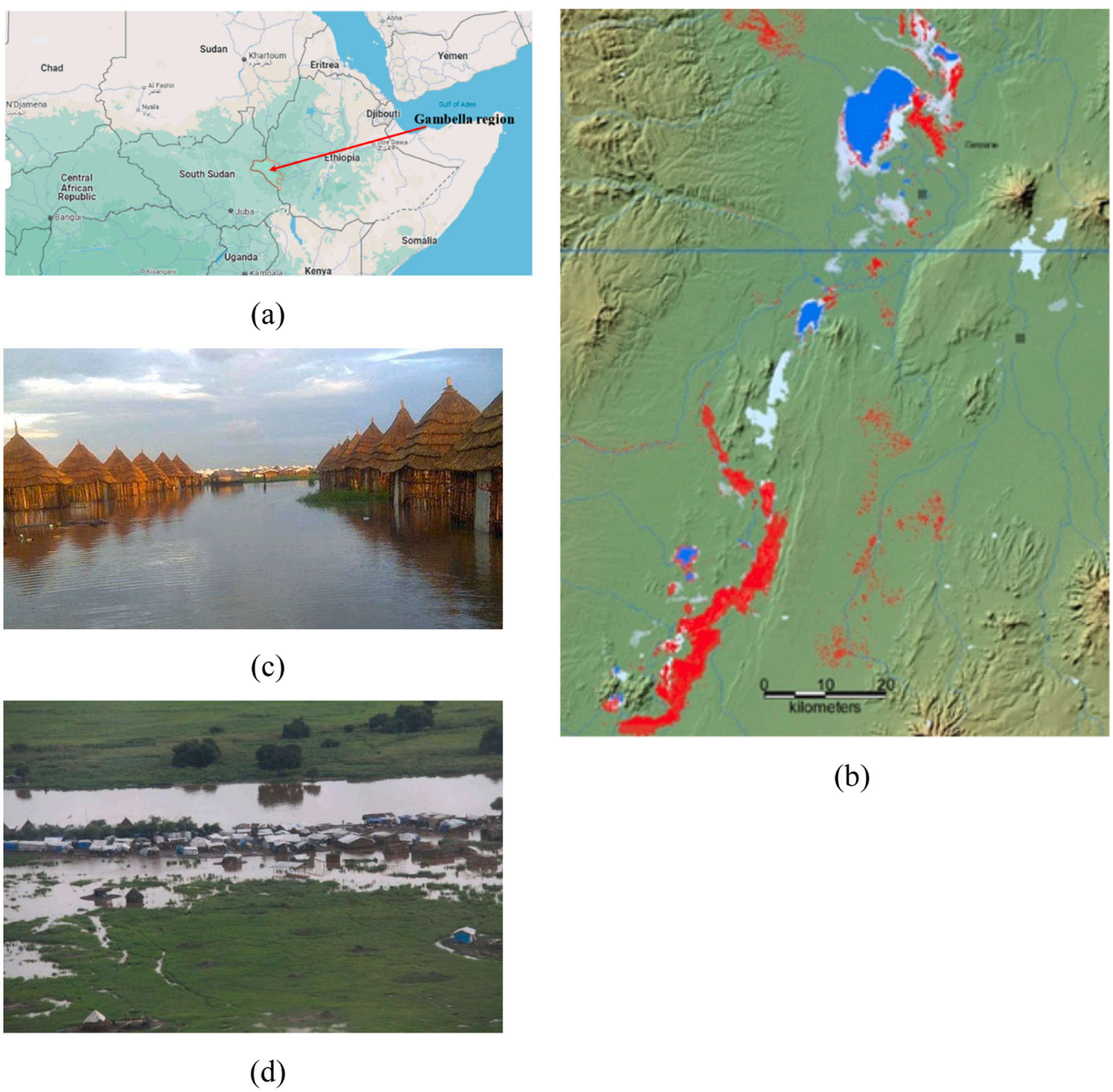

Fig. 1. (a) Gambella region of Ethiopia (b) Maximum Observed Flooding for Ethiopia for data range until September 7th 2020. Key: Red is all mapped flooding from recent events, Blue is a reference normal water extent (the mean annual flood) and Light grey is all previously mapped flooding, since 1999 [25]. (c) Illustration of poor stormwater management in Lietchuor refugee camp located in Gambella region of Ethiopia (Source: [26]). (d) An aerial view of the flooded Leitchuor camp in western Ethiopia's Gambella region [27]-UNHCR/K.GebreEgziabherv).

drainage conditions for the Lietchour refugee camp, Gambella region of Ethiopia, and how engineered wetlands and gravity-flow biofilters can be used in mitigating these flooding issues surrounding this region.

The main health risks associated with poorly managed stormwater include contamination of water supplies by wastewater, damage to refugee shelters, disease vectors breeding and drowning [16,23,24,28]. Flood events and stormwater ponding are directly responsible for triggering vector-borne diseases in refugee camps. Severe flooding in Peru, South America in 2017 was linked with significant dengue an and chikungunya epidemic across the affected region, with >19,000 dengue cases [29]. Patwary et al. [30] reported on deadly floods amid the COVID-19 crisis creating a major public health concern for the world's largest refugee camp in Bangladesh. Whilst countries like Bangladesh continues to struggle in coping with the increase of the COVID-19 pandemic, the Rohingya camp has recently been further exacerbated by the negative impact of extreme storm events and flooding. Thus, an integrated environmental engineering action plan is needed and must be implemented in reducing the risk of vector-borne disease and the impact of stormwater flooding in disaster locations. Flooding results to have a significant impact on the physical and socio-cultural landscape of the area in and around refugee camps. Some literature showcases that the SuDS are among better potential solutions to reduce the floods in the refugee camps with minimum effort [31–33]. Hence, this research aims to evaluate the impact of the potential sustainable drainage systems (SuDS) as a Low-Impact development system applicable to refugee camps. In achieving the goal mentioned above, we focused on evaluating the efficacies of two laboratory-scale SuDS technologies (engineered wetlands and gravity biofilters) for RWH and stormwater management across THS. In addition, this research study addressed the requirements for adequate stormwater treatment with the goals of achieving acceptable levels for stormwater reuse and recycling to improve the public health of the refugees in the Lietchuor camp in the Gambella region and the host communities.

2. Sustainable drainage systems (SuDS)

SuDS primary function is to provide effective surface water drainage, flood risk protection and pollution control. SuDS mimics normal catchment forms and can be a more acceptable methodology in refugee and IDP camps, contrasting with typical urban stormwater control via open channelling and storage arrangements. The concept behind SuDS is to adopt the most appropriate system that recognises the distinctive area catchment characteristics, including seepage systems linked to area land use and qualities [4,34]. The nature and degree of SuDS performances relies on the catchment conditions across IDP and refugee camps. Broad utilisation of SuDS approaches will lessen the volume of stormwater and runoff overflowing into waste streams and sewer frameworks. This could contribute to a reduction of pluvial flooding dangers and contamination risks. SuDS provides for catchment control and quality improvement at, or close to, the source of the contamination. In this way downstream contamination risks are potentially reduced, an example would be the benefits of local SuDS approaches affecting the contamination risks associated with surcharge from combined sewer overflows [16,35,36]. A number of SuDS and low impact development (LID) technologies could potentially provide non-potable water supply sources within IDP and refugee camps locations. This could assist in achieving water proficiency goals and greater sustainability for refugees and IDPs. Similarly, SuDS provide a potential means to recharge aquifers in locations that enhance the potential for subsequent groundwater abstraction to support sustainable supply systems. Following precipitation events in combined sewerage catchments, SuDS reduce both the peak levels of flows entering wastewater treatment works and associated pumping levels [37]. Reductions in stormwater pumping demands, storage and the concentration of wastewater produced by increased water use in sanitation could result in the more proficient treatment of wastewater in refugee and IDP camps. Furthermore, an ascent in refugee and IDP populace could bring about wastewater and sewage treatment processes coming as far as possible to their maximum limitations.

2.1. Engineered wetlands

Engineered wetland systems are SuDS designed and constructed to use physical, biological, and chemical mechanisms to remove pollutants from water (or improve water quality) similar to natural wetlands [38,39]. The main components of the engineered wetlands are vegetation, topsoil, substrate materials and inlet and outlet pipes. While there are different types of engineered/constructed wetlands, factors considered in selecting the type to be implemented include size, cost, operability, health related issues and ancillary benefits [16,35]. Relying on large-scale Wastewater Treatment Plants (WwTP) and implementing traditional stormwater infrastructure have proven limited success in coping with the mentioned problem in IDPs [40]. The cost-benefit analysis of incorporating engineered wetlands has shown that they have easier construction advantages and operational cost benefits over conventional WwTPs [38,39,41]. Alternatives based on Nature-based Solutions (NbS) such as engineered wetlands have the potential to deliver de-centralised stormwater treatment as well as additional socio-environmental benefits for the improvement of these poor conditions (Brasil et al. [42]). The costs and environmental externalities, as well as the area requirements and the contaminant removal efficiencies of engineered wetlands, can be significantly beneficial to the environment of these zones well as the health and well-being of the refugees and the host communities [40,43].

2.2. Gravity biofilters

Gravity biofilters has been used for over a century, adapted from slow sand filters, operated to reduce microbiological, chemical, and physical water contaminants, and drinking water pollutants, preventing water related diseases as well as vector-borne diseases [44–46]. Utilising gravity flow biofilters in refugee and IDP camps for stormwater treatment could potentially increase the range of useful water sources across the camps. Performance of the biofilters can be improved for control of synthetic organic chemicals by including various layers of filter media, such as granular activated carbon and geotextile membranes. Benefits of gravity flow stormwater filters include: (i) abilities to properly drain surface runoff, (ii) possibility to recharge groundwater and reuse water from precipitation events and surface runoff as irrigation or household use, (iii) treatment of stormwater at a very early stage (iv) avoids damages to infrastructure (houses/accommodation units) and (v) flood prevention based on the nature of hydrology to the camp site's location [47–49]. Water, waste and sanitation engineers and practitioners must consider that the treatment mechanisms in slow sand filters include physical, microbiological, and chemical processes may not be the case in low-tech scenarios such as refugee camps or temporary facilities built to provide immediate protection and assistance to vulnerable people. However, stormwater runoff is an occasional event and much depends on the nutrient and DO levels sustained in what can be viewed as aerobic systems. The nutrient levels from harvested rainfall could be extremely variable. If the source (rainwater harvesting) is from a very direct route which flows from the roof to a water treatment system and is adopted to a biological treatment system which is established before the storm event, the overall water treatment performance can be weak in comparison to the scale of the initial pathogen challenges facing refugee camps. Conversely, in dry periods and depending on contamination levels, microbial activity resulting from gross contamination could deplete dissolved oxygen levels to cause anoxic conditions to develop in system storage arrangements. The storage residence time and consistent loading rates can be very important on the desired water quality.

3. Material and methods

3.1. Materials for construction the engineered wetlands and gravity biofilters

The SuDS systems have been designed and constructed at laboratory-scale following the guidelines from the UK's CIRIA SuDS Manual [50]. The two sets of evaluation experiments (engineered wetlands and gravity biofilters) were designated, constructed, and tested for two different treatment systems; stormwater treatment system-one (S1) and stormwater treatment system-two (S2). The approach carried out was testing parallel systems of S1 and S2 and comparing the stormwater treatment capabilities from these varying configurations and different approaches of SuDS. S1 systems consists of four (4) vertical flow engineered wetlands S1-a, S1-b, S1-c and S1-d (see Fig. 2) while S2 systems are six (6) rigs of gravity flow biofilters S2-a, S2-b, S2-c, S2-d, S2-e and S2-f (Fig. 3).

These S1 s are vegetated engineered systems containing a variation of filter media with no geotextile membranes between layers and no storage layer, while S2 s are unvegetated systems containing a variation of filter media, variation of the location of geotextile membranes between layers, and sorbent pillows.

Materials used for constructing the S1 systems are Golden Variegated Sweet Flag plants, topsoil, gravel, sharp sand, coal, peat, and limestone while materials for S2 systems are sorbent pillows, sharp sand, gravel, peat moss and geotextile. The factors considered in selecting the materials are sustainability, ease of maintenance, pollutants removal efficacies and availability across African countries and other parts of the world [39,51]. Different wetland plants and densities of plant affect the treatment and nutrient uptake process. The Acorus gramineus 'Ogon' or Golden Sweet Flag wetland plant was selected to mimic similar wetland plants in the African region for high march zones due to the proximity of the refugee camp along rivers which floods and drains to the adjacent areas. Its roots and leaves are well-adjusted to sitting in shallow water or consistently wet soil as it is normally found in wetlands. The Golden Sweet Flag plant (*Acorus gramineus 'Ogon'*) was chosen for the S1 systems because of its ability to thrive well in clay, loam, sand, and silt soils; a low or no maintenance requirement, erosion control, aesthetic appeal and suitability for different weather and climatic conditions [52]. The topsoil in S1 systems supports growth of the wetland plants by retaining nutrients and enabling root formation. Sharp sand, limestone and gravel were included as part of the substrates in both systems because of their high filtration and infiltration performances. The enhancement of pollutant removal by crushed coal and peat, principally linked to their high carbon contents, was the main reasons for including them as substrate materials in the experiments. Sorbent pillow in S2 systems was included because of its ability to remove oils and greases from stormwater which are found quite frequently around similar case-study refugee camps. Geotextile membrane was included in S2 systems for separation of layers and filtration of fine particles, while enhancing drainage of water through the S2 systems [53,54]. A commercially available, economical geotextile membrane was selected for the experimental rigs. The specific geotextile membrane is designed for applications in surface water drainage, filtration, and separation systems, fabricated from a non-woven low-carbon material with 180 µm pore size systems and a thickness of ≈ 0.9 mm (Terram Geosynthetics, Essex, UK). The selected geotextile membranes were manufactured from UV-stabilised, high tenacity, polypropylene fibres which were thermally and mechanically bonded to provide the appropriate strength and excellent filterability characteristics of SuDS.

Stormwater runoff and gully pot liquor was collected daily at various locations across Medway Campus of the University of Greenwich, Kent, UK. All stormwater was obtained from rainwater storage tanks and gully pots. The rainwater originating from roof runoff and gully pot liquor was channelled and mixed in a tank. Prior to application to the SuDS, the stormwater mixture was texted for key physiochemical parameters in duplicate. Thereafter the collected stormwater of 5 L/day was uniformly applied to the surfaces of each text rig in 24 h. Standard procedures in sample collection were practiced after the trials for collection and transportation to the laboratory.

In addition, the impact of external factors on the treatment mechanisms of both S1 and S2 systems was minimised by ensuring that the experiments were conducted during regular high-intensity rainfall periods with no chance of snowfall (January to April) in England to enable a correlation between the conditions of the stormwater collected as influent from drain inlets at Medway in England and the rainy seasons in Ethiopia.

3.1.1. S1 systems (Engineered wetlands)

The construction of the S1 systems (S1-a, S1-b, S1-c and S1-d) was done using rectangular plastic tanked containers of dimensions 380 mm × 330 mm × 280 mm (Length × Width × Depth). A perforated 15 mm diameter plastic pipe connected to an outflow valve was installed to the lower part of each box for effluent collection. The materials for constructing the engineered wetlands are presented below in Table 1. Details of the S1 systems are illustrated in Figs. 2(a) to (d).

The cost of constructing and setting up the pilot-scaled engineered wetlands experiment is presented below in Table 2. As presented in Table 2, when compared to conventional stormwater or wastewater treatment systems, constructed, or engineered wetlands are low cost to build, are easily operated and maintained, and have a strong potential for applications in refugee camps by rural communities.

3.2.1. S2 systems (Gravity biofilters)

The construction of the Gravity Biofilters referred to as S2 systems (S2-a, S2-b, S2-c, S2-d, S2-e and S2-f) was done using plastic water tanks of dimensions 350 mm × 350 mm × 780 mm (Length × Width × Depth). The materials for constructing the gravity biofilters are presented below in Table 3. Details of the S2 systems are illustrated in Figs. 3(a) to (f).

The S2 systems were built from multiple layers of aggregates and geotextiles. The systems were filled with designed filter media combinations of peat moss, sand, gravel (Φ the mean diameter of gravel ≈20 mm), sorbent pillows and geotextile membrane. All systems had similar deeper drainage layers comprising 250 mm of medium sized sand supported by 300 mm gravel, a thin layer of geotextile was included between the layers. The thickness of the geotextile membranes was 2 mm. The geotextiles were made from ultra-violet balanced out, high steadiness, polypropylene strands which were both mechanically and thermally attached to give high quality and excellent filterability attributes [55]. An outflow valve was installed to the lower part of each rig for effluent collection. The cost of setting up the stormwater biofiltration experiment is presented below in Table 4.

3.2. Methods of evaluating the efficacies of the S1 and S2 systems for degrading pollutants in harvested stormwater samples

The water quality tests on influents and effluents of both systems (S1 and S2 systems) were carried out at the Hydraulics Engineering Laboratory of the University of Greenwich, Medway campus, England, United Kingdom. The tests performed on both systems for TDS, BOD_5, COD, turbidity, colour, phosphates, ammonium, and nitrites. These tests are part of recommended water quality tests by the World Health Organisation [15]. All stormwater quality analysis followed standard methods so that the effective treatment and environmental performance of each SuDS could be studied [56]. The tests on influents and effluents of both systems were performed from 02 – 01 – 2017 to 17 – 04 – 2018 (n = 61 weeks). The influent volume for all the experiments was 5 litres of stormwater per day.

3.2.1. BOD_5 tests on both S1 and S2 influents and effluents

The BOD_5 tests were performed using Lovibond BOD incubator TC135S. BOD_5 levels of influents and effluents of both S1 and S2 systems

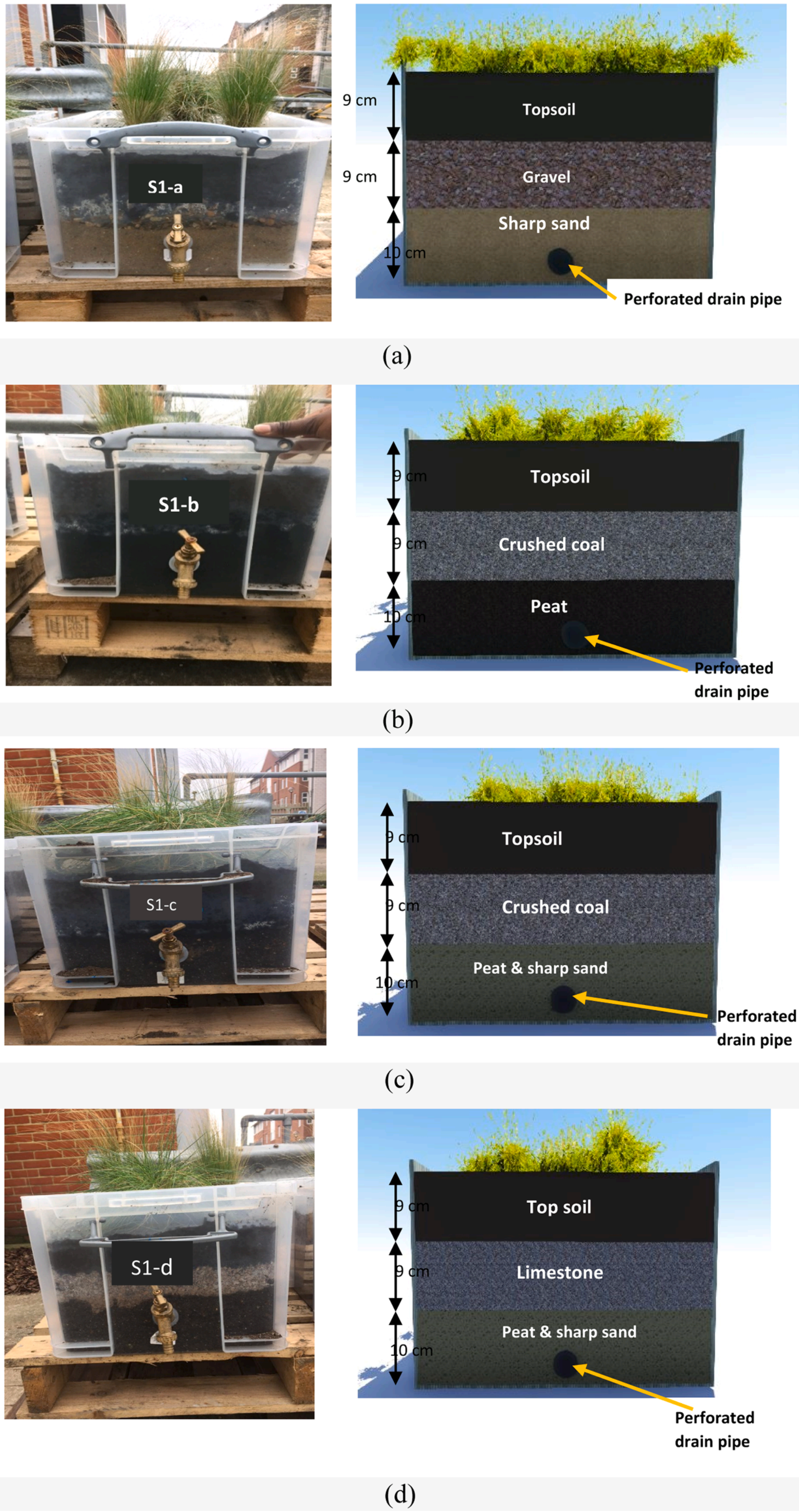

Fig. 2. Illustration of the Constructed Stormwater Treatment Systems (S1 systems). The density of the wetland plants are three (3) plants per experimental rig. (each plant approximately 4 cm in width, 7.5–8 cm in height and around 5 cm with relatively established roots). (a) Constructed Stormwater Treatment System (S1-a) and its cross section; (b) Constructed Stormwater Treatment System (S1-b) and its cross section; (c) Constructed Stormwater Treatment System (S1-c) and its cross section; (d) Constructed Refugee Camp Stormwater Treatment System (S1-d) and its cross section.

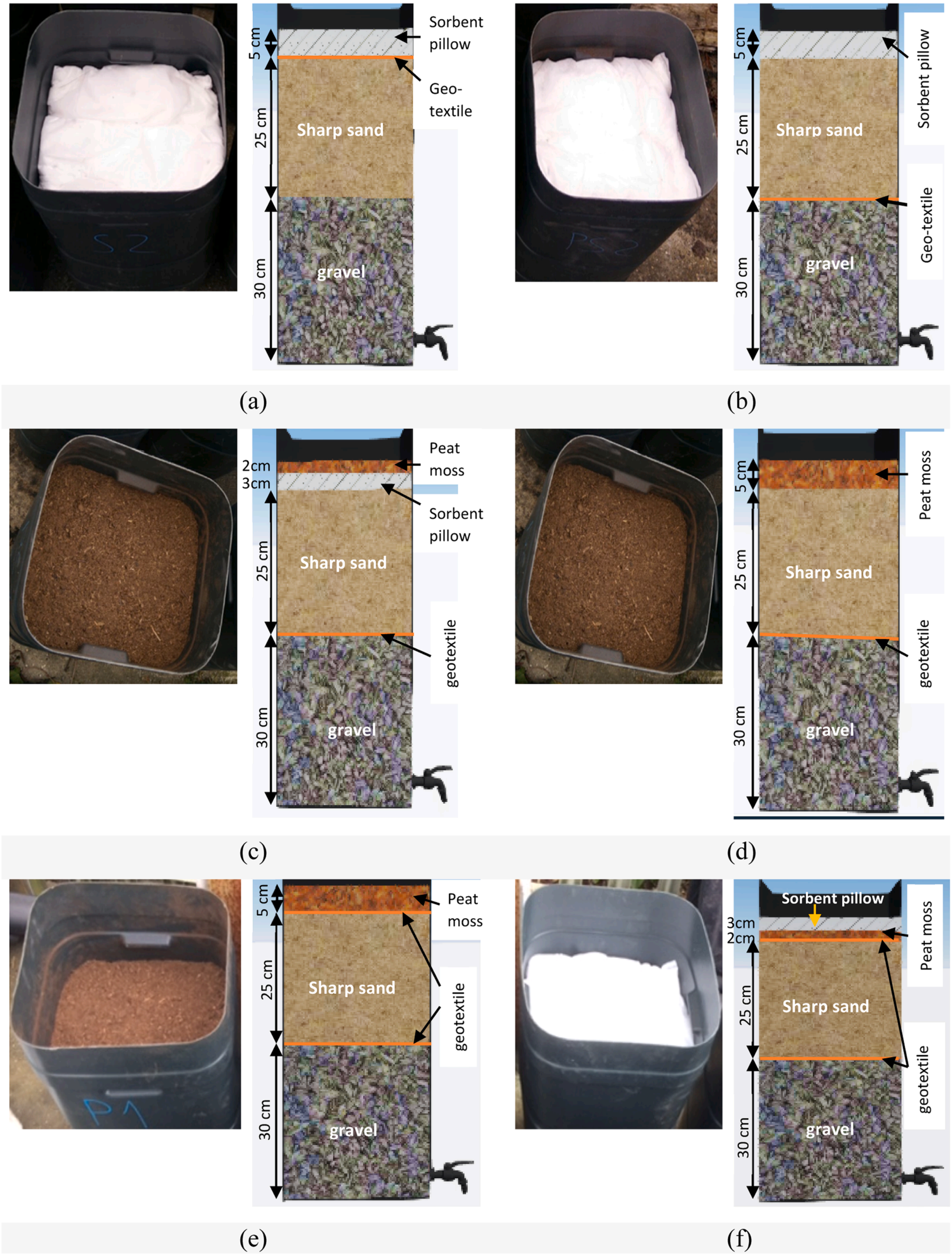

Fig. 3. Illustration of the Refugee Camp Engineered Stormwater Treatment Systems (S2 systems) (a) Illustration of S2-a and its cross-section; (b) Illustration of S2-b and its cross-section; (c) Illustration of S2-c and its cross-section; (d) Illustration of S2-d and its cross-section; (e) Illustration of S2-e and its cross-section; (f) Illustration of S2-f and its cross-section.

Table 1
Components of the engineered wetlands (S1-a, S1-b, S1-c & S1-d).

Engineered wetlands	Materials of each wetland			
	Plant	Substrates		
S1-a	Golden Sweet Flag	Topsoil (9 cm)	Gravel (9 cm)	Sharp sand (10 cm)
S1-b	Golden Sweet Flag	Topsoil (9 cm)	Crushed coal (9 cm)	Peat (10 cm)
S1-c	Golden Sweet Flag	Topsoil (9 cm)	Crushed coal (9 cm)	Peat & sharp sand (10 cm)
S1-d	Golden Sweet Flag	Topsoil (9 cm)	Limestone (9 cm)	Peat & sharp sand (9 cm)

Table 2
Bill of quantities for the stormwater treatment system (S1) materials (Purchased in 2016–2017 from varying European and British suppliers).

Items	Description	Quantity	Unit	Rate US$	Amount US$
1	Plastic water boxes	4	Pcs	5.19	20.76
2	Peat	3	Kg	5.31	15.93
3	Crushed coal	5	Kg	1.19	5.36
4	Sharp Sand	7	Kg	1.06	7.42
5	Gravel (Φ the mean diameter of gravel ≈20 mm)	8	Kg	1.26	10.08
	Total				59.55

were evaluated to obtain and compare milligrams of oxygen per litre of water samples consumed by bacteria in the samples as organic matter is oxidised under aerobic conditions [57]. For all the tests, 10 drops of Allyl Thiourea (ATH) nitrification inhibitor was added to 428 ml water samples in each BOD bottle because of the potential low range of BOD_5 in the samples. Prior to incubating the prepared water samples for 5 days at 20 °C, 4 drops of Potassium Hydroxide (KOH) were placed in the seal gasket of each BOD bottle to prevent accumulation of carbon dioxide (CO_2).

3.2.2. COD tests on both S1 and S2 influents and effluents

The COD tests were performed using HACH LANGE dry thermostat LT200, HACH LANGE DR1900 spectrophotometer, COD LCK 1414 cuvette reagents and 0.5 mL pipettes. The purpose of performing the COD tests is to determine the total quantity of oxygen required to oxidise all organic materials into CO_2 and water. For all the tests, 2.0 mL of water samples was added to COD LCK 1414 cuvette reagents. The cuvettes were tightly covered and heated in the HACH LANGE thermostat for 2 h to attain temperature of 148 °C. COD values of the water samples were measured using the spectrophotometer after allowing temperature to reduce to 18 °C - 20 °C.

3.2.3. Phosphate tests on both S1 and S2 influents and effluents

The phosphate tests were performed using Phosphate LCK 348 cuvette reagents, HACH LANGE dry thermostat LT 200, HACH LANGE DR 1900 spectrophotometer and pipettes. For all the tests, 0.5 mL of water samples was added to the cuvette reagents, covered tightly and mixed thoroughly. The cuvettes with the samples in them were heated to 100 °C for 1 hour using the thermostat. After allowing the temperature of the mixture to reduce to 18 – 20 °C, 0.2 mL of recommended standard LCK solution B was added to the mixture and the cover of the cuvettes were replaced with recommended LCK cap C. The phosphate values were read using the DR 1900 spectrophotometer.

3.2.4. Ammonium tests on both S1 and S2 influents and effluents

The ammonium tests were performed ammonium LCK 303 and 304 cuvette reagents, HACH LANGE DR 1900 spectrophotometer and pipettes. For all the tests, 0.2 mL of water samples was added to the cuvette reagents using pipette, covered tightly, and mixed thoroughly for 15 min. The ammonium levels in the mixture were read using the spectrophotometer.

3.2.5. Nitrite tests on both S1 and S2 influents and effluents

The nitrite tests were performed using Nitrite LCK 342 cuvette reagents, HACH LANGE DR 1900 spectrophotometer and pipettes. For all the tests, 0.2 mL of water samples was added to the cuvette reagents using a pipette, covered tightly, and mixed thoroughly for 10 min. The values of the nitrite levels in the water samples were read using the DR 1900 spectrophotometer.

3.2.6. Turbidity tests on both S1 and S2 influents and effluents

The turbidity tests were performed using HANNA Instruments HI 93,703 microprocessor Turbidity meter and 10 mL standard cuvettes supplied with the instrument. For all the tests, the turbidity meter was first calibrated with distilled water filled up to one-quarter of a 10-mL standard cuvette. This was followed by carefully putting water samples in the 10-mL standard cuvettes up to one-quarter of their capacities. The turbidity levels of the water samples were read by putting the cuvettes filled with water samples in the turbidity meter.

3.2.7. TDS tests on both S1 and S2 influents and effluents

The TDS tests were performed using HM digital EC/TDS/TEMP instrument. The TDS concentration in the samples were directly measured by simply inserting the instrument in the samples.

3.2.8. Colour tests on both S1 and S2 influents and effluents

The colour tests were performed on all the water samples using a colour checker instrument and 10 mL cuvettes. The colour checker was first calibrated with deionised water prior to tests on the water samples.

Table 4
Bill of quantities for refugee camp stormwater treatment system (S2) materials (Purchased in 2016–2017 from varying European and British suppliers).

Items	Description	Quantity	Unit	Rate US $	Amount US$
1	Plastic water tanks	6	Pcs	38.59	231.54
2	Sorbent Pillows	1	5 × Pcs	39.61	39.61
3	Peat Moss	3	Kg	5.31	15.93
4	Geotextile Membrane	1	2 m × 25m	39.94	39.94
5	Sand	7	Kg	1.06	7.42
6	Gravel				
(Φ ≈20 mm)	9	Kg	1.26	11.34	
	Total				345.78

Table 3
Components of the stormwater treatment system (S2) systems (S2-a, S2-b, S2-c, S2-d, S2-e & S2-f).

Biofilters	Filter media					
S2-a	Sorbent pillow	Geotextile	Sand	Gravel	–	–
S2-b	Sorbent pillow	Sand	Geotextile	Gravel	–	–
S2-c	Peat moss	Sorbent pillow	Sand	Geotextile	Gravel	–
S2-d	Peat moss	Sand	Geotextile	Gravel	–	–
S2-e	Peat moss	Geotextile	Sand	Geotextile	Gravel	–
S2-f	Sorbent pillow	Peat moss	Geotextile	Sand	Geotextile	Gravel

4. Stormwater treatment mechanisms of S1 (Engineered wetlands) and S2 (Gravity biofilters) SuDS technologies

The S1 (engineered wetlands) and S2 (gravity biofilters) SuDS technologies are bio-filtration systems that utilise biological, chemical, and physical mechanisms, such as adsorption, filtration, sedimentation, precipitation and dissolution, bacterial and biochemical interactions as well as infiltration to remove pollutants in stormwater [57–59]. In addition, the plants utilised in engineered wetlands influence pollutants removal performance of the wetlands by absorbing nutrients such as phosphorus and nitrates and filtering suspended solids (Woods-Ballard [60]). Unlike the conventional wastewater treatment systems, such as activated sludge, biofiltration systems such as engineered wetlands can effectively treat wastewater with low organic concentrations (<50 – 80 mg/L BOD_5) such as stormwater [61]. Arguably, the large range of fixed film and membrane systems currently available in low-cost settings have been ignored in recent catastrophic events. Their smaller carbon and water footprints and performance envelopes are important matters in the decision-making processes for water control and treatment systems. The hydraulic retention time is conceivably the main factor influencing the effectiveness of the treatment mechanisms [59]. The hydraulic retention time is the average time that stormwater remains in the bio-filtration systems for all the treatment mechanisms to be completed. The hydraulic retention time can be generally expressed as given in Eq. (1) [59].

$$\text{Hydraulic retention time} = \frac{\text{mean volume of biofiltration system}}{\text{mean outflow (or inflow)}} \quad (1)$$

For the S1 and S2 experiments, the hydraulic retention time ranged between 15 – 20 h. Both S1 and S2 systems use sedimentation, bio-filtration and microbial decomposition mechanisms to remove BOD, COD, solids, heavy metals, phosphates, and synthetic organic pollutants from stormwater under gentle inflow conditions [59]. In addition, solids are removed from stormwater by bacterial decomposition, adsorption to filter media materials and plant roots [62]. Depending on the oxygen concentration, organic compounds are degraded biologically both anaerobically and aerobically [57]. Nitrogen compounds in stormwater runoff (ammonia, nitrates, and nitrites) typically exerts high oxygen demands, supporting a biological nitrification process [59]. Quite often in natural hydrosystems, this leads to a decline in dissolved oxygen (O_2) concentrations < 3 mg/L. Biofiltration systems and NbS such as those adopted for S1 and S2 can effectively reduce nitrogen content in stormwater through volatilisation and uptake by vegetation (in S1 systems), matrix adsorption, ammonification, and nitrification/denitrification in S2 [63]. Nonetheless, the main mechanism in which both S1 and S2 systems remove nitrogen is microbial nitrification and denitrification [61]. The plants in the S1 systems also oppose blockage of the substrates as they develop root networks and absorb nutrients from stormwater [63]. In addition, dissolved nutrients are removed from stormwater by S1 and S2 systems via ion exchange and chemical precipitation mechanisms [59]. Pollutants removal efficiency of S1 and S2 systems were calculated using Eq. (2):

$$\text{Pollutants removal efficiency (\%)} = \frac{\text{Inflow concentration} - \text{outflow concentration}}{\text{Inflow concentation}} \times 100 \quad (2)$$

5. Results and discussions

It should be noted that the hydraulic retention times (HRT) remained a control for this study, however increasing and decreasing the HRT would directly impact on the pollutant removal process or overall stormwater polishing mechanisms imposed by the selected SuDS. HRTs of 15–20 h can improve the overall water quality effluent in meeting the desired water quality standards. Nutrient concentration of < 1.0 mg/L had almost minimal impact on the lower HRT < 15 h from previous experiments and can increase in concentrations based on the health and well-being of the SuDS throughout its operation. The results of laboratory tests carried out for the related pollutants such as: TDS, turbidity, colour, phosphates, ammonium, nitrite, COD and BOD are presented in Figs. 4–11 and Tables 5–12. The weekly results are obtained from the five-day weekly average. The tests were conducted for 61 weeks from Monday to Friday.

5.1. Performance of S1 and S2 systems for removal of pollutants in stormwater

5.1.1. Total dissolved solids (TDS)

The results of performance of S1 and S2 systems for TDS removal are presented below in Figs. 4(a) & (b) and Table 5.

From the results presented in Figs. 4(a) and 4(b), the harvested stormwater samples had an average value of 568 mg/L of TDS over the 61-week period.

From Fig. 4(a), S1-d symbols from the box plots illustrates daily measurements collected over the 61 weeks period of study. S1-d (Fig. 4a) was the most effective of the four wetlands with average TDS concentration removal efficacy of 31.7 % (from 568 mg/L down to 395 mg/L) while S1-a, S1-b and S1-c wetlands could only achieve 20.9 %, 6.97 % and 14.95 % average TDS removal efficacies respectively. This shows that the combination of limestone, peat and sharp sand are more efficient wetland substrate material for TDS removal in stormwater relative to substrate materials in the other three wetlands. On the other hand, in Fig. 4(b), S2-c was the most effective biofilter reducing TDS down to 124 mg/L (equivalent to 78.17 % average removal rate) while S2-a, S2-b, S2-d, S2-e and S2-f produced average TDS removal efficacies of 75 %, 71 %, 52.5 % and 68 % respectively. Sorbent pillows and peat moss combined media with one layer of geotextile produced the best TDS reduction rate compared to other biofilter rigs. Generally, water with TDS level below 600 mg/L is good as drinking water while water with TDS levels greater than 1000 mg/L is unpalatable [15]. Therefore, concentrations of TDS in all the effluents of S1 and S2 systems are within acceptable limits for drinking water. In addition, low values of deviation of S1 (standard deviation < 3) and S2 (standard deviation < 1) performances presented in Table 5 shows that the mean TDS removal efficacies of the two systems illustrated in Figs. 4(a) – (b) are consistent.

5.1.2. The 5-Day biochemical oxygen demand (BOD_5)

The results of performance of S1 and S2 systems for BOD_5 removal are presented below in Figs. 5(a) – (b) and Tables 6.

From the results presented in Figs. 5(a) and 5(b), the harvested stormwater samples had an average value of 1.37 mg/L of BOD_5 over the 61 weeks period. As illustrated in Fig. 5(a), S1-a was the most effective of the four wetlands with average BOD_5 concentration removal efficacy of 59.5 % (from 1.37 mg/L down to 0.56 mg/L) while S1-b, S1-c and S1-d wetlands had average BOD_5 removal efficacies of 50 %, 30 % and 40 % respectively. This shows that the combination of gravel and sharp sand are more efficient wetland substrate material for BOD_5 removal in stormwater compared to substrate materials in the other three wetlands. The BOD_5 results were not as effective from any of the S2 systems;

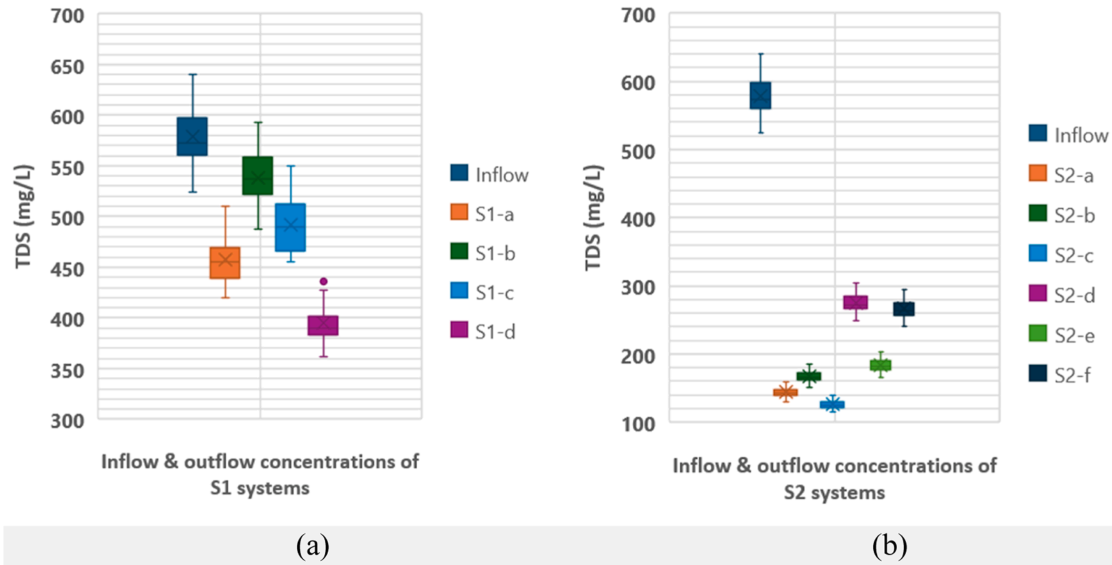

Fig. 4. Results of performance for Total Dissolve Solids (TDS) removal in harvested stormwater from January 2017 to April 2018 (sample - no of weeks 'n' = 61).(a) S1 system and (b) S2 system.

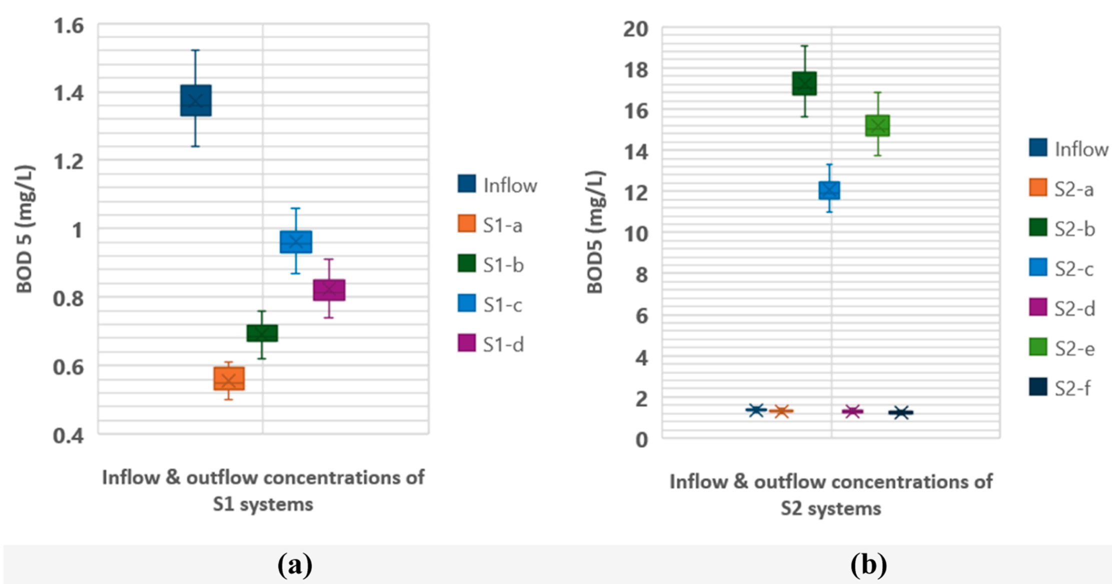

Fig. 5. Results of performance for BOD_5 removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system (b) S2 system.

especially S2-b, S2-c and S2-e which showed an increase in biochemical oxygen demand. The main reason for the increase in BOD concentrations and significantly higher values was due to the negative impact of peat moss. Peat moss is soils that contain biological and organic impurities, so when the stormwater enters the biofilter and percolates through the peat moss filter media zone it collects and absorbs and adsorbs extra organic loads. As a result, the BOD_5 level of effluent water increased rather decreased.

Furthermore, low values of deviation of S1 (standard deviation $<$ 1) and S2 (standard deviation $<$ 3) performances presented in Table 6 shows that the mean BOD_5 removal efficacies of the two systems illustrated in Figs. 5(a) – (b) are reliable.

5.1.3. Chemical oxygen demand (COD)

The results of performance of S1 and S2 systems for COD removal are presented below in Figs. 6(a) – (b) and Tables 7.

From the results presented in Figs. 6(a) and 6(b), the harvested stormwater samples had an average value of 64.7 mg/L of COD over the 61 weeks period of analyses when it entered S1 and S2 systems. As illustrated in Fig. 6(a), S1-b was the most effective of the four wetlands with average COD concentration removal rate of 82 % while S1-a, S1-c and S1-d wetlands had average COD removal rates of 70 %, 31 % and 76 % respectively. This shows that the combination of crushed coal and peat are more efficient wetland substrate materials for removal of COD in stormwater compared to substrate materials in the other three wetlands. Conversely, S2-a, S2-d and S2-f had an average COD removal efficiency of 100 %. However, S2-b, S2-c and S2-e produced an average removal rate of 76 %, 90 % and 75 % in COD content respectively. Additionally, low values of deviation of S1 (standard deviation $<$ 1) and S2 (standard deviation $<$ 1) performances presented in Table 7 shows that the mean COD removal efficacies of the two systems illustrated in Figs. 6(a) – (b) are reliable.

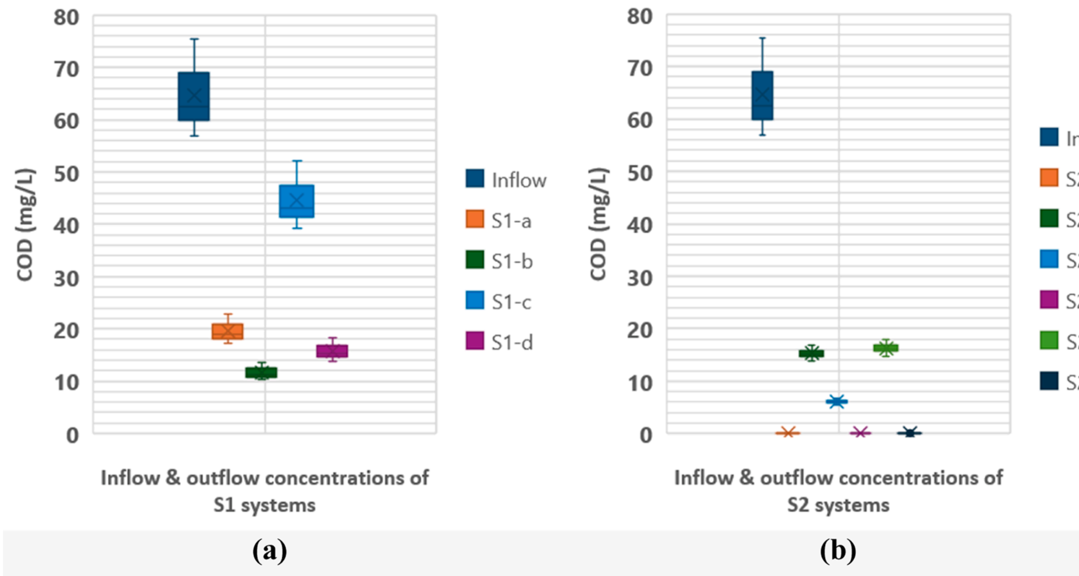

Fig. 6. Results of performance for COD removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

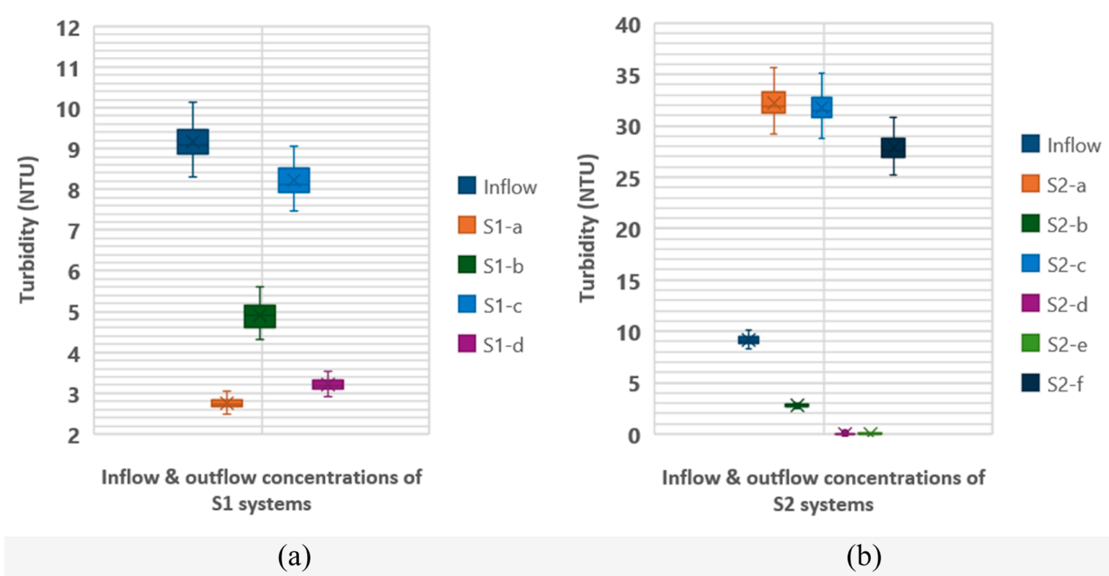

Fig. 7. Results of performance for turbidity reduction in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

Removing as much as possible COD helps to provide improved water quality for stormwater. In addition, this helps in protecting aquatic life and preventing eutrophication. Therefore, COD control of stormwater is an essential task.

5.1.4. *Turbidity*

The results of performance of S1 and S2 systems relating to turbidity reduction are presented below in Figs. 7(a) – (b) and Table 8.

From the results presented in Figs. 7(a) and 7(b), average inflow turbidity over the 61 weeks period was 9.2 NTU. The concentration of effluents in Fig. 7(a) shows that S1-a wetland had the best average turbidity reduction performance (from 9.2 NTU down to 2.75 NTU; equivalent to 70 %). However, wetlands S1-b, S1-c and S1-d had average turbidity reduction performance of 47 %, 10 % and 65 % respectively. Conversely, from Fig. 7(b) S2-d and S2-e biofilters were the most effective of the six S2 systems with mean effluent concentrations of 0.02 NTU and 0.04 NTU respectively. While the S2-b biofilter achieved a turbidity reduction performance of 69.8 %, biofilters S2-a, S2-c and S2-f failed significantly to reduce turbidity levels of the inflow water. Only the effluent quality of S2-b, S2-d and S2-e effluent met the World Health Organisation (WHO) drinking water standards requirements regarding turbidity levels of < 4 NTU [15]. Furthermore, low values of deviation of S1 (standard deviation < 3) and S2 (standard deviation < 1) performances presented in Table 8 shows that the mean turbidity removal efficacies of the two systems illustrated in Figs. 7(a) – (b) are reliable.

Turbidity removal is essential for improved water quality. In addition to the protection of aquatic life and enhanced water quality levels, removing turbidity helps indirectly to reduce sediment buildup in water cruises. This helps in flood control. Therefore, improving the water quality standards of stormwater runoff have many indirect impacts to the society.

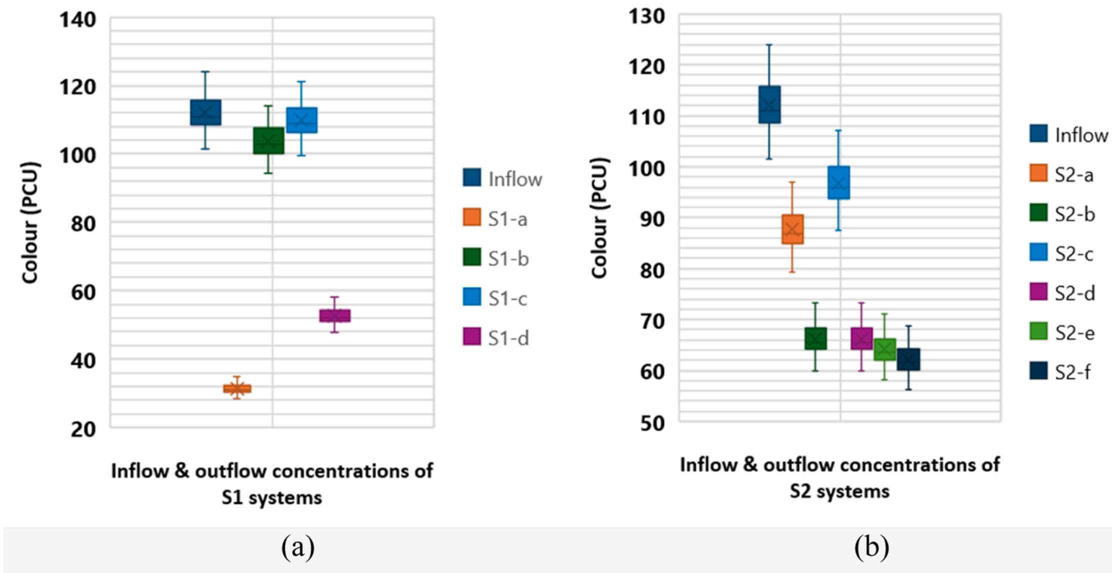

Fig. 8. Results of performance for colour removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

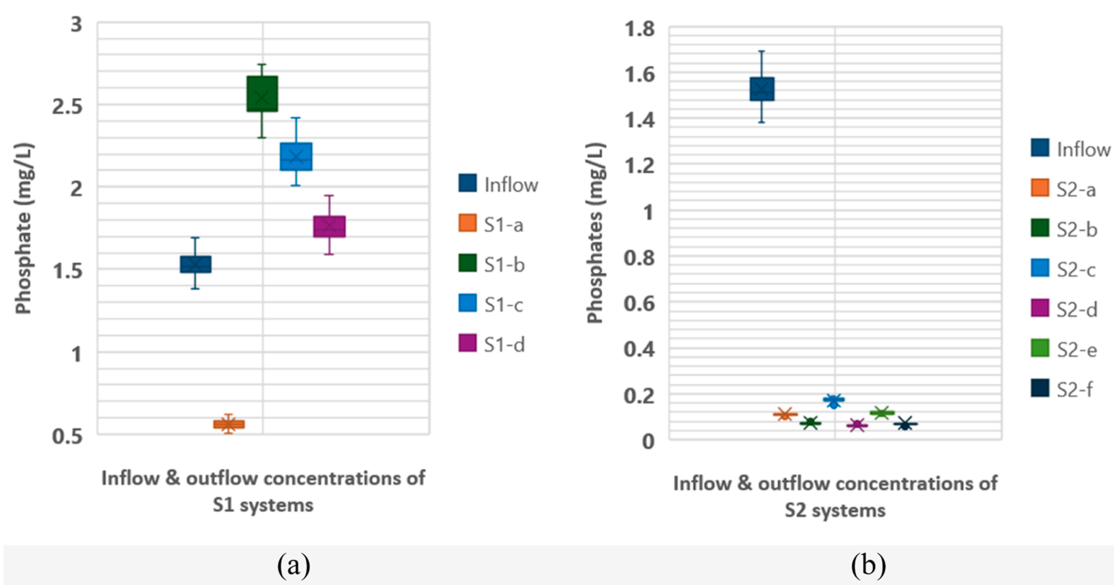

Fig. 9. Results of performance for phosphate removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

5.1.5. *Colour*

The results of performance of S1 and S2 systems for colour improvement of harvested water are presented below in Fig. 8(a) – (b) and Table 9.

From the results presented in Figs. 8(a) and 8(b), average value of colour of inflow water samples was 112 PCU. In Fig. 8(a), wetland S1-a had the best colour improvement performance by reducing PCU (Platinum Cobalt Units) in the stormwater samples to an average of 31.38 PCU over the 61 weeks period. Wetlands S1-b, S1-c and S1-d achieved average colour improvement efficiencies of only 7.4 %, 2 % and 53 % respectively. This contrasts with the results presented in Fig. 8(b), these show that biofilters S2-b and S2-d effectively reduced the PCU in water samples by an average of 41 %, while S2-e and S2-f achieved average PCU reduction efficacies of 43 % and 45 % respectively throughout the 61 weeks duration of the test period. Although there is no health-based guideline value regarding colour for drinking water, drinking water should not have PCU levels visible to human eye [15]. Moreover, low values of deviation of S1 (standard deviation < 1) and S2 (standard deviation < 1) performances presented in Table 9 shows that the mean colour removal effectiveness of the two systems illustrated in Figs. 8(a) – (b) are consistent.

Colour of the water is an indirect measurement to discuss the impurities dissolved in water. Therefore, improving colour levels to No colour status is highly important in the justification of water quality standards. In addition, the aesthetic value of the water is enhanced. Furthermore, that could ensure less impact from industrial waste to the stormwater.

5.1.6. *Phosphates (PO_4 -P)*

The results of performance of S1 and S2 systems for phosphate removal from harvested water samples are presented below in Fig. 9(a) – (b) and Table 10.

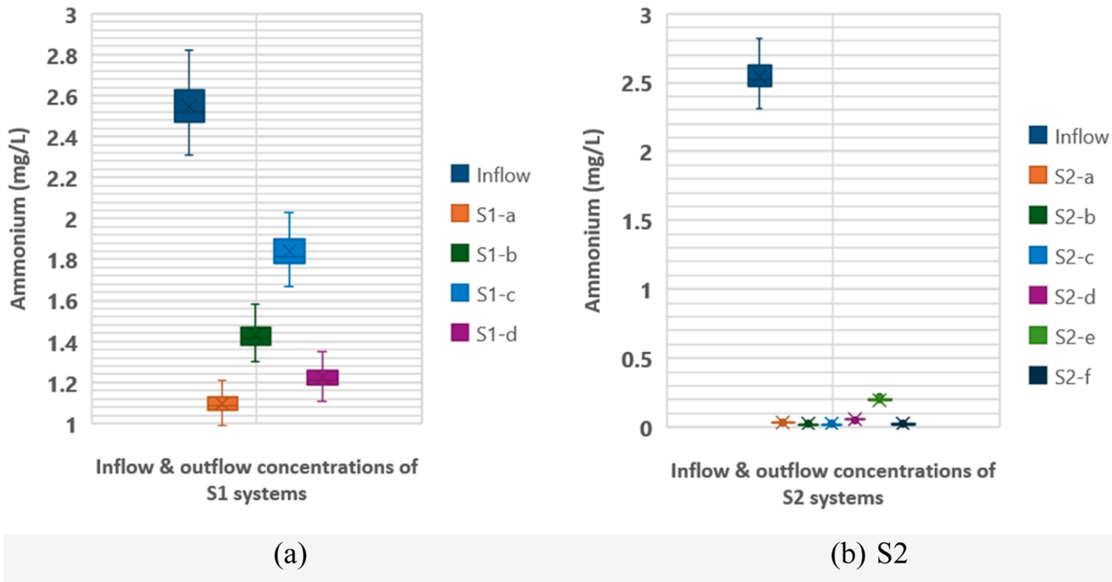

Fig. 10. Results of performance for ammonium removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

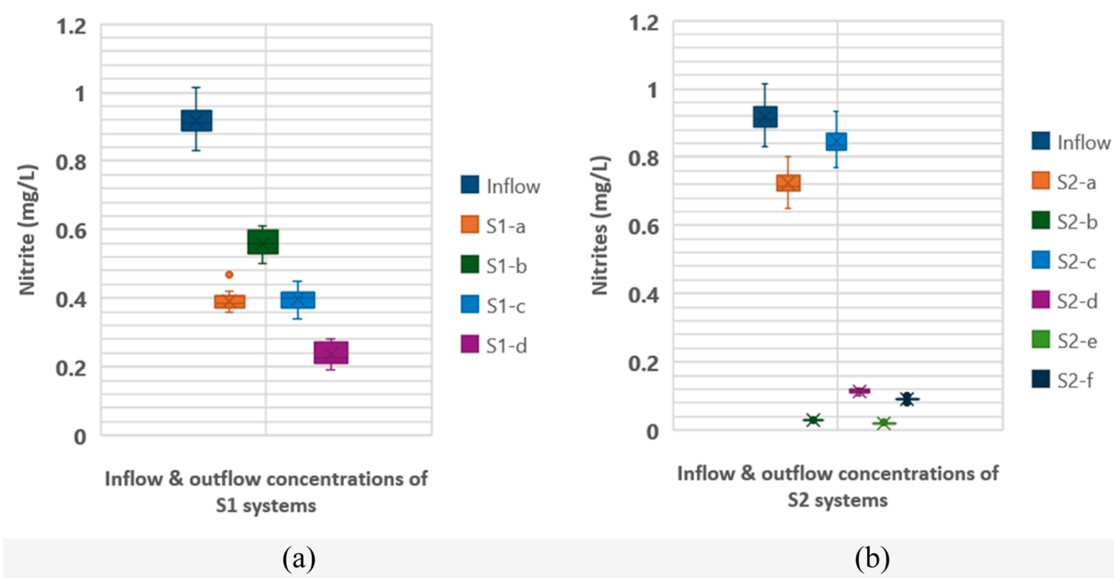

Fig. 11. Results of performance for nitrite removal in harvested stormwater from January 2017 to April 2018 (water quality sampling and analysis number of weeks 'n' = 61) (a) S1 system and (b) S2 system.

Table 5
Standard deviation of 61 weeks of analysis for daily stormwater TDS removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	2.6392		2.8224	2.8010		2.5620
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005

Table 6
Standard deviation of 61 weeks of analysis for daily stormwater BOD_5 removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.9142		0.2487	0.1849		0.3815
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.2369	2.6644	2.9013	0.3018	2.1448	0.4318

Table 7
Standard deviation of 61 weeks of analysis for daily stormwater COD removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.0274		0.0202	0.0326		0.0149
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.0827	2.1930	0.8858	0.0597	2.3402	0.0513

Table 8
Standard deviation of 61 weeks of analysis for daily stormwater turbidity reduction performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.0327		2.1604	0.4391		0.3203
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.1231	0.0284	0.1016	0.3193	0.5391	0.1000

Table 9
Standard deviation of 61 weeks of analysis for daily stormwater colour removal & colour improvement performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.0496		0.5362	0.1116		0.0463
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.0026	0.0029	0.0029	0.0029	0.0022	0.0027

Table 10
Standard deviation of 61 weeks of analysis for daily stormwater phosphates removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.3261		2.1267	1.8774		1.4959
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.1753	0.1797	0.2191	0.1676	0.1633	0.1710

The amount of phosphate in raw water (harvested stormwater) that entered both S1 and S2 systems in the 61 weeks period was over 1.5 mg/L but on average < 2.0 mg/L. The results are presented in Fig. 9(a) and indicate that the wetlands S1-b, S1-c and S1-d failed to reduce phosphate concentration in the water samples. The increase in phosphate levels in the effluents of these three wetlands resulted from excess phosphate in the topsoil and peat that is included in their substrate materials. However, S1-a had a significant average phosphate level reduction in the water samples by 63 %. On the other hand, all six S2 systems had an average phosphate reduction rate of around 90 %; especially biofilters S2-b, S2-d and S2-f which recorded the most effective removal of phosphates during the experimental programmes. Moreover, low values of deviation of S1 (standard deviation < 3) and S2 (standard deviation < 3) performances presented in Table 10 shows that the mean phosphate removal efficiencies of the two systems illustrated in Figs. 9(a) – (b) are consistent.

Reduction of potential algal blooms in water sources is one of the most important aspects of minimizing phosphate levels in stormwater runoff. A significant portion of stormwater runoff finally reaches the nearby water sources and protecting aquatic life, and then to conserve the environment is highly important. Therefore, phosphate reduction is essential.

5.1.7. *Ammonium (NH_4 -N)*

The results of performance of S1 and S2 systems for ammonium removal from harvested water samples are presented below in Fig. 10(a) – (b) and Table 11.

Average ammonium level of the inflow stormwater that entered both S1 and S2 systems was 2.5 mg/L for the 61 weeks duration. From Fig. 10 (a), S1-a had the best ammonium removal performance in the water samples with average efficiency of 57 % while S1-b, S1-c and S1-d also had significant ammonium concentration reduction performance of 44 %, 28 % and 52 % respectively. In Fig. 10(b) however, all the six biofilters had excellent ammonium level reduction performance of 92 - 99 %. S2-c had the best removal efficiency of ammonium as well as TDS. Nevertheless, S2-e showed the lowest reduction of ammonium levels present in the water (mean outflow concentrations of 0.196 mg/L). Furthermore, low values of deviation of S1 (standard deviation < 3) and S2 (standard deviation < 3) performances presented in Table 11 shows that the mean ammonium removal rates of the two systems illustrated in Figs. 10(a) – (b) are consistent.

Similar to phosphate removal, minimizing ammonium levels in stormwater has a wider importance. It prevents the water to polluted by algal blooms and then enhances the water quality for aquatic life. When it is combined with phosphate removal the system helps to reach higher water quality standards.

5.1.8. *Nitrites (NO_2 -N)*

The results of performance of S1 and S2 systems for nitrite removal from harvested water samples are presented below in Fig. 11 and Table 12.

From the results presented in Figs. 11(a) and 11(b), average value of nitrite of inflow water samples was 0.92 mg/L. From Fig. 11(a), S1-d had the best average nitrite removal efficacy (74 %) while S1-b had the least performance (mean efficacy of 39 %). However, the results in Fig. 11(b) show that four biofilters (S2-b, S2-d, S2-e and S2-f) had excellent nitrite removal efficacies of 97 %, 88 %, 98 % and 90 % respectively. Nevertheless, S2-c performed poorly in removing nitrite concentration in water samples. Similarly, low values of deviation of S1 (standard deviation < 3) and S2 (standard deviation < 1) performances presented in Table 12 shows that the mean nitrite removal efficacies of the two systems illustrated in Figs. 11(a) – (b) are reliable.

Reduction of toxicity to aquatic life is one important aspect of minimizing nitrites in stormwater runoff. In addition, a part of the stormwater runoff reaches to the groundwater table and causes significant contamination. Reduction of the impurities in stormwater runoff

Table 11
Standard deviation of 61 weeks of analysis for daily stormwater ammonium removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	0.1403		0.1378	0.1048		0.1041
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.0532	0.0456	0.0384	0.0995	0.0731	0.1049

Table 12
Standard deviation of 61 weeks of analysis for stormwater nitrite removal performance.

S1 system	Wetlands	S1-a		S1-b	S1-c		S1-d
	Standard deviation	2.6513		2.0177	2.4220		2.7970
S2 system	Gravity biofilters	S2-a	S2-b	S2-c	S2-d	S2-e	S2-f
	Standard deviation	0.2959	0.1453	0.4586	0.2887	0.0981	0.2966

has many indirect importance in addition to the reuse of the water in IDPs.

5.2. Summary of performance of S1 and S2 systems

A summary of overall mean stormwater treatability performance of both S1 (engineered wetlands) and S2 (gravity biofilters) systems is presented in Table 13. This summary (Table 13) mainly focuses on the overall stormwater pollutants removal performance and efficacies throughout the 61 weeks period. There was a consistent performance regarding the selected parameters based on the trends observed between the inflow and outflow samples. It should be noted that the engineered wetland systems (S1) continued growing tall and dense across the SuDS experimental rigs displaying very healthy development and environmental performance.

The overall performances of the engineered wetlands (S1 systems) and gravity biofilters (S2 systems) are presented in Table 13 and show that both systems are suitable for water quality improvement across African refugee and IDP camps. Among the S1 systems, S1-a with a combination of gravel and sand substrate materials had the best BOD, turbidity, colour, phosphate, and ammonium removal efficacies. Similarly, S1-d (combination of limestone, peat and sharp sand substrate materials) achieved the best TDS and nitrite removal efficacies while S1-b (combination of crushed coal and peat substrate materials) had the best COD removal rates. However, all the S2 systems achieved high TDS, COD, phosphate and ammonium removal rates relative to the S1 systems. The sand layer of filter media/substrate material was found to be generally effective in reduction of contaminants.

Both engineered wetlands and gravity biofilters have shown promising alterations for effective flood control. Flood control is essential, especially within highly dense regions like temporary settlement camps. The post-flood environmental conditions negatively impact public health in many ways including lack of access to drinking water, vector-borne diseases, etc. As a result, the humanitarian services may have to be altered. According to the United Nations, access to clean water and sanitation is one of the primary human rights. Hence, improving the health and well-being of the people who are impaired in conflicts can be further accelerated if the authorities can develop SuDS-induced sustainable infrastructures. In addition, these implementations will ensure the effective projection from natural disasters for these impaired communities.

The proposed SuDS technique has been introduced to the Lietchuor refugee camp in the Gambella region in Ethiopia for the first time. This refugee camp is well known for spreading vector-borne diseases such as diarrhoea, especially during the rainy season. The presence of SuSDs in this specific region will help to minimize the flooding conditions and the consequent environmental impacts and the drinking water shortages, which triggered the vector-borne diseases. Hence, the ultimate goal of this proposed SuDS technique is to improve the quality of life for the occupant with enhanced water and sanitation facilities."

According to the United Nations Humanitarian Agency, millions of people worldwide are currently displaced due to severe political situations and adverse climate effects. Therefore, providing temporary settlements for these internally displaced persons (IDPs) and refugees is vital for improving their security, health, and overall well-being. Additionally, as the world faces increasingly adverse climatic conditions, including intense rainfall, these settlement areas become highly vulnerable to flash floods. Therefore, implementing the proposed nature-based solutions is essential for enhancing the well-being of IDPs, regardless of their location.

6. Conclusions

Constructed wetlands and gravity flow biological stormwater filters are relatively sustainable drainage systems which could be utilised in African refugee and IDP camps for reducing the pollutant levels in stormwater runoff, whilst providing effective management of the stormwater runoff volumes. Both the constructed wetlands and gravity biofilters tested performed relatively well and there was little clogging of the filter media/substrates of either of the Sustainable Drainage Systems (SuDS) during the experimental test programme. However, regular scheduled maintenance of both systems is required to ensure

Table 13
Summary of average pollutants removal rates for stormwater treatability of S1 and S2 systems over 61 weeks.

	TDS	BOD	COD	Turbidity	Colour	Phosphates	Ammonium	Nitrites
S1-a	21 %	60 %	70 %	70 %	72 %	63 %	57 %	57 %
S1-b	7 %	50 %	82 %	47 %	7 %	68 %	44 %	39 %
S1-c	15 %	30 %	31 %	10 %	2 %	67 %	28 %	57 %
S1-d	32 %	40 %	76 %	65 %	53 %	64 %	52 %	74 %
S2-a	75 %	5 %	100 %	–	22 %	93 %	99 %	21 %
S2-b	71 %	–	76 %	70 %	41 %	95 %	99 %	97 %
S2-c	78 %	–	91 %	–	14 %	89 %	99 %	8 %
S2-d	52 %	5 %	100 %	100 %	41 %	96 %	98 %	88 %
S2-e	68 %	-	75 %	100 %	43 %	93 %	92 %	98 %
S2-f	54 %	10 %	100 %	–	45 %	95 %	99 %	90 %

that the efficiencies of the wetlands and biofilters do not diminish over time. The results showed that the various permutations and combinations of filter media/substrates for both systems could result in significant differences being recorded for stormwater influent and system effluent concentrations. Overall, the wetlands and biofilters successfully reduced most of the water contaminants tested. However, some of the S1 designs failed to reduce phosphate levels while some of the S2 designs failed to achieve an effective reduction of the BOD_5 levels in the influent stormwater. The environmental engineering project illustrated that a range of vertical flow engineered wetlands and stormwater treatment filters could be configured as SuDS systems and had the potential to be successfully applied in refugee and IDP camp settings. These systems do provide a very efficient approach of overall stormwater quality improvement and a useful focus for ongoing research to refine and quantify understanding of the factors that influence stormwater management (treatment performance, attenuation, storage, and recycling) across refugee and IDP camps. Wetland plant growth and behavioural analysis will be considered in future studies as mentioned in earlier sections, wetland vegetation is the main component in the performance and durability of engineered wetlands is such extreme conditions.

Finally, this study adds empirical evidence by exploring the potential of SuDS such as engineered wetlands and biofilters can contribute to changes in the physical landscape of temporary humanitarian settlements and refugee camps. The aim of integration of SuDS within such environments can provide non-potable water reuse (captured stormwater, treated, remediated) and used for non-drinking purposes to refugees such as toilet flushing, washing of clothes and irrigation on site. In addition, there is a potential to use SuDS as a reliable and economical nature-based solution to control the floods in refugee camps. The implementation of relevant policy guidelines is essential for enforcing nature-based solutions in affected areas [64].

The implementations of this research findings can be further incorporated into the United Nations' sustainable developmental goals of good health and wellbeing (SDG 3) of the occupants of these temporary shelters by assuring the accessibility to clean water and sanitation (SDG 6), while improving the quality of life of the internally displaced communities (Peace, justice and strong institutions - SDG 16)

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CRediT authorship contribution statement

Kiran Tota-Maharaj: Writing – original draft, Supervision, Conceptualization. **Oluwatoyin Opeyemi Ajibade:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Shanika Arachchi:** Writing – original draft, Visualization, Software, Methodology. **Colin Douglas Hills:** Writing – review & editing, Validation. **Upaka Rathnayake:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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