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Abstract

Flood management has long been perceived from a technical point of view. The term "technical flood management" entails the physical control of runoff and river flows, achieved by using engineering structures such as flood defence walls, urban drainages, human-made tidal barriers, etc. But these engineered structures may not always be cost effective. Relying solely on them is increasingly being perceived as inadequate and unsustainable in the face of climate change. A broader approach, particularly employing nature and the need to consider the opportunities and benefits of flood incidents is termed Natural Flood Management (NFM). NFM refers to a number of interventions, which perform together, to slow the flow of water throughout the catchment as one integrated system. It is an approach to managing floods which works with natural hydrological processes in a catchment or watershed to store, delay or utilize flood waters during flood events. It aims to reduce the downstream maximum water level of a flood (the flood peak) or to delay the arrival of the flood peak downstream, increasing the time available for preparedness to cope with the flood. This paper presents the concepts, techniques and possible applications of NFM in Nigerian catchments towards the development of a Flood Hydrology Road Map for the country. River and catchment based NFM techniques include: woodland creation or afforestation, watershed management measures, creation of wetlands both constructed and natural, and river floodplain restoration. NFM can be cost effective and conservative of the natural environment, hence, adoptable to the holistic management of flood risks over wide hydrological areas. The application of NFM in Nigeria is, therefore, not only feasible but imperative and will lead to the development of waterways and hydrological pathways – a hydrological road map – for the country.

Keywords: Natural Flood Management, Flood risk, Watershed Management, Catchments, Flood hydrology.

1. Introduction

Flood depends on its context. A river flood is the inundation of the river floodplains adjacent to the river channel due to inadequate capacity to convey the current flow. It may be caused by the collection in the upstream channel network of excess rainfall-runoff water over the catchment, or the failure of a dam or an embankment. The capacity of the river channel may be limited by an obstruction or sedimentation. An urban flood can be due to inadequacy of

drainage system capacity or due to the through flow of runoff water generated on catchments adjoining the urban area. In coastal areas, land may be inundated due to high water levels from tidal surges or earthquake-generated tsunamis.

Whereas the three primary phases of flood management (from “source” through “pathways” to their impact on “receptors”) provide a general framework, innovative research and development are required to

improve the content and dynamic of each phase. There is a progressive increase in the opportunity to manage floods, with little at the source (rainfall, dam failure or earthquake), more scope along the pathways (catchment, stream channel network or coastal area) and yet more potential with the receptors (property or people). The different spatial phases of the flooding process demand an integrated approach to management along the lines of catchment management planning and best practices. But flood management also has three temporal phases: the preparedness phase (involving hazard reduction), the operational phase (emergency and disaster management) and the recovery-restoration phase (post-flood reconstruction).

Traditionally, management response to severe flooding was typically ad hoc – the quick implementation of a project that considers both the problem and its solution as self-evident, giving no thought to the consequences for upstream and downstream flood risks. Thus, flood management practices largely focussed on reducing flooding and the susceptibility to flood damage, employing both structural and non-structural as well as institutional interventions. Such traditional interventions are summarized below:

- i. Source control to reduce runoff (permeable pavements, afforestation, artificial recharge);
- ii. Storage of runoff water (wetlands, detention basins, reservoirs);
- iii. Capacity enhancement of rivers (bypass channels, channel deepening and/or widening);
- iv. Separation of rivers and populations (land-use control, dikes, flood proofing, zoning);
- v. Emergency management during floods (flood warnings and sensitisation, evacuations);

- vi. Flood recovery (counselling, compensation or insurance).

There is a need to adopt novel approaches to flood management in the face of future and changing climate (Merz et al., 2010). By opening up to new approaches more sustainable ways of controlling and managing floods will be achieved. However, recognizing the need for this change does not mean that new ways of working out these approaches are easily achieved (Washbourne and Dicke, 2001). According to Waylenet *al.* (2015), a lot of institutional challenges are likely to be encountered, and these must be better understood in order to overcome and enable change.

Natural Flood Management (NFM), in its broadest sense, aims to slow the flow of water (runoff) through the landscape and, therefore, entails working with new groups for catchment-scale co-ordination of land-use and river management (Waylenet *al.*, 2017). The practice of NFM is currently of interest in many countries worldwide (Wesselink *et al.*, 2015). A case study is Scotland (UK), where there is strong support for new approaches in flood management, but where progress in NFM implementation has so far been slow (Cook *et al.*, 2016).

2. Concept of Natural Flood Management (NFM)

Flood management has long been centred on ‘technical flood control’, i.e. the physical control of runoff water in catchments and rivers (Cook et al., 2016). Resulting structural solutions such as concrete flood defence walls and tidal barriers or temporary structures have played paramount roles in reducing the damages from flooding. However, relying solely on these measures is increasingly perceived as inadequate, perhaps in the face of future climate change and other societal pressures (Merz et al., 2010). Wheeler (2006) reported that

technical measures in managing floods are very costly, may have unintended consequences, and may not be able to cope with increases in the frequency and size of future flood events. As a result, many have recommended the use of a broader measure or approach, particularly applying nature (Evans, 2004) and the need to fundamentally reconsider how we practice, conceive, and assess flood management (Lane et al., 2011). The ‘Sustainable Flood Management’ (SFM) approach is a philosophy which prioritizes risk reduction, through measures that can include structural measures, but are more economically and environmentally sustainable than relying only on structural measures (Cook et al., 2016). Natural Flood Management (NFM) is part of this new philosophy.

NFM involves techniques that aim to work with natural hydrological and morphological processes, features and characteristics to manage the sources and pathways of flood waters (Forbes et al., 2015). It refers to a number of interventions, which perform together, to slow the flow of water throughout the catchment as one integrated system. NFM typically involves slowing or storing flood waters through techniques such as restoration, enhancement and alteration of natural features and characteristics, but excluding traditional flood defence engineering that works against or disrupts the natural processes. In addition to other possible benefits of floods, these techniques can also incorporate and contribute to improvements in biodiversity, water quality, and carbon storage which, in turn, improve access to wildlife, health and wellbeing, recreation, and jobs (Forbes et al., 2015).

Related terms to NFM include ‘Making Space for the River’ (Warner et al., 2013), ‘Ecosystem-based Flood Risk Management’ (Huq and Stubbings, 2015), ‘Engineering with Nature’ (Bridges and Walker, 2011),

‘Working with Natural Processes’ (Cooper and McKenna, 2008) and ‘Nature-Based Solutions for Water’ (UN-WWDR, 2018). NFM can benefit flood management at both coastlines and catchments (Waylen et al., 2017). In catchments, NFM entails slowing the movement of water (runoff) through the landscape by co-ordinating river management and land-use across landscapes so as to re-shape hydrological and morphological processes (Rouillard et al., 2015; SEPA, 2016; Waylen et al., 2017). This is achieved through diverse measures ranging from installing upland wetlands and ponds to placing woody debris in-stream, re-meandering river channels and planting trees or other ground cover (Waylen et al., 2017). In all, these measures can also provide ecosystem services and biodiversity. NFM, thus, supports Sustainable Flood Management by enabling more economically and environmentally sustainable management of water and flood risks (Iacob et al., 2014; Cook et al., 2016).

SEPA (2016) provides an overview of the range of NFM measures and current knowledge on their effectiveness. However, NFM is relatively novel with many gaps in understanding (Spray et al., 2009). For example, McIntyre and Thorne (2013) reported that NFM measures are thought to reduce flows in floods with small return periods but there is less certainty about their effectiveness in larger flood events.

3. NFM Measures and Techniques

Natural flood management involves managing the pathways of water and enhancing the capacity of features throughout a catchment to store and pass floodwater (Murray, 2017; Janes et al., 2017). Techniques discussed here are grouped into catchment and river based natural flood management. Natural flood management measures within a catchment seeks to regain the natural ability of the land

to store or slow water, in other words to manage the source of flood waters. While river based natural flood management manages the pathway of water in order to help minimize the impact of flooding on people, homes and farm lands. Natural flood management measures within a river catchment aim to reduce the rate or amount of runoff and/or improve the ability of rivers and their floodplains to manage flood water. River and catchment based natural flood management techniques are woodland creation (catchment woodlands, floodplain woodlands and riparian woodlands); land management (land and soil management practices, agricultural and upland drainage modifications, non-floodplain wetlands and overland sediment traps); and river and floodplain restoration (river bank restoration, river morphology and floodplain restoration, instream structures and washlands and offline storage ponds).

3.1 Woodland Creation

This is planting and management of woodland areas at a range of scales throughout the catchment from floodplains to headwaters (Forbes et al., 2015; Murray, 2017). Well-managed floodplain and riparian woodland provide important wildlife habitat and increased canopy shade and shelter for water-based flora and fauna. Among many other benefits, they can also provide shelter and shade for livestock and prevent damage to crops and soil erosion. Effects of woodlands on large scale floods have not been verified, modelling data suggests that woodlands have an effect on local flooding (catchments less than 100km²) or more frequent flood events (Forbes et al., 2015). Trees have the potential to manage the sources and pathways of flood waters in a number of ways. Field-based evidence shows that they can reduce water yield by improving the infiltration rates of woodland soils as well as losing water through the process of

evapotranspiration. The high input of organic matter into the soils of well-managed woodlands can also protect soil from disturbance and improve its structure, in turn enhancing soil infiltration pathways and water storage capacity and reducing surface runoff, erosion and sediment loss. Woodlands can also act to slow down surface runoff by increasing the frictional resistance to this runoff. Floodplain woodland as a NFM measure depends on the size and positioning of the woodland in relation to the size of the floodplain. Floodplain woodland is thought to offer the greatest potential for downstream flood mitigation (Scottish Environmental Protection Agency Natural Flood Management, 2015). Riparian woodlands are usually planted as buffer zones, in between the watercourse and adjacent land, which allows the maximum amount of contact between the trees and water. According to Forbes et al. (2015), they are typically up to 30m wide on both sides of the watercourse, and offer the benefits of infiltration, hydraulic roughness and evapotranspiration and also the potential for woody debris (porous dams which can encourage out-of-bank 'spill over' and therefore delay downstream flood flows). The extent to which woodlands attenuate flood risk is dependent on its species composition and management. However, semi-natural woodlands with limited management are thought to offer greater scope for flood reduction than more managed plantation forests (Parrot et al., 2009). One study shows that soil infiltration rates are up to 60 times higher where young native cross slope woodlands were present compared to adjacent heavily grazed pasture (Carroll et al., 2006). Woodlands planted in parts of the catchment where soils generate rapid runoff in to streams, such as heavy soils prone to waterlogging, can also be beneficial for flood attenuation. As with all natural flood management measures; hydrological

modelling of the soils, land use and pathways of water movement in to streams is essential when designing and locating woodlands for flood attenuation (Parrot et al., 2009).

Additional Benefits of Woodland Creation.

Woodlands have a range of other benefits relating to climate change adaptation and mitigation. Woodlands can help mitigate against climate change when managed as a permanent landscape feature. Riparian woodlands generally help to improve water quality by absorbing diffuse nutrients which arise primarily from agriculture and plantation forestry (State of the Environmental Report EPA, 2016), as well as trapping sediment from running off land in to waterways. Sediment becomes a problem when too much of it enters rivers, and as the amount of sediment arising from erosion increases with heavy rainfall, trapping sediment is one of the challenges to be addressed in climate change adaptation. With increased frequency and severity of precipitation events likely to arise from climate change, this is an important climate change adaptation measure. Conversely, artificial fertilizers applied for forest management can result in nutrient pollution to waterways and soil disturbance from forest management can cause sedimentation (State of the Environmental Report EPA, 2016).

3.2 Land Management

Land management incorporates good practice for the purpose of increasing infiltration of water and sediments into soils and reducing surface runoff. Land management measures are land based techniques and practices that seek to influence flood generation by reducing the amount of surface runoff reaching the river network (Forbes et al., 2015). They achieve this primarily by improving soil structure, increasing infiltration, and ultimately

increasing the capacity of the land to store water. In addition to reducing runoff, these measures can also reduce soil erosion. The land's ability to slow down and store runoff is influenced substantially by how agricultural land is managed. Activities which result in a higher risk of soil erosion and soil compaction and leave less vegetative cover over the rainy season can reduce the potential for infiltration of surface runoff. The adoption of good land and soil management practices can reduce the risks to soil posed by certain land management practices and in many cases can improve overall yield by improving the productivity of soils. Techniques that may be adopted include: cover crops, checking for and relieving compaction where necessary, soil aeration, machinery practices that minimize compaction, and runoff control features.

3.3 River and Floodplain Restoration

This involves stabilization of excessively eroding river banks in order to reduce deposition of sediment downstream. NFM measures associated with land management seek to reduce flood water generation, while NFM measures in the river channel or on its banks or floodplain seek to improve the ability of rivers to manage those flood waters. This is achieved by restoring a more natural hydrological response and regime, for example, by slowing flows (e.g. re-meandering or the use of instream structures) and reducing excessive supplies of fine sediment (e.g. bank stabilization) or by increasing the potential for the floodplain to store water. A number of measures is often used, which may also include riparian and floodplain planting. Measures to manage unnaturally high rates of erosion of river banks should, where possible, focus on better riparian management that allows the river banks to re-vegetate and stabilize naturally. This may be as simple as the installation of fencing where livestock are

present or direct re-vegetation of the banks through the planting of young plants and trees and the sowing of seeds. In some cases, however, the rate of erosion may be so severe or happening so quickly that intervention is required to stabilize and re-profile the bank. Re-shaping the banks can damage habitats and disrupt the natural functioning of the river so it requires a clear justification for its use. Natural materials may need to be used to protect the bank from erosion in the future.

Generally according to UK Parliamentary Office of Science and Technology (2011), NFM aims to reduce the downstream maximum water height of a flood (the flood peak) or to delay the arrival of the flood peak downstream, increasing the time available to prepare for floods (Fig. 1). These aims are achieved by restricting the progress of water through a catchment. NFM strategies can be loosely classified by their likely location and distribution in a catchment (Fig. 1). They rely on one, or a combination, of the following underlying mechanisms:

- **storing water** by using, and maintaining the capacity of, ponds, ditches, embanked reservoirs, channels or land.
- **increasing soil infiltration**, potentially reducing surface runoff, although this can be offset by greater subsurface flows. Free-draining soil will make saturation less likely, and evaporation from soil can also make space for water.
- **slowing water** by increasing resistance to its flow, for example, by planting floodplain or riverside woods.
- **reducing water flow connectivity** by interrupting surface flows of water, for example, by water storage or planting buffer strips of grass or trees.

4. Nature-Based Solutions (NBS) for Flood Management

According to the UN-WWDR (2018), NBS entails working with nature to improve the management of water resources, achieve water security, and ensure sustainable development.

4.1 The Role of Ecosystems in the Water Cycle

Ecological processes in a landscape influence the quality of water and the way it moves through a system, as well as soil formation, erosion, and sediment transport and deposition – all of which can exert major influences on hydrology. Although forests often receive the most attention when it comes to land cover and hydrology, grasslands and croplands also play important roles. Soils are critical in controlling the movement, storage and transformation of water. Biodiversity has a functional role in NBS whereby it underpins ecosystem processes and functions and, therefore, the delivery of ecosystem services.

Ecosystems have important influences on precipitation recycling from local to continental scales. Rather than being regarded as a ‘consumer’ of water, vegetation is perhaps more appropriately viewed as a water ‘recycler’. Globally, up to 40% of terrestrial rainfall originates from upwind plant transpiration and other land evaporation, with this source accounting for most of the rainfall in some regions. Land use decisions in one place may, therefore, have significant consequences for water resources, people, the economy and the environment in distant locations – pointing to the limitations of the watershed (as opposed to the ‘precipitationshed’) as the basis for management.

Green infrastructure (for water) uses natural or semi-natural systems such as NBS to

provide water resources management options with benefits that are equivalent or similar to conventional grey (built/physical) water infrastructure. In some situations, nature-based approaches can offer the main or only viable solution (for example, landscape restoration to combat land degradation and desertification), whereas for

different purposes only a grey solution will work (for example supplying water to a household through pipes and taps). In most cases, however, green and grey infrastructure can and should work together. Some of the best examples of the deployment of NBS are where they improve the performance of grey

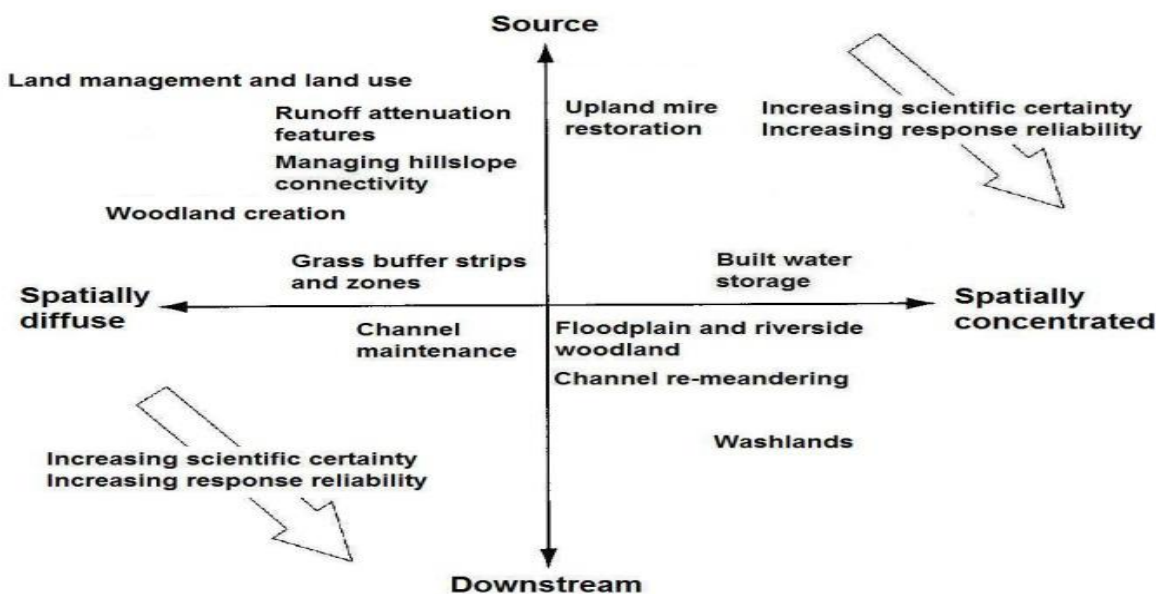


Figure 1: A Catchment-scale Classification of NFM Strategies (UK Parliamentary Office of Science and Technology, 2011).

infrastructure. The current situation, with ageing, inappropriate or insufficient grey infrastructure worldwide, creates opportunities for NBS as innovative solutions that embed perspectives of ecosystem services, enhanced resilience and livelihood considerations in water planning and management.

A key feature of NBS is that they tend to deliver groups of ecosystem services together – even if only one is being targeted by the intervention. Hence, NBS usually offer multiple water-related benefits and often help address water quantity, quality and risks simultaneously. Another key

advantage of NBS is the way in which they contribute to building overall system resilience.

4.2 NBS for Managing Floods

Water-related risks and disasters, such as floods and droughts associated with an increasing temporal variability of water resources due to climate change, result in immense and growing human and economic losses globally. Around 30% of the global population is estimated to reside in areas and regions routinely impacted by either flood or drought events (UN-WWDR, 2018). Ecosystem degradation is the major cause of increasing water-related risks and extremes,

and it reduces the ability to fully realize the potential of NBS.

Green infrastructure can perform significant risk reduction functions. Combining green and grey infrastructure approaches can lead to cost savings and greatly improved overall risk reduction.

NBS for flood management involves water retention by managing infiltration and overland flow, and thereby the hydrological connectivity between system components and the conveyance of water through it, making space for water storage through, for example, floodplains. The concept of 'living with floods', which, among other things, includes a range of structural and non-structural measures that help to 'be prepared' for a flood, can facilitate the application of relevant NBS to reduce flood losses and, most importantly, flood risk.

The potential of natural water storage (particularly subsurface, in aquifers) for disaster risk reduction is far from being realized. Storage planning at river basin and regional scales should consider a portfolio of surface and subsurface storage options (and their combinations) to arrive at the best environmental and economic outcomes in the face of increasing water resources variability.

4.3 NBS Multiple Benefits, Challenges and

Limitations

NBS are able to enhance overall water security by improving water availability and water quality while simultaneously reducing water-related risks and generating additional social, economic and environmental co-benefits. They allow for the identification of win-win outcomes across sectors. For example, NBS in agriculture are becoming mainstream because they deliver increased sustainable agricultural productivity and profitability but also enhance overall system-wide benefits, such as improved water availability and reduced downstream

pollution. Watershed restoration and protection has become increasingly important in the context of meeting multiple challenges in sustaining water supplies to rapidly growing cities and reducing risks in them. Urban green infrastructure can yield positive results in terms of water availability, water quality and flood and drought reduction. In the context of water and sanitation, constructed wetlands for wastewater treatment can be a cost-effective NBS that provides effluent of adequate quality for several non-potable uses, including irrigation, as well as offering additional benefits, including energy production.

Challenges to upscaling NBS so that they reach their full and significant potential are somewhat generic across the sectors and at global, region-specific or place-based scales. There remains a historical inertia against NBS due to the continuing overwhelming dominance of grey infrastructure solutions, from public policy to building codes and regulations. This dominance also exists in civil engineering, market-based economic instruments, the expertise of service providers, and consequently in the minds of policy makers and the general public. These and other factors collectively result in NBS often being perceived to be less efficient than built (grey) systems.

NBS often require cooperation among multiple institutions and stakeholders, which can be difficult to achieve. Current institutional arrangements did not evolve with cooperation in mind. There is a lack of awareness, communication and knowledge at all levels, from communities to regional planners and national policy makers. The situation can be compounded by a lack of understanding of how to integrate green and grey infrastructure at a given scale, and an overall lack of capacity to implement NBS in the context of water. Myths and/or uncertainty remain about the functioning of

natural or green infrastructure, and about what ecosystem services mean in practical terms. There is a lack of technical guidance and tools to determine the right mix of NBS and grey-infrastructure options. The hydrological functions of natural ecosystems, like wetlands and floodplains, are much less understood than those of grey infrastructure. Consequently, NBS are neglected in policy appraisal and in natural resource and development planning and management. This situation is partly due to insufficient research and development in NBS and particularly by the lack of robust assessments of NBS currently in use, especially in terms of their hydrological performance and comparison of their cost-benefit analyses in conjunction with grey solutions.

There are limits to what ecosystems can achieve, for example, ‘tipping points’ beyond which negative ecosystem change becomes irreversible. It is, therefore, necessary to recognize the limits of the carrying capacity of ecosystems and to determine the thresholds where any additional stresses (e.g. the addition of contaminants and toxic substances) will lead to irreversible damage to the ecosystem. The high degree of variation in the impacts of ecosystems on hydrology (depending on ecosystem type or subtype, location and condition, climate and management) cautions to avoid generalized assumptions about NBS. For example, trees can increase or decrease groundwater recharge according to their type, density, location, size and age. Natural systems are dynamic and their roles and impacts change over time. Site-specific knowledge on the field deployment of NBS is essential, and yet often inadequate.

5. Towards the Development of NFM in Nigeria

Creating the enabling conditions for the development of NFM in Nigeria requires appropriate responses to the challenges

discussed above. It will involve enabling the conditions for the approach to be considered equitably alongside other options for water resources/flood management, such as presented below.

Leveraging Financing

NFM does not necessarily require additional financial resources but will involve redirecting and making more effective use of existing financing. Investments in green infrastructure are being mobilized as a result of the increasing recognition of the potential of ecosystem services to provide system-wide solutions that make investments more sustainable and cost-effective over time. Assessments of the returns on investments in NFM often do not factor in the positive externalities, just as those for grey infrastructure often do not take all negative environmental and social externalities into account.

Payment for environmental services schemes provide monetary and non-monetary incentives to upstream communities, farmers and private land owners to protect, restore and conserve natural ecosystems and to adopt sustainable agricultural and other land use practices. These actions generate benefits to downstream water users in the form of water regulation, flood control, and erosion and sediment control, among others, thus ensuring a constant, high-quality water supply, and helping reduce water treatment and equipment maintenance costs. The emerging ‘green bond’ market shows promising potential for mobilizing NFM financing and, notably, demonstrates that NFM can perform well when assessed against rigorous standardized investment performance criteria. The private sector can also be further stimulated and guided to advance NFM in the areas in which it operates. Building in-house expertise and

awareness of the effectiveness of NFM will facilitate this.

Transforming agricultural policy represents a significant pathway for financing the further uptake of NFM. This requires overcoming the fact that the vast majority of agricultural subsidies, and probably the majority of public funding and almost all private sector investment in agricultural research and development, support the intensification of conventional agriculture, which increases water insecurity. Mainstreaming the concept of sustainable ecological intensification of agricultural production, which essentially involves deploying NFM (e.g. improved soil and landscape management techniques), is not only the recognized way forward in order to achieve food security, but would also be a major advance in NFM financing.

Assessing the co-benefits of NFM (through a more holistic cost-benefit analysis) is an essential step in achieving efficient investments and tapping into financial resources across multiple sectors. All benefits, not just a narrow set of hydrological outcomes, need to be factored into an assessment of investment options. This requires a detailed systematic approach that will lead to significant improvements in decision making and overall system performance.

Creating Enabling Regulatory and Legal Frameworks

The current regulatory and legal frameworks for water management were developed largely with grey-infrastructure approaches in mind. Consequently, it can often be challenging to retrofit NFM into these frameworks. However, rather than expecting drastic changes in regulatory regimes, much can be achieved by promoting NFM more effectively through existing frameworks. In places where enabling legislation does not yet exist, identifying where and how NFM

can support grey infrastructure approaches at different scales can be a useful first step in this process.

National legislation to facilitate the implementation of NFM at the local level is particularly crucial. Opportunities for NFM deployment can be created through the harmonization of legislation and policies regarding agriculture, water resources and the environment. At the global level, NFM offers the country a means to respond to and use the various multilateral environmental agreements (especially the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the Ramsar Convention on Wetlands, the Sendai Framework on Disaster Risk Reduction, agreed frameworks for food security and the Paris Agreement on Climate Change), while also addressing economic and social imperatives. An overarching framework for promoting NFM is the 2030 Agenda for Sustainable Development with its Sustainable Development Goals (SDGs). NFM has a high potential to contribute to the achievement of most of the targets of SDG 6 (on water). Areas in which this contribution translates into particularly positive impacts on other SDGs are: water security for underpinning sustainable agriculture (SDG 2, notably Target 2.4), healthy lives (SDG 3), building resilient (water-related) infrastructure (SDG 9), sustainable urban settlements (SDG 11) and disaster risk reduction (SDG 11 and, as related to climate change, SDG 13). The co-benefits of NFM are as related to the ecosystem/environment-related SDGs, including reduction of land use pressures on coastal areas and the oceans (SDG 14) and the protection of ecosystems and biodiversity (SDG 15). Other areas where the co-benefits of NFM facilitate achievement of the SDGs include agriculture; energy; sustainable economic growth; productive employment and decent

work for all; making cities and human settlements safe, resilient and sustainable; ensuring sustainable consumption and production patterns; and combating climate change and its impacts.

Improving cross-sectoral collaboration

NFM requires much greater levels of cross-sectoral and institutional collaboration than grey-infrastructure approaches, particularly when applied at landscape scale. However, this can also open opportunities to bring those groups together under a common approach or agenda. The national policy landscape remains highly fragmented across MDAs. Better harmonization of policies across economic, environmental and social agendas is a general requirement in its own right. NFM is not only a beneficiary of such harmonization but also a means to achieve it, because of its ability to deliver multiple, and often significant, co-benefits beyond just hydrological outcomes. A clear mandate from the highest policy level can significantly accelerate the development of NFM best practices and foster improved intersectoral cooperation.

Improving the knowledge base

Improving the knowledge base on NFM, including in some cases through more rigorous science, is an essential overarching requirement. Established evidence helps convince decision makers of the viability of NFM. For example, a frequently raised concern is that NFM takes a long time to achieve their impact, implying that grey infrastructure is quicker. However, the evidence shows that this is not necessarily the case and timescales to deliver benefits can compare favorably with those of grey-infrastructure solutions. Traditional or local-community knowledge of ecosystem functioning and the nature–society interaction can be a significant asset. Improvements need to be made in the

incorporation of this knowledge into assessments and decision making.

A priority area is to develop and deploy common criteria against which both NFM and other options for water resources/flood management can be assessed. Common general criteria for an assessment of management options (e.g. green versus grey solutions) can be developed on a case-by-case basis. The inclusion of all hydrological benefits, other co-benefits and the entire range of the costs and benefits of ecosystem services for each option is a key requirement. This in turn will require consensus building across the various relevant stakeholder groups.

6. Some Examples of NFM Application

In recent decades urban and agricultural expansion and intensification, often onto historic floodplains, has resulted in the loss of capacity of floodplains to attenuate flooding. Dredging continues on many river channels despite its tendency to exacerbate downstream flooding. Agricultural land use changes have reduced the permeability of soils and increased paving has reduced permeability in urban areas. Drainage and infilling of wetlands has resulted in loss of natural flood water storage basins. Unfortunately, natural flood management is an approach that is virtually unknown in Nigeria and has not been widely discussed in any relevant spheres, despite the growing problem of widespread flood damage in recent years and forecasts of worse to come. Natural flood management has gained recognition in many countries as a viable and cost effective approach to flood risk management, with extensive projects across Europe and further afield that have restored peat bogs, planted riparian woodlands, restored and created new wetlands, re-

profiled rivers and their floodplains to hold back floodwaters (Murray, 2017).

6.1. Peatland Restoration for Flood Attenuation

Blanket bogs in the uplands are made up of wet peat soils which are, in their healthy state, saturated for most of the year. Drainage networks in upland blanket bogs act to lower the water table, hence increasing soil moisture deficit and increase

the water storage potential of these environments (Williams et al., 2012). Healthy peat bogs also attenuate flooding by slowing the movement of surface and sub-surface water from heavy rainfall events because of the rough surface vegetation (Williams et al., 2012). Peatlands with tall woody or coarse vegetation, many small surface depressions and pools and with little surface channel connectivity will tend to hold surface water

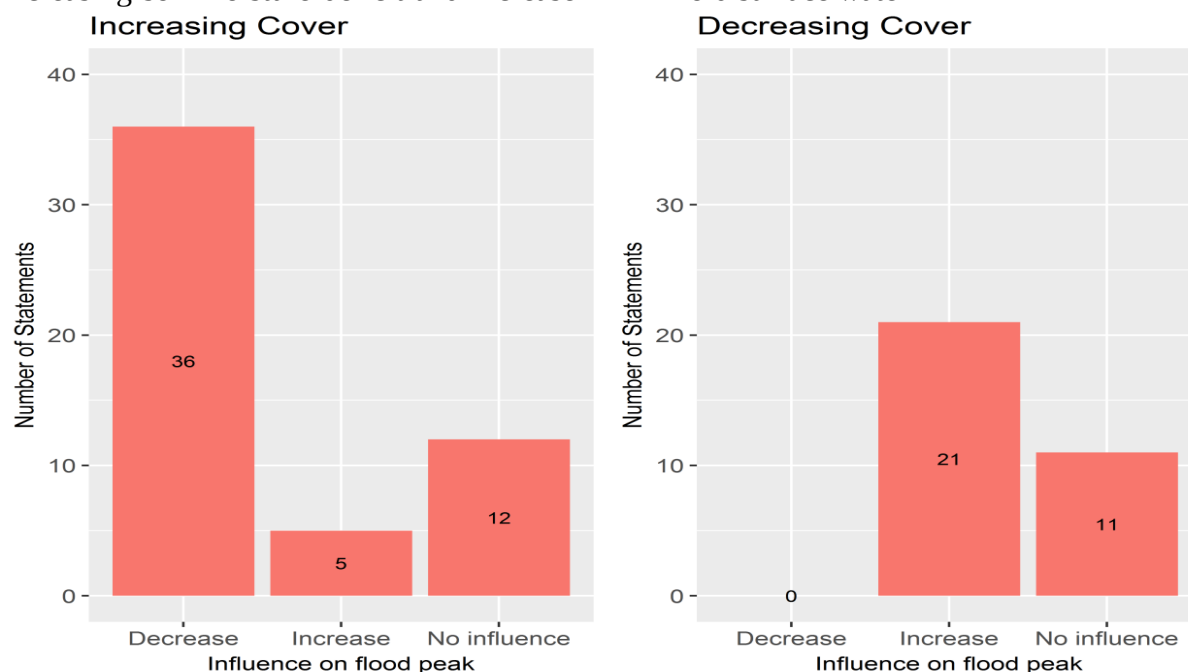


Figure 2: Results of combined analysis of all statements, distinguishing solely on the basis of increasing or decreasing tree cover (Stratford et al., 2017)

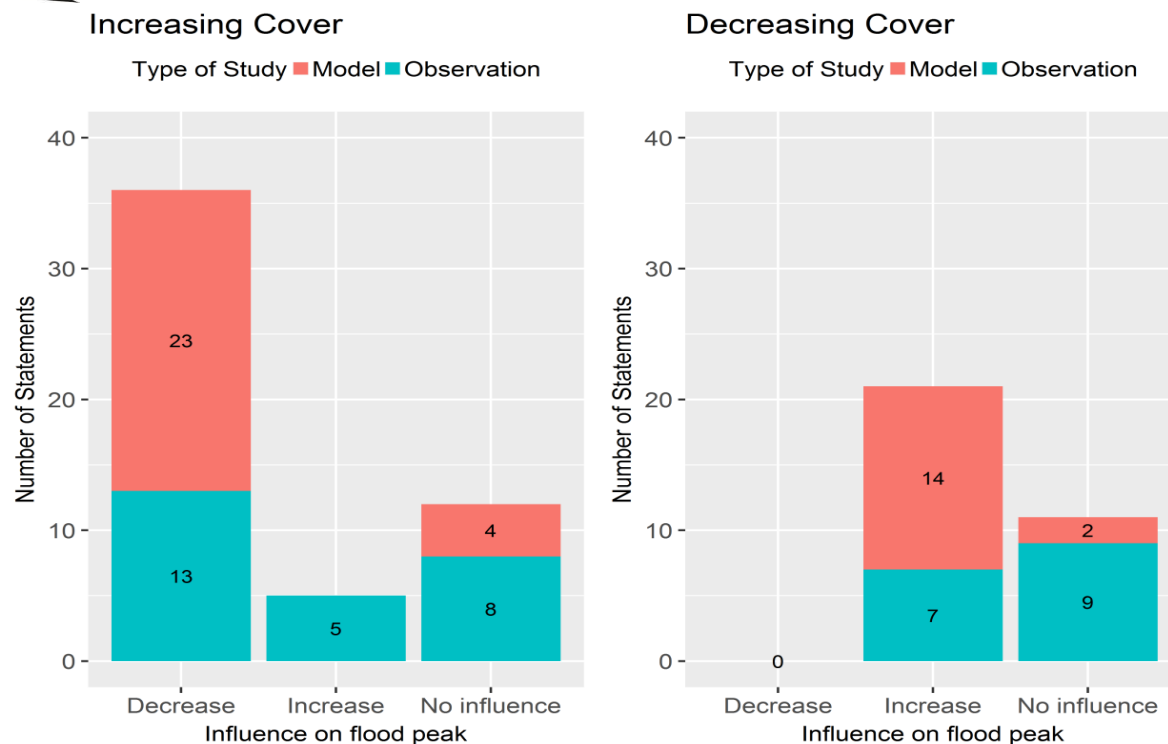


Figure 3: Results of combined analysis of all statements, distinguishing both on the basis of tree cover (observed) and basis of result (modeled) (Stratford et al., 2017)

for longer, so delaying water discharge to downstream channels (Williams et al., 2012). This is a positive impact for reducing flood peak. Raised bogs which occur in lowland landscapes, generally in the middle reaches of a catchment, have a complex relationship with floodwaters. Each wetland has unique hydrological characteristics and the extent to which each attenuates flooding will need to be assessed through detailed measurements and hydrological modeling. While evidence is difficult to collate because of the complexity of landscape scale water movement and variability of such a wide range of factors, and it has been suggested that peatland restoration may not provide significant peak flow benefits during extreme floods, but can improve flood warning times and therefore reduce flood damage (Ballard et al., 2011).

To assess the benefit of peatland restoration at any given site, hydrological modelling followed by implementation of small-scale peatland drain blocking will be necessary.

Understanding small scale alterations to a peatland site will help to understand the dynamics of the bog in its catchment (Ballard et al., 2011; Yorkshire Peat Partnership, 2012).

6.2 Woodland Creation for Flood Attenuation

The Nigerian Forest Commission has to work with the Environmental Agency to implement 'Woodlands for Water' scheme. Landowners should be incentivized with Rural Development Programme (RDP) payments to target planting to reduce flood risk and/or diffuse pollution. This payment for landowners should be additional to the grants offered for afforestation under the national afforestation plans.

6.3 Some Recommendations

In Nigeria, the Forest Service must consider offering an additional payment on top of existing afforestation grants, perhaps via the 'Woodlands for water' scheme; to create woodlands in areas where hydrological data

indicates that flood alleviation benefits would be delivered. In addition, pilot schemes for tree planting for flood alleviation are needed in Nigeria, which incorporate detailed hydrological modeling component. This will also further lend understanding of tree planting for flood alleviation and water quality and help to demystify the approach. Stratford et al. (2017) considered the number of statements regarding the influence of trees on river floods. The results of those analyses are presented in the Figures 2 and 3 below. From the figures, it can be seen that the effect of increasing tree cover is to decrease flood peaks, thus a decrease in tree cover will increase flood peaks.

7. Conclusion

As mankind charts its course through the Anthropocene, and tries to avoid the tragedies of the past, adopting NFM is not only necessary for improving water management outcomes and achieving water security, it is also crucial to ensuring that the co-benefits which are essential to all aspects of sustainable development are delivered. NFM will play a major role in water management in the future. The key issues are summarized below:

- Ecological processes driven by vegetation and soils in forests, grasslands, wetlands, as well as in agricultural and urban landscapes, play a major role in the movement, storage and transformation of water.
- Nature-based solutions (NBS) use or mimic natural processes to enhance water availability (e.g., soil moisture retention, groundwater recharge), improve water quality (e.g., natural and constructed wetlands, riparian buffer strips), and reduce risks associated with water-related disasters and climate change (e.g., floodplain restoration, green roofs).

- NBS offer significant potential to address contemporary water management challenges across all sectors, and particularly regarding sustainable agriculture and sustainable cities.
- NBS contribute to reversing trends in ecosystem degradation, a major cause of water problems worldwide.
- NBS are essential to achieving the water-related Goals and Targets of the 2030 Agenda for Sustainable Development and directly contribute to meeting several other interdependent Goals and Targets.
- NBS generate social, economic and environmental co-benefits, including human health and livelihoods, food and energy security, sustainable economic growth, decent jobs, ecosystem rehabilitation and maintenance, and biodiversity.
- NBS include green infrastructure that can substitute, augment or work in parallel with built (grey) infrastructure in a cost-effective manner, providing alternative options for coping with insufficient or ageing water infrastructure while improving system-wide resilience and performance.
- NBS, like grey infrastructure, have limits: they are not a panacea but must be evaluated and deployed based on locally specific conditions.
- Water management remains heavily dominated by grey infrastructure, such that the considerable potential for NBS is largely under-utilized. The objective is to find the most appropriate balance between green and grey infrastructure that maximizes benefits and system efficiency while minimizing costs and trade-offs.
- There are emerging innovative options for financing NBS, such as

payment for ecosystem services schemes and green bonds. The substantial value of the co-benefits from NBS can tip investment decisions in their favor.

Sustainable water security will not be achieved through business-as-usual, and Natural Flood Management (NFM) provides an essential means of moving beyond conventional approaches. However, adopting new ideas or approaches is often quite challenging. This study indicates that NFM application in Nigeria is feasible. The study also shows that nature can help or support efforts to reduce the challenges of flood disasters and climate change impacts, which in turn saves costs and conserves the environment.

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