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Policy Brief

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Remote Sensing for Flood Management in Urban Africa

Benefits, Challenges and Potential Solutions

⇒ **In African cities, flood risk is rising** due to increasing urbanisation, land-use change and global warming.

⇒ **Simultaneously, Africa's urban population is among the fastest-growing in the world** and is expected to rise to 1.5 billion by 2050.

⇒ **Space-based technologies such as remote sensing can support flood risk reduction and mitigation** by providing reliable, near real-time data of large areas.

⇒ **Local capacity-building such as training of local experts is crucial** to effectively apply space-based technologies for flood management.

⇒ **Intergovernmental cooperation is needed to ensure capacity-building and sustainability** of knowledge transfer and continuous access to high quality satellite data.

What's the Issue?

Floodplains supply many of the key natural resources for a vast share of the world population. However, floods turn into hazards when human lives and infrastructures are negatively affected. The more frequent floods occur, the higher the potential negative effects. Global warming exerts increasing pressure on eco- and hydrological systems leading to more frequent and more severe events such as extreme precipitation or extreme coastal high water. The number of disastrous floods has increased all around the globe. In Africa, the number of recorded floods quadrupled between 1980 and 2006, claiming the most lives with over 45% of the global water-related disaster fatalities.

Especially in cities, climate change alongside urbanisation and land-use change leads to exacerbated flood risks. This results from a variety of factors such as an increase of impervious surfaces, the disappearance of green areas, reduced water infiltration, insufficient drainage, inappropriate waste management, scarce development and built environments along floodplains in waterways or reclaimed wetlands.

Space-based technologies hold a multitude of opportunities for effective flood management considering the multi-dimensional character of urban floods. Remote sensing data facilitates forecasting, mapping and assessing floods, providing crucial information used for planning, monitoring and responding to flood events. However, a general lack of local capacities and data access are observed, when applying the technology in some African countries.

Why is This Important?

The African continent is considered one of the most vulnerable regions to the negative effects of the climate crisis. Simultaneously, Africa's urban population is among the fastest-growing worldwide. By 2050, it is expected to increase from 548 million (2018) to 1.5 billion urban inhabitants – representing almost 60% of the predicted population in Africa.

The increasing occurrence of floods puts millions of lives at risk. Effective flood prevention, preparedness, response and recovery can save lives, prevent injuries and ill-health and damages. Successful flood management can thus improve and contribute to sustainability in all three pillars of sustainability, promoting social, economic and environmental resilience well-being.

Climate change and natural hazards are non-trivial issues with multidimensional causes. Urban vulnerabilities i.a. result from inequalities, poverty, insecurity or lack of development in rural areas. Improving the application conditions for satellite remote sensing can thus result in more effective flood management, advancing civil protection, mitigating displacement and reducing infrastructure damage and financial loss.

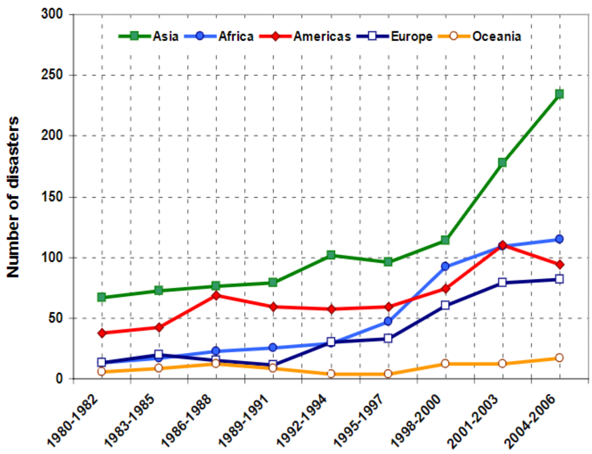

Fig. 1. Recorded numbers of floods by region 1980 - 2006. Source: (Adikari and Yoshitani, 2009, 10)

What Should Policy-Makers Do?

Effective flood risk management can be supported by the use of space-based technologies throughout the whole disaster management cycle of prevention, preparedness, response and recovery. Satellite remote sensing provides comprehensive coverage of large areas in near real-time. The high data reliability as well as the absence of geographical constraints, such as site accessibility, emphasise the technology's potential in the field. The provided data contributes to flood risk reduction and mitigation efforts as well as to humanitarian action in the form of rapid flood mapping.
To enable a frictionless use of satellite remote sensing, decision-makers shall enact policies that promote awareness-raising, focus on prevention, boost capacity-building, and encourage international cooperation.

Awareness-Raising

Insufficient awareness about the space sector and its impact on society poses a significant drawback for the development and deployment of respective technical tools. In order to enhance public acceptance, thus improving the effective and efficient use of space-based information, it is important to raise awareness on several levels. This includes the general public, but also institutional and governmental entities. A broader perception of the significance of remote sensing technologies for disaster risk reduction and emergency response might ideally increase the application of these technologies and result in respective developments.

Capacity-Building

For flood management projects to have a sustainably positive impact, knowledge transfer to local actors is required as well as ensuring that technical capacities remain available after a project's expiration.
Local expertise allows putting space-based data into context by linking the data to geographical, social and economic particularities. Thus, building capacity and providing disaster managers with a basic understanding of advantages and limitations associated with space-based information is necessary to sustainably leverage the benefits of satellite remote sensing.
Still, local ownership can only be ensured if data access as well as the necessary technical and financial resources are secured. Implementing and enhancing technical infrastructure should be considered a continuous priority in order to strengthen long-term and self-sufficient flood risk management across the African continent.

Focus on Prevention

The majority of efforts from the space community addresses humanitarian response by providing and further optimising the accuracy of flood extent maps. However, a strong focus on preventive measures is essential for sustainable long-term flood risk management. Space-based technologies allow forecasting and identifying zones that are exposed to an increased flood risk due to their topological and geographic characteristics before disasters strike. These analyses provide a quantitative basis for land-use policies and enforced building codes. Hence, the results support resilient urban planning, mitigate displacement and harm of society, and reduce damage of infrastructure and financial loss.
Since the resolution of publicly available digital elevation models or donated data is often insufficient for this matter, data access and technical resources for processing and hydrological modelling represent limiting factors.

Multi-Stakeholder Cooperation

Climate change and natural hazards are non-trivial issues with multidimensional causes. Urban vulnerabilities i.a. result from inequalities, poverty, insecurity or lack of development in rural areas.
In this context, innovative forms of collaboration allow transcending the barriers of lacking capacity-building, access to data and to technical resources for using earth observation tools for flood risk management in cities across the African continent.
However, to ensure effective partnerships, a clear analysis of different stakeholders and their interests needs to be undertaken in order to understand which forms of collaboration allow the most impact.
As an area of improvement, engaging in collaborations with privately held companies was identified. Especially, implementing data-sharing policies could support disaster management agencies in accessing remote sensing data of private companies with higher spatial and temporal resolution. This also applies to cloud computing-based resources to allow rapid mapping during humanitarian emergencies.

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Space-Based Technologies for Effective Flood Management in Urban Africa: Benefits, Challenges and Potential Solutions

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ABSTRACT

Global warming exerts increasing pressure on hydrological systems leading to more frequent and more severe natural hazards such as floods. Especially in cities, climate change alongside increasing urbanisation and land-use change exacerbate flood risks. The African continent is considered one of the most vulnerable regions to the negative effects of the climate crisis. Simultaneously, Africa's urban population is among the fastest-growing in the world and is expected to rise to 1.5 billion urban inhabitants by 2050. Space-based technologies are vital tools in the context of hazard management and urban development. Satellite remote sensing provides comprehensive information coverage of large areas in near real-time. The high data reliability as well as the absence of geographical constraints, such as site accessibility, emphasise the technology's potential in the field. The provided data contributes to flood risk reduction and mitigation efforts as well as to humanitarian action in the form of rapid flood mapping. This paper investigates the role of satellite remote sensing with regard to flood risk management in African cities. Considering the UN75 initiative promoting communication and dialogue, a qualitative study was conducted with subject matter experts from UN entities, (inter-) governmental institutions, academia and the private sector. The interview partners highlighted the multi-dimensional character of urban floods and multiple opportunities offered by earth observation tools. However, a general lack of capacities was stressed so as to leverage the scope of satellite remote sensing - particularly when addressing long-term flood prevention. Prospective forms of cooperation were advocated as possible solutions to make more effective use of the technology's potential.

1 Introduction

Global warming exerts increasing pressure on ecosystems including the hydrological cycle, leading to globally more frequent and more severe events such as extreme precipitation or extreme coastal high water (IPCC, 2012). The continent of Africa is considered one of the most vulnerable regions to climate change risks (Filho et al., 2018). Due to land-use change, climate change and urbanisation, cities in particular are at risk of multiple hydro-meteorological hazards such as floods and droughts. Pluvial floods resulting from high-intensity precipitation are increasingly likely in urban areas and are expected to become more frequent in the upcoming decades (Breinl et al., 2017). Simultaneously, Africa's urban population is among the fastest-growing in the world. By 2050, it is expected to increase from 548 million (2018) to 1.5 billion urban inhabitants (United Nations, 2019, 23).

To reduce the negative effects of these hazards in urban communities, flood risk management is critical. Efficient flood risk management can be supported by the application of space-based technologies throughout the whole disaster management cycle of prevention, preparedness, response and recovery (IPCC, 2012). The provided data enable forecasting, mapping and assessing floods, representing crucial information used for planning, monitoring and responding to flood events (UNESCO, 2020).

The United Nations Office for Outer Space Affairs (UNOOSA) aims at supporting *"[...] developing countries to use all types of space-based information in all phases of the disaster management cycle [...]"* (United Nations, 2007) with the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER).

Research Question and Motivation

Coherently with the UN75 initiative to encourage UN-internal and -external dialogues (United Nations, 2020), the need has been identified for exchanging perspectives, experiences and solutions in the matter of space-based flood management in urban Africa. Based on these observations, this paper seeks to answer the following research questions:

(i) How are space-based technologies used to identify flood risks in urban Africa?
(ii) What further potentials can be identified?

This paper aims to investigate how satellite remote sensing is currently contributing to flood-risk management. The interest includes the benefits of its application, the challenges faced, possible solutions at hand as well as further potentials in the field. The conducted interviews and results shall contribute to four global priority engagement areas: the United Nations 2030 Agenda for Sustainable Development, the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the UN75 initiative on building bridges and fostering exchange between UN- as well as non-UN-organisations.

2 Context and Framework

The following chapter allows a brief introduction to the field of interest's status quo in the structure of i) floods, ii) cities and urbanisation, iii) space-based technologies and iv) international frameworks and UN involvement.

2.1 Floods

Floodplains are natural appearance and part of the water cycle that supply a number of critical natural resources for a vast share of the world population (WMO, 2009, 3). Floods turn into risks when human life and infrastructures are negatively affected. The more frequent floods become in inhabited locations, the higher the potential adverse effects. In the last decades, flood events have become more and more frequent all over the globe as shown by Fig. 1. In Africa, the number of floods quadrupled between 1980 and 2006. Since 1900, floods, droughts and windstorms accounted for almost 90% of the thousand most disastrous events. Flood disasters on the African continent claimed the most lives with over 45% of the global water-related disaster fatalities, even though over 80% of flood-related events took place in Asia (Adikari and Yoshitani, 2009).

The multiple hydro-meteorological disasters include several types of floods such as a) fluvial floods occurring as river floods through excessive rainfalls, b) coastal floods caused by sea-level rise or storm surges, c) pluvial floods resulting from high-intensity precipitation, d) flooding from overflowing channels and drains and e) groundwater flooding from subsurface to ground levels (Breinl et al., 2017; Douglas, 2017; Salami et al., 2017). Global warming, land-use change and urbanisation have significantly exacerbated the risk of and vulnerability to water-related hazards in cities.

Floods are associated with impoverishment, insecurity and ill health as they can cause death, damages to both public and private properties, erasing houses and workplaces. In African cities, the lower-income population is especially exposed to pluvial floods (Douglas, 2017). Pluvial floods in particular are expected to become more frequent in urban areas due to climate change, high densification, impervious surfaces and inadequate drainage (Breinl et al., 2017). Furthermore, this flood type is highly volatile in time and space making it more difficult to predict (Miller and Hutchins, 2017). The increased exposure in local cities results from the tendency of living in poor housing conditions, working on the streets and possessing less resources to compensate for flood-related damages (Cobbinah and Kosoe, 2019; Falconer et al., 2009).

Urbanisation, as well as unorganised informal settlement in and around cities, can significantly increase the local flood risk. This may be induced by a variety of factors such as an increase of impervious surfaces, the disappearance of green areas, reduced water infiltration, insufficient drainage, inappropriate waste management, scarce development and built environments along floodplains in waterways or reclaimed wetlands. (Pauleit et al., 2015; Amoako and Inkoom, 2018; Nkwunonwo et al., 2020).

2.2 Cities and Urbanisation

In the scientific community, there are no internationally agreed-upon and standardised definitions of the terms *"city"* and *"urban area"* (Weisz and Steinberger, 2010, 185). In this paper, cities are considered as places of agglomeration and concentration, as places where large numbers of people live and work. We understand cities as locations of large linear metabolisms with high flows of energy and materials. We consider them to be spe-

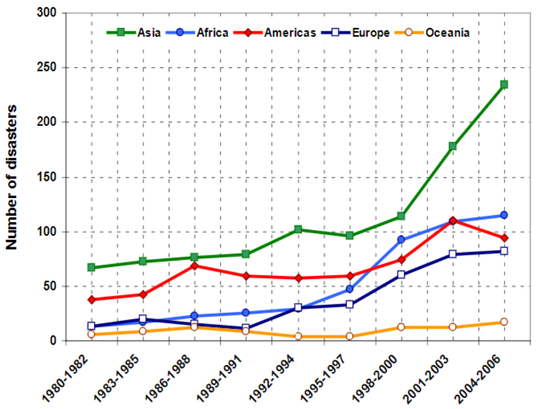

Fig. 1. Recorded numbers of floods by region 1980 - 2006. Source: Adikari and Yoshitani (2009, 10)

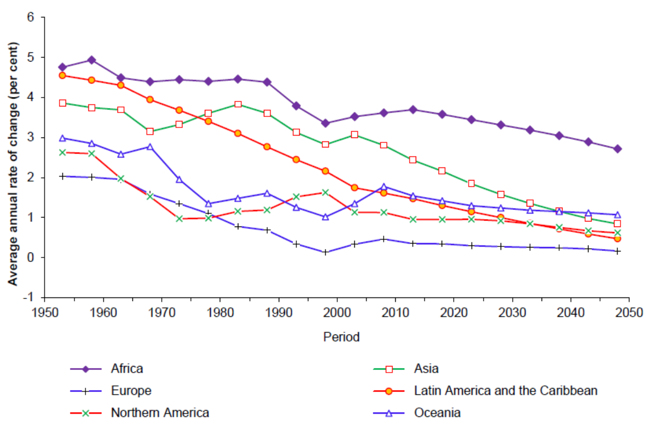

Fig. 2. Average annual rate of change of the urban population by region 1950 - 2050. Source: United Nations (2019, 24)

cialised in production, transformation and consumption rather than in resource extraction (Kennedy et al., 2011, 1). As a result, cities rely on their hinterlands for the provision of goods, resources and services (Weisz and Steinberger, 2010, 185). Simultaneously, increasing urbanisation evokes a dilemma: fertile lands are sealed and transformed into urban areas, reducing hinterland provision (Siedentop, 2015, 17). Acknowledging the disparity of the two terms *"city"* and *"urban area"*, they are used synonymously in this paper for the means of simplification.

Between 1950 and 2050, Africa's urban population has been and is projected to remain the fastest-growing of all continents (see Fig. 2). This urbanisation trend is expected to apply to all of the continent's 58 countries (United Nations, 2019, 35). As Fig. 3 indicates, many of the African cities increased tenfold between 1950 and 2015. The five largest urban areas in Africa are four global hubs for business, media and policy making in Cairo, Lagos, Johannesburg and Kinshasa. It is notable that most urban areas across Africa are located along the coastal line, making them especially vulnerable to coastal flooding and erosion. The South-West African Club region is distinctly the area with the highest number of urban agglomerations and simultaneously is home to the highest number of people living in such agglomerations, mostly along the coast (OECD and SWAC, 2018).

According to UN-HABITAT, *"[...] African urbanism needs to be rethought 'from the slums', as that is where the majority of urban dwellers live [...]"* (UN Habitat, 2015, 43).

2.3 Space-Based Technologies

Space-based technologies are vital tools in the context of hazard management and urban development. This particularly refers to the use of remote sensing technologies due to their capability to efficiently provide comprehensive coverage of large areas in near real-time with high reliability of data acquisition and immunity to geographical constraints such as site accessibility (Kitsikoudis et al., 2020; Biancamaria et al., 2011).

Satellite remote sensing has become a central element in disaster risk management [DRM] effort since the breakthrough development of meteorological forecasts based on the TIROS-1 satellite in the early 1960s. A better understanding and increased monitoring capabilities enabled improved prediction of meteorological hazards (Le Cozannet et al., 2020, 1210).

This paper focuses on the use of remote sensing which NASA (2020) defines as the *"[...] technology of acquiring data and information about an object or phenomena by a device that is not in physical contact with it. In other words, remote sensing refers to gathering information about the Earth and its environment from a distance, a critical capability of the Earth Observing System"*. In the context of flooding, satellite remote sensing provides valuable information regarding forecasts, emergency mapping and damage assessment (Refice et al., 2018; Jeyaseelan, 2004).

2.4 International Frameworks and UN Involvement

The UN's Sustainable Development Goals (SDGs) define a clear vision on climate action (SDG 13) and building sustainable cities and communities (SDG 11). By adopting the Sendai Framework for Disaster Risk Reduction in 2015, the United Nations take a crucial role in decreasing urban hazards like floods in a global context. The Sendai Framework is the successor instrument to the Hyogo Framework for Action and provides a foundation *"to prevent and reduce disaster risk through the implementation of integrated and inclusive [...] measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery and thus strengthen resilience."* (UNDRR (former UNISDR), 2015).

Since then, several international initiatives further addressed the use of space-based disaster information and services, namely the Group on Earth Observations, the International Charter Space and Major Disasters, the European Union's Copernicus programme, the Japanese supported Sentinel-Asia, or the GMES and Africa programme of the African Union Commission.

In the General Assembly resolution 61/110 from 2007, the United Nations emphasised the need for *"[...] enhancing international coordination at the global level in disaster management and emergency response through greater access to [...] space-based services"* (United Nations, 2007, 1) Consequently, the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) was established. Its aim is *"[...] to provide universal access [...] to all types of space-based in-*

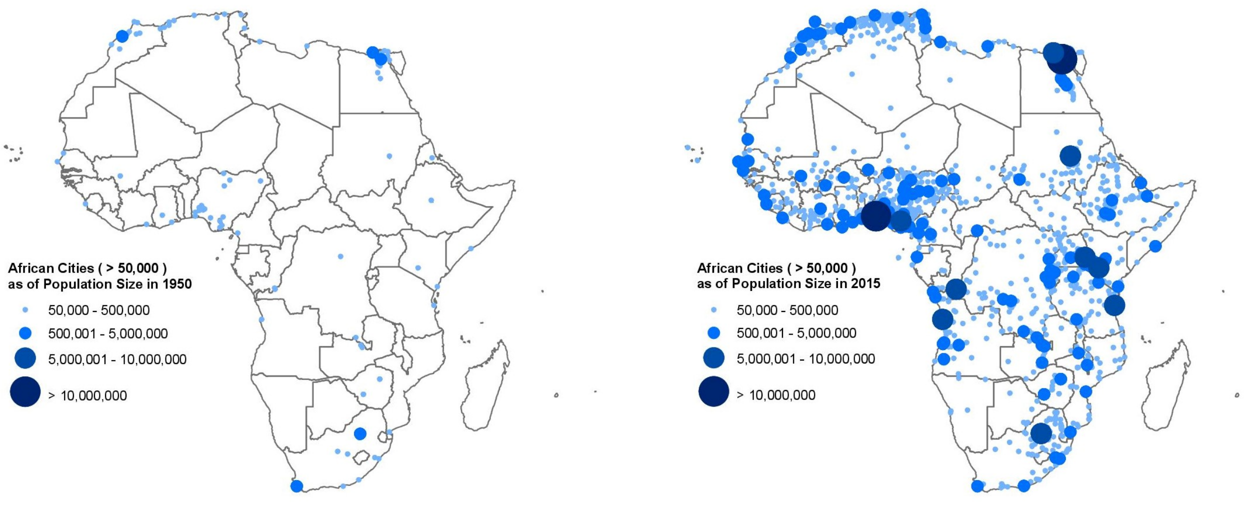

Fig. 3. Development of African cities' population size in 1950 and in 2015. The depicted cities count at least 50,000 citizens. In 1950, Cairo, Egypt, was the continent's biggest city with over 2.5 million inhabitants. 65 years later, it is home to almost 23 million, remaining Africa's biggest city in terms of population. The second most populated city in 1950 was Alexandria, Egypt, counting approximately 1 million citizens. Second place in 2015 scored Lagos, Nigeria, with almost 12 million inhabitants. Image Source: Own illustration. Data Sources: ESRI et al (2018); OECD and SWAC (2018)

formation and services relevant to disaster management to support the full disaster management cycle [...]" (UNOOSA, 2020c). UN-SPIDER facilitates capacity-building and institutional strengthening in particular for so-called developing countries by serving as a bridge connecting disaster management and space communities (United Nations, 2007).

In case of emergency situations arising from natural hazards, mechanisms such as the International Charter Space and Major Disasters or the European Union's Copernicus Emergency Management Service (EMS) can be activated to provide countries with geospatial information within hours or days after service request.

3 Methodology

This study aims to identify areas of improvement and further potentials of the use of satellite remote sensing in UN-connected flood risk projects in urban Africa.

As the field of interest mainly involves two aspects, i) the status quo and ii) the possible gaps and further potentials, we conducted a literature review in combination with qualitative interviews. Firstly, the literature review provided for status quo knowledge and for the interview guide's questionnaire. Secondly, semi-structured interviews with experts of various backgrounds allow the provision of a holistic perspective. The questionnaire guideline ensures the inclusion of all research-relevant topics and simultaneously permitted a certain level of comparability among the individual interviews. The format allowed for an open range of answers, aspects, levels and spheres in the topic's nexus, wider than could have been achieved with a closed quantitative approach (Mey and Mruck, 2007; Jandura et al., 2011).

The study's sampling included subject matter experts of different professional and organisational backgrounds and nationalities. Interview partners held knowledge and experience in the fields of space-based technologies, floods and hydrology as well as in DRM and urban planning. In total, nine interviews were conducted with one female and eight male experts. In spite of the efforts made, we did not succeed in balancing the interviews' gender ratio. The contacts to the interview partners were established through partners at UNOOSA and involved UN staff as well as non-UN staff. Table 1 shows an overview of the interviewee's background organisations. These UN- and non-UN organisations have been selected due to the link to their field of work and the research subject and the availability of contacts. Employees of UN-organisations shared relevant knowledge and experience from within the UN-nexus, that is, allowing a reflection on challenges and potential solutions in the said field. Employees of non-UN-organisations, such as governmental institutions, UN-consultants from academia or the private sector, shared their perspective on what is and could be done from their point of view.

The collected data was then interpreted by applying a qualitative content analysis, a reductive approach. Its structured character aims to decrease subjective biases during interpretation (Mayring, 2008). The questionnaire guideline can be found in the appendix.

As a transdisciplinary research team based in Austria and Germany, we do not claim a neutral stance towards the questions asked and the way we analysed the interviews. As we are aware, our personal socialisation in the so-called Global North influences our perspective; a geographical as well as social distance exists towards the research subject at hand. During the entire research process, we endeavoured to incorporate a self-reflexive stance to decrease the existing biases towards the research subject.

4 Results

The following chapter presents the findings drawn from the conducted expert interviews. The results are structured and elaborated in three sections: the benefits of remote sensing for flood management in urban Africa (4.1), the challenges and difficulties faced during its application (4.2) and possible solutions to transcend said barriers (4.3).

4.1 Benefits

Space-based technologies have emerged in our everyday life and proven crucial for many day-to-day practices - from communication satellites transmitting messages to remote villages, to satellite navigation and positioning, to remotely measured climate data and warning systems about immediate hazards and threats. Remote sensing allows a deeper understanding of the climate crisis by providing vital information on the development and effects of global warming as well as feeding into the climate essential variable (ECVs) (Bojinski et al., 2014). The additional, accurate and near real-time data collected make reports more precise and actionable (I3).

Data Provision for Flood Disaster Mitigation

"Space-based technology immensely contributes to the response, [and] the management of the flood greatly [sic!]" (Interviewee 6, I6)

Remote sensing allows imaging earth in different frequency and spatial resolution ranges - from every week to multiple times a day, from low to high spatial resolution. It enables a synoptic view of larger areas. In case of emergency, not only *"cutting edge output"* (I9) but already *"lower quality tools"* (I9) can provide relevant insights. In the context of floods, space-borne data informs and facilitates monitoring the volume and flow of water in near real-time and in advance. Due to the high frequency and wide surface coverage, interview partners stressed remote sensing's massive application potential in fast-paced changing environments as is applicable in many African cities prone to floods. Earth observation increasingly used by governmental disaster management agencies, UN and UN-sub organisations such as the World Bank as both frequency and resolution have improved within the last decades.

In addition, interviewees emphasised the technology's potential in areas, where data is scarce and/or difficult to collect. They highlighted a clear lack of data in some African countries (see 4.2). When there is no or only little ground data to work with, remote sensing provides the only source of quantifiable and highly reliable data. Rather than the physical observatories on the spot (I7), much of today's data collection depends on the spatial input as the satellite data provides *"full coverage"* (I8). Interviewees reported

Table 1. Interview partners' employers.

UN Organisations	Governmental Organisations	Private Corporation / Academia
UNOOSA/UN-SPIDER	African Union Commission	Planet Labs Inc.
UNESCO	National Disaster Management Organization, Ghana	University of Salzburg
World Bank	National Space Research and Development Agency, Nigeria	Fraunhofer Institute

that even though ground data is still needed for verification, the dependency on it has declined.

"There is a clear lack of availability of data. So the only option for us [is] to use the satellite images, the satellite technology. [...] Whether you like it or not, I mean, we have to use this, if you want to have reliable data, quantifiable data, to do any kind of analysis." (I8)

Interview partners confirmed the availability of *"many"* (I7) geospatial tools. As an example, in the event of a flood, a national space agency provides up-to-date maps of the flooded areas for the national emergency management agency. These satellite maps support emergency response activities, such as the positioning of helpers and planning the harvest in the city's hinterlands.

"It's just fantastic! As a user it just couldn't be better to have that [satellite] infrastructure in place!" (I7)

Data for Flood Prevention and Forecasting

Remote sensing is a tool used for further studies and analytical work such as models and predictions. As an example, collected climate information contributes to developing weather scenarios which then support experts and decision-makers in assessing risk levels in different areas. Working with predictions and models requires data of considerable quantity and quality which can be provided by satellite remote sensing technologies. Thus, remote sensing is highly relevant for climate change mitigation and adaptation in urban areas.

The generated detailed models enable the detection of a city's districts with the highest and lowest flood risks as a basis for sustainable urban planning. On the one hand, space-borne information is essential for assessing a city's topography. The data acquired allows developing detailed Digital Elevation Models (DEM) of the observed area. The DEMs contain information about highlands and lowlands, that in combination with surface condition information and hydrological modelling indicate which areas are likely to be flooded in the future.

On the other hand, remote sensing increased understanding of the current state of local urbanisation, enabling the tracking of urban development and population movements. High spatial and temporal resolution assists in visualising new buildings and can also give volumetric information, such as the height of construction referring to the quality of a building. The overlay shows the relation of the locations with increased flood risk, the number of citizens in danger and the type of infrastructure affected. The findings then present opportunities for safer land-use practices and urban planning, within and outside of the city. Consequently, land-use policies can be derived that minimise flooding during extreme events.

In addition, remote diagnostics can be particularly powerful when thinking outside of the box. It enables measuring several indicators indirectly by monitoring other factors aside from *"traditional"* (I7) approaches. As an example, an interviewee shared the experience of successfully measuring population movements in data-scarce environments by using night light intensity data instead of *"traditional"* approaches such as household surveys. Such work-around techniques could also be supportive when collecting data for flood mitigation and prevention.

"[Measuring related indicators with remote sensing] makes you wonder why you didn't do it earlier!" (I7)

"[Remote sensing can be used] to understand how risk has been growing over the decades. If there's something that's good about the space community, [it] is the archive imagery over decades that helps understand how exposure has been growing over the years, particularly in urban areas and in areas exposed to hazards. So understanding risk, how it has changed, is one of those things that we can get from satellite imagery." (I4)

Satellite imagery is considered vital for the establishment of early warning systems. In the near term, precipitation estimations and weather state reports allow the prediction of shortly upcoming extreme weather events such as heavy rainfall in specific areas. In the long term, space-based observation can help to identify the location and composition of flood-prone and vulnerable cities and districts. The information provided can contain road conditions, housing types, ground levels, location of construction and commercial activities and accommodation as well as trend indicators of the city's general urban development. The space-borne data is used to calculate probabilities and possibilities to redirect the water or divert the population living in the threatened areas. The DEMs then provide information that can serve as a base for potential migration recommendations to other less, flood-prone districts in order to geographically avoid floods in the long run. This space-born data analysis can result in understanding where residential areas overlap with floods and where public services are needed.

Satellite remote sensing allows global access to local information unaffected by site accessibility. This absence of geographical constraints allows stakeholders to identify and deal with issues originating in neighbouring countries. As an example, high-resolution satellite imagery enables monitoring of the water level of potentially endangering dams in neighbouring areas.

Financial Scope

When it comes to the financial component, satellite remote sensing was described in varying spot-lights. Some interview partners stressed how the application of space-based technologies can reduce costs as they allow preventive actions which are usually considered cheaper than damage repair. Others stated that even though the financial benefits are recognised, they do not exceed the advantages of speed and availability of data collection.

"I think speed and accessibility and availability [of the data] are as important, so I wouldn't just do a cost-based argument" (I7)

Nevertheless, many interviewees stressed how the financial factor in general poses challenges to some countries in Africa. This issue along with other challenges faced when applying satellite remote sensing for flood management in African cities is further elaborated in the following paragraphs.

4.2 Challenges

"[. . .] particularly in the context of urban floods in Africa [. . .] the technology is there and the information, the services, but it could be definitely much more used, integrated and taken up [. . .]." (I1)

As addressed in the previous sub-chapter, space-based information provides opportunities when tackling disaster risks. Nevertheless, interview partners noted that remote sensing data is not as much integrated into projects involving flood management as it could be. Interviewees pointed towards the benefits of more African countries being actively involved in this area since so far only fourteen of fifty-four African countries host national space agencies (Space in Africa, 2020). Interview partners identified the reasons for not fully streamlining space-based technologies as follows.

Multi-Dimensional Flood Risk Assessment

Floods are highly complex events and take place all over the globe. In most African cities they occur in different scopes and with varying impacts. The reasons and effects of floods involve a multiplicity of components and cannot be reduced to one or two indicators. In this context, earth observation data is useful due to the additional information provided, which can then feed into indicators that allow measuring the effects of floods. However, there are numerous reasons for urban floods and their varying negative effects - from blocked or insufficient drainage to not abiding by or lacking building codes and land-use policies. To address these issues, space-based technologies can only partially assist. Additionally, hydrological, political, social and economic factors must be considered in plans and considerations. As an example, people who newly migrate from the countryside to cities might settle in risk zones, disregarding flood security and driven by poverty and general insecurity. Furthermore, defining flood-risk-areas may lead to conflicts arising and ceasing development of the respective areas due to decreasing property values.

Lacking Awareness

"And given the fact that floods is [sic!] a major problem within the country, we have tried as much as we can to demonstrate how space technology can be used to address that." (I2)

A lack of awareness has been identified as one of the key reasons why space-based technology is underused. Often, people are not aware of the existence or features of the technology and their benefits in the climate hazard prevention sector. Also, as stated by some interviewees, in some countries the environmental management agencies do not prioritise issues such as climate change, waste management and blocked drainage. To an extent, they depend on the citizens to focus on these issues, which interviewees report as not being the case.

Flooding issues lack political priority and areas that are flood-prone are not high up on the political agenda. This lack of political awareness prevents any kind of long term change. The awareness of policy and decision-makers was especially stressed. Interviewees claimed that policy-makers are often not aware of how space-based technologies could benefit different government agencies. One of the interview partners explicitly wished for more awareness from the side of the so-called developed countries. *"People from the developed nations could try to appreciate what [...] many underdeveloped countries are facing"* (I8).

Once an area has been identified as likely to be flooded, the local communities need to be informed and convinced to relocate in order to prevent disasters. This task has been described as highly challenging and requires raised awareness in the general population as well as effective communication.

Access to Data and Funds

"Generally, accessing knowledge can be a challenge, not only in the case of earth observation data, but also limited access to journal papers, networks..." (I1)

For successful flood management in urban territories, it is necessary to have access to appropriate and relevant remote sensing data. High-resolution imagery and software offered by the private sector can be too expensive for many African countries and software requires specialised knowledge. To overcome this barrier, a number of projects start focusing on open source solutions. However, these are often not pre-processed and of lower resolution which hinders successful flood management in urban contexts.

To install effective flood-forecasting and preventive measures, high-resolution DEMs in combination with hydrological modelling are necessary. The open-source data available through the European Union's Copernicus programme, for example, deliver extensive output on a large scale. However, for local urban case studies, its resolution is too low. Also, due to the high number of clouds in tropical areas, optical sensors do not produce relevant outputs for flood mapping in many of these areas. To detect ground information through clouds, Synthetic Aperture Radar (SAR) sensors are necessary. There again, some more remote areas might not be covered in high resolution. In addition, uneven surfaces and double bounce backscatter amplify the complexity of flood mapping in urban areas. Thus, accessing the relevant data for effective flood mapping and preventive measures presents a challenge in the African context.

The price satellite data should or can have is a debated subject. Furthermore, policy legislation to regulate the sharing of data (national spatial data infrastructure, SDI or NSDI) is lacking and therefore, data sharing sometimes does not work. One interview partner wishes for more countries to get access to the relevant kind of data. In contrast, a different interview partner did not perceive restrictions in the accessibility of data and was referring to the high amount of public engagement from NASA and ESA.

"Space science and technology is highly technical and so it's not everyone that is able to cope with the rigour of the technology." (I2)

The above-mentioned quote highlights the difficulty of accessing trained experts for working on space-based technology for flood risk reduction. Sufficiently trained technical staff was noted to be lacking, but necessary to be able to leverage space-based technologies. Technology facilitators are required to train new technical staff as well as to translate the acquired data for non-technical staff. Although the designs have improved in the last few years, tools still *"look very technical"* (I1, I7) and are thus limiting the number of users. The users therefore wish for the interface to be as intuitive (*"as Apple-like"*, I7) as possible.

Additional challenges arise through lacking technical resources such as bandwidth and processing capacities of computers in many African countries. This has been reported to potentially result in trained staff that does not have access to technical resources.

In other words, being able to purchase satellite imagery is one financial barrier, while processing the images is often another. According to an interview partner, the costs of processing the imagery are often overlooked when considering acquiring a satellite (I9). Therefore, capacities to fund technical resources as well as trained staff in an agency or at a project are crucial.

Local Capacity-Building and Cooperation

In the contexts of project work, an interview partner described the lacking interoperability of resulting output. According to the interviewee (I9), some projects focus on generating output in order to justify funding. This output is then left aside for a new project, even though the new project might aim at a similar output. The lacking fusion of the different projects' results was described as challenging, despite improvements being sighted in this area (I9).

When it comes to potential cooperation with the private sector, attempts to combine data between the two spheres were highlighted, but also described as problematic. Due to the diverging interests of different sectors, it is seen as a challenge to find ways of collaboration. The interviewees stated that these challenges need to be solved on a human level (I3).

"There's no capacity-building. [...] As long as the project duration is available, [...] the data will be available and after that, it won't be available but that should not be the case." (I8)

Another interview partner described situations in which foreign experts are stationed in an African country for the duration of a project. When the project terminates, the experts leave the country and access to data is lost. Also, in some cases, local staff is not being trained. Thus, interviewees claimed a lack of knowledge transfer and local ownership installed in projects. In this context, an interview partner further stressed that most data his agency is using is retrieved from so-called developed countries such as Europe or Japan which increases dependency (I6).

4.3 Suggested Solutions

The previous passages described the benefits and challenges encountered when applying space-based technologies for urban flood risk reduction in Africa. The following subchapter shall provide an overview of solutions to transcend said barriers as suggested by interview partners .

Raising Awareness

As elaborated previously in this paper, insufficient awareness about the space sector and its impact on society poses a significant drawback for the development and deployment of respective technical tools. In order to enhance public acceptance, thus improving the effective and efficient use of space-based information, it is important to raise awareness on several levels. This includes the general public, but also institutional and governmental entities. A broader perception of the significance of remote sensing technologies for disaster risk reduction and emergency response might ideally increase the application of these technologies and result in respective developments.

Besides creating *"[...] awareness for people to understand that space is a common good for all humanity [...]"* (I5), it is just as important to communicate about the public availability of space-based data. Platforms such as the Copernicus Open Access Hub provide simple, direct and individual access to remote sensing data. A variety of open-source processing software such as the Sentinel Application Platform (SNAP) and a wide range of tutorials allow individually tailored applications which can be supplemented by open-source geographic information systems (GIS). Although often in restricted resolution, the amount of freely available data and the number of application capabilities with no financial requirements needs to be more clearly communicated. It allows for a variety of applications such as flood extent mapping, urban footprint mapping and agricultural monitoring. However, as indicated in previous passages, the spatial resolution is not sufficient for detailed analyses and modelling justifying compulsory policies and building codes.

Raising awareness is a long-term process limited by various resources. Thus, it is important to engage with politicians as well as policy- and decision-makers in order to allocate funding for communicating a basic understanding of societal benefits associated with the application of remote sensing technologies. This may inherently allow for promoting collaborations, improving infrastructures and developing expertise in this context.

Building Capacity and Local Ownership

As clearly expressed by an interviewee, you cannot *"[...]just throw the technology out there and expect people to use it[...]"* (I3). It is necessary to have adequately trained human resources present at responsible institutions dealing with disaster prevention and relief. Thus, building capacity and providing disaster managers with a basic understanding of advantages and limitations associated with space-based information is necessary to sustainably leverage the benefits of satellite remote sensing. This also applies for frontline responders regarding their capacity to effectively make use of the obtained information in the field.

In this regard, local ownership and cooperation based on equity take an important role. Projects need to incorporate science communication and knowledge transfer as an integral component to obtain locally sustained capacity and thus have a positive and long-term impact. Another advantage of local capacity and ownership is that remote sensing can be complemented by in-situ data and knowledge of the local context.

Furthermore, interviewees suggested that African pupils and students must be supported in science, technology, engineering and mathematics (STEM)-related subjects at an early stage. The high population growth and the relatively young average age in the majority of African countries represents a significant chance to sustainably develop capacity and train young Africans to *"[...] develop Africa on all matters including space [...]"* (I5). This educational focus is part of the African Union Commission's priorities and proves essential regarding the future development of the space sector and its societal implications.

Data Access, Processing and Communication

Data accessibility poses another challenge of critical importance. The financial constraints associated with the development and the operation of satellite technologies drastically limit the number of African-launched spacecraft. However, as outlined in the previous chapters, there is plenty of information available through satellite remote sensing, crucially contributing to disaster risk reduction efforts. Thus, access to data of sufficient resolution must be a priority in order to support self-sufficiency and strengthen local ownership in the long-term.

With regard to the necessities of capacity and access to relevant data and technical resources, international collaborations between (inter-) governmental organisations, academia, NGOs and the private sector offer significant opportunities for achieving long-term benefits. Due to innovative technologies and high-quality products, the private sector in the space industry is of increasing importance. It is useful to engage in collaborations with privately held companies and relevant stakeholders to establish data sharing policies. This does not only concern satellite imagery, but also derived products such as DEMs. Furthermore, joint education and research programmes support democratising access to space through knowledge transfer and cooperations.

Interview partners highlighted the recent trend towards the use of cloud computing resources. It enables bypassing technological requirements regarding internet bandwidth and computing power, which are often insufficiently fulfilled or not fulfilled at all as interviewees reported. Cloud computing allows for comprehensive data processing with minimum constraints due to lacking local resources. However, a variety of such platforms is already operational such as the System for earth observations, data access, processing & analysis for land monitoring (SEPAL) tool from the United Nations Food and Agriculture Organization (FAO).

Prevention

While the majority of efforts from the space community address humanitarian response by providing and further optimising the accuracy of flood extent maps, it was clearly pointed out that more efforts are needed with regard to early-warning and prevention. Identifying zones that are exposed to an increased flood risk due to their topological and geographic characteristics supports resilient urban planning, mitigates displacement and harm of society, and reduces damage of infrastructure and financial loss.

High-resolution DEMs allow for such precise geographical assessments if combined with hydrological modelling. Based on these analyses, land-use policies and building codes can be developed accordingly and flood protection measures such as drainage systems and polders implemented. Since the resolution of publicly available DEMs and donated data is often insufficient for this matter, data access becomes the limiting factor again.

In order to demonstrate the importance of preventive measures, it was suggested to elaborate a figure on savings per cost based on individual countries' geographic, demographic and political conditions.

5 Discussion

As stressed by interview partners, flood management assisted through space-based technologies is a complex field. Firstly, the hydrological phenomenon of floods cannot be determined by only one or a few indicators. Secondly, the handling of satellite remote sensing technology needed for detailed modelling and prediction requires specific expertise. Thirdly, the various technical and social components necessitate bringing stakeholders of different backgrounds to the table, including scientists, international and national political actors, the private sector and civil society.

The following passages discuss the presented major findings drawn from the interviews in relation to existing literature.

5.1 Multi-Dimensional Flood Management

"Sustainable development cannot be achieved unless disaster risk is reduced." (UNDRR, 2015, v)

Floods are caused and shaped by a multitude of biophysical factors such as the types of local and surrounding vegetation, temperature, soil moisture, proximity to river or coast, the percentage of urbanised areas or geology (UNESCO-IHE, 2020). Nevertheless, floods need to be understood in a broader societal context. The *"human factor"* is considered to play a crucial role when it comes to the development of flood probabilities. In their book *"Urban Vulnerability and Climate Change in Africa"*, (Pauleit et al., 2015, 390) conclude that *"[...] human factors such as the growth of urban populations, scarce development or disappearance of green areas, and unorganized informal settlement sprawl in and around the cities may be even more relevant to accelerate the consequences of climate change [...]"*. Notably, land-use change and urban planning as *"soft/non-structural measures"* (UNESCO, 2020, 65) pose great opportunities for disaster risk reduction. Urban structure designs can improve flood resilience by including functional drainage systems, providing *"safe flooding spaces"* and allowing the city to act *"as a 'sponge'"* (UNESCO, 2020, 65).

This underlines the importance of human behaviour and decisions for the development of urban flood risks. Similarly, interview partners stressed the number of challenges on a human and social level in comparison to the technical challenges when applying remote sensing to flood management. To address these human challenges, awareness among stakeholders needs to be increased in order to form the political will to change the current situation.

5.2 Local Sustainable Capacity-Building

"One thing that has always struck me [. . .] is how important it is to work with local stakeholders [...], because [...] you can have all of the space-based information in the world, but if you don't have some local knowledge and context on the ground, it's very hard to understand what's relevant." (I3)

One of the main issues encountered during the interview process is the perpetuation of power inequalities between the so-called Global North and Global South when implementing space-based earth observation tools for flood management. While the vulnerability of African cities is increasing (Pauleit et al., 2015), knowledge production and technology to reduce these vulnerabilities with remote sensing is primarily located in developed, Western nations. Countries of the Global South are dependent on accessing knowledge and technology since most data and knowledge are not produced in African countries (Collyer, 2018, 65).

These power hierarchies are reproduced through projects in which foreign experts fulfil their tasks without building local capacities as interviewees noted. For projects to have a sustainable positive impact, knowledge transfer to local actors needs to take place as well as ensuring that the technical capacities remain available after a project ends.

Furthermore, capacity-building efforts need to be community- and gender-inclusive in order to unlock the full potential of space-based technologies in a local context (UNESCO, 2020). Accordingly, the African Union listed supporting women's engagement in the tech sector as one of the priorities (African Union, 2020).

Additionally, with increased local capacity and ownership, in-situ data and knowledge of the specific settings can be better leveraged, as highlighted by the above-mentioned quote. This process was considered to be effective in application and taken on quickly by users in generating findings.

"It's always interesting to see that people can orientate themselves 10-15 minutes after they have looked into [the satellite image] [...] and say 'Okay this is the path, this is the river and here is this mango tree where we always meet together.' [...]." (I1)

Local capacities are especially important when it comes to developing a comprehensive and integrated strategy for flood management. Although there are many similarities when it comes to challenges that African cities face in regards to flooding, it should not lead to the adoption of a one-size-fits-all approach. Solutions and strategies should include geographical, social and economic particularities (Pauleit et al., 2015, 345).

In a nutshell, the interviews revealed two main components to increase local capacities: training and accessibility. The first aspect includes an increased focus on local capacities through awareness-raising and training of local actors. An introduction to the technological possibilities and basic knowledge should already start in schools and be supported by local education institutions as well as global education efforts. An example of global efforts are Massive Open Online Courses (MOOC) on different aspects of earth observation for DRM (Sarti et al., 2020; Indian Space Research Organisation, 2020).

The second aspect focuses on making remote sensing applications more approachable and accessible, to bridge the gap between scientists, project managers and policy-makers. An increasingly unified and streamlined access to all of the relevant information and applications is desired by the interview partners. This mainly includes academic exchanges and having shared platforms. The UN-SPIDER Knowledge Portal, for example, makes a strong effort to share *"[...] the links to websites that host satellite imagery or products, or online services that facilitate access to products already generated"*. (I4)

Also, today's trends show an increasing use of cloud computing and web-tile applications, implemented for instance by the FAO's SEPAL project (Open Foris and FAO, 2020). Even though these technical changes do not directly increase local capacities, access to information is broadened for people with lacking bandwidth and computing resources.

5.3 Cooperation Potential

"Cooperation is always very fruitful!" (I1)

Climate change and natural hazards are non-trivial issues with multidimensional causes. Urban vulnerabilities i.a. result from inequalities, poverty, insecurity or lack of development in rural areas (Pauleit et al., 2015). As highlighted by interviewees, international cooperation allows for consistent measuring and assessing of risk indicators, posing opportunities for the space and disaster management community. Therefore, cross-sectoral collaboration is crucial to successfully implement disaster risk reduction. Correspondingly, interdisciplinarity and multi-stakeholder approaches are required to extensively leverage the potential of satellite remote sensing for effective flood management. For instance, a globally consistent picture is currently missing regarding the availability and state of operational early warning systems for floods (UNESCO, 2020).

Cooperation can take place at different levels of organisations - from municipal or intra-national over inter-governmental to inter-sectoral. To ensure effective partnerships, a clear analysis of different stakeholders and their interests needs to be undertaken in order to understand which forms of collaboration allow the most impact.

As addressed in the previous sub-chapter, urban administrations directly confronted with floods require access to adequate training in space-based technology applications for DRM. UN-SPIDER actively cooperates with different national levels by conducting technical advisory missions and training activities for national disaster management agencies (UNOOSA, 2020a). Distributing the acquired knowledge intra-nationally to municipal levels remains the responsibility of national entities (I4). This may complicate an efficient transfer of application expertise and data access to local experts.

"[UN SPIDER's] point of contact is usually the national disaster management agency. It's hard for [UN SPIDER] to really reach down to the level of cities [...] [as it] would really require permission from the national governments [...]. So, [UN SPIDER provides] products to national government agencies with the hope that they will reach cities and rural areas." (I4)

As mentioned earlier, the private sector in the space industry is of significant importance due to innovative technologies and high-quality products. Engaging in collaborations with privately held companies therefore offers opportunities for achieving long-term progress in the context of flood management. Implementing data-sharing policies could support disaster management agencies in accessing remote sensing data of private companies with higher spatial and temporal resolution. This also applies to cloud computing-based resources to allow rapid mapping during humanitarian emergencies. According to one interviewee, especially insurance and reinsurance companies have a growing interest in the use of remote sensing for estimating flood risk and damage scopes.

In addition to UN-SPIDER's efforts in sustainable knowledge transfer and institutional strengthening, the Operational Satellite Applications Programme (UNOSAT) of the United Nations Institute for Training and Research (UNITAR) also engages in supporting local authorities in the use of space-based technologies for disaster management. Due to the thematic similarity of both institutions, frequent exchange and coordination should be in place to create synergies and to avoid duplicating efforts.

5.4 Prevention

The described lack of consistent early warning systems represents one area of improvement in the prevention phase of the disaster management cycle (see Fig. 4). This particularly deserves attention in regard to achieving the goals set in global agendas such as the Sendai Framework and the SDGs (Perera et al., 2019). In order to break the *"[...] vicious cycle of disaster > response > dependency > repeat."* (UNDRR, 2020), a clear focus on prevention needs to be established. Many of the interviewees stressed the importance and yet lack of prevention activities.

Satellite remote sensing in combination with emerging technologies such as machine learning and cloud computing can provide new opportunities for mainstreaming more effective preventive measures. Still, potentials and difficulties in implementation not only occur on the technical spectrum, but also on the financial, institutional and social as described by the interviewees and the UN World Water Development Report 2020 (UNESCO, 2020).

Challenges on the social and institutional level include the lack of technical expertise, limited human resources to perform forecasts, and lack of knowledge about the operational effectiveness of early warning systems. Developing physically-based models requires expertise in remote sensing as well as in-depth knowledge about local hydrological parameters. Even then, the calculated models might have inherent errors (Mosavi et al., 2018, 1536). Interview partners described difficulties in effectively implementing preventive strategies and in the communication of displacement recommendations.

Furthermore, the prevention phase proves to be challenging due to the multifaceted character of floods (as discussed in subsection 4.2 and subsection 5.1). From the technological perspective, predicting floods conventionally involves a number of physical models and monitoring hydrological events such as storm rainfall/runoff shallow water conditions. These methods require vast amounts of ground data through physical observatories and intensive computing which hinders the short-term prediction of floods (UNOOSA, 2020b).

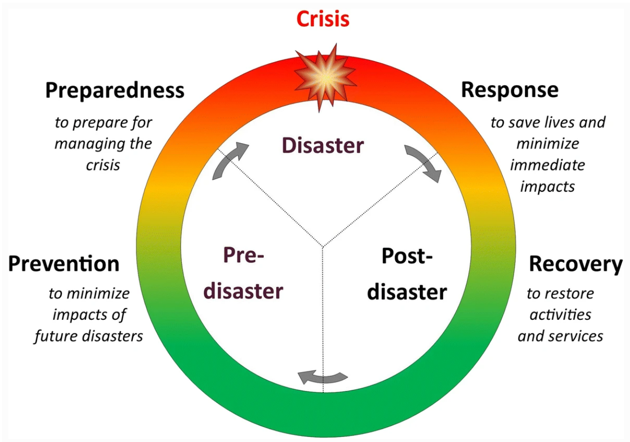

Fig. 4. The disaster management cycle. Source: Le Cozannet et al. (2020, 1213)

Machine learning has proven useful to predict, map and monitor flood events to support transcending said barriers of technical expertise and human resources. This may provide better performance and a cost-effective solution. Further development of the existing flood prediction models essentially promotes preventive efforts in order to inform policy making and finally to minimise the loss of human lives and property damage. Flood prediction using machine-learning algorithms is especially effective since different data sources can be used. Still, the algorithms require development and training with access to previous data sets to successfully improve their prediction accuracy (UNOOSA, 2020b).

Finally, prevention efforts, like any other endeavour, require resources and political will. Especially in times of the COVID-19 pandemic, resources are scarce and need to be invested carefully. As presented, interviewees as well as literature plead for positioning flood risk prevention high up on the political agenda of respectively flood-prone cities.

6 Conclusion

Despite floodplains supplying many of the key natural resources for the world population, floods can become hazards when threatening lives and infrastructure. Especially in cities, climate change alongside increasing urbanisation and land-use change exacerbate flood risks. In African cities, an upward trend for flood risk and urban population growth has been identified.

The nine expert interviews conducted show a variety of benefits and challenges when applying satellite remote sensing for urban flood management. Space-based technologies provide information crucial for flood mapping, forecasting and risk modelling and allow monitoring and analysing historical and near real-time data. However, their applications have not been extensively established and are predominantly limited by lack of awareness, local capacities and to a certain extent data accessibility.

For flood management projects to have a sustainably positive impact, knowledge transfer to local actors is required as well as ensuring that technical capacities remain available after a project's expiration. Local expertise allows putting space-based data into context by linking the data to geographical, social and economic particularities. However, local ownership can only be ensured if the necessary technological and financial resources and data access are secured.

Implementing and enhancing technical infrastructure should be considered a continuous priority in order to strengthen long-term and self-sufficient flood risk management across the African continent. Our four key recommendations aim at mid-term effects and are based on intra-national, international and cross-sectoral collaboration:

Firstly, intra-national mechanisms should be expanded to ensure the transfer of knowledge and skills from national agencies to local municipalities where necessary. UN-SPIDER conducts technical advisory missions and training activities for national disaster management agencies. In this case, transferring knowledge and skills to local bodies, i.e. frontline responders, mainly lies within the national authorities' responsibility.

Secondly, vital capacity-building and awareness-raising are long-term endeavours that require adequate resources and funding. Therefore, frequent communication and respective coordination among thematically related UN institutions such as UN-SPIDER and UNOSAT is important to achieve synergies and to avoid duplicating efforts.

Thirdly, engaging in collaborations with privately held companies offers potential for the future. Implementing data-sharing policies could support disaster management agencies in accessing remote sensing data of private companies with higher spatial and temporal resolution. This also applies to cloud computing-based resources to allow rapid mapping during humanitarian emergencies.

Finally, a strong focus on prevention is essential for sustainable long-term flood risk management. Space-based technologies allow forecasting and identifying zones that are exposed to an increased flood risk due to their topological and geographic characteristics before disasters strike. These analyses provide a quantitative basis for land-use policies and enforced building codes. Hence, the results support resilient urban planning, mitigate displacement and harm of society, and reduce damage of infrastructure and financial loss.

To conclude, said endeavours can only be accomplished through sufficient awareness about flood risk and space-based information as well as political will. Especially in times of crises, resources are scarce and time is limited. Effective application of space-based technologies for flood prevention, mitigation and response allows limiting financial loss and saving lives.

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Appendix: Interview Guideline

Introduction

- Would you kindly briefly introduce yourself and describe your field of work and background? We would like you to touch upon two aspects: central focus of your work and your connection to the UN.

General setting of the stage for the field of interest

Urbanisation is one of today's megatrends. UN-Habitat expects an outstanding increase of the urban population in Africa in the upcoming decades. However, literature shows i) an increasing risk of floods in many African cities (such as Lagos, Accra, Dar Es Salaam) due to climate change and urbanisation, as well as ii) increased vulnerability due to rapid urbanisation and land-use change.

Personal experiences and views

- From your work perspective and experience: is flooding risk in urban Africa an issue that can be addressed through space-based technologies? If yes: how? What is currently being done in this field?
- Can you name important initiatives in this context? Please elaborate on their relevance and what makes them important or impactful.
- How are space-based technologies used in this project?
- How is the UN or a specific UN sub-organization involved in this initiative/project?
- How do other non-UN organisations you are familiar with use space-based technologies for flood management in urban contexts, specifically across Africa?
- Do you think space-based technologies offer an area of improvement in the field of flood management in urban contexts?
- To look at the other side of the coin: what is not being done? Can you perhaps tell us reasons why space-based technologies are not being used in said context?
- What has not been working and why?
- How can the use of space-based technologies for flood management in practice/projects be improved?
- What would you wish for?
- Which type of cooperation or work would you wish to see in this particular field/in your field of expertise?
- Thought experiment: we are now in the year 2030 - how would you draw the future of this theme if everything was possible? Please elaborate on the ideal scenario in your perspective.
- Now, what do you think will actually have happened by 2030?

Additional questions

We have now reached the end of the questions from our side. From your side:

- Is there any topic we have not discussed?
- What extra comments would you like to add?
- Would you like to tell us anything else?

Closure

- What do you recommend - with whom should we definitely talk about the topic of space-based technologies for flood management in urban Africa?
- Is there anybody you know who uses innovative and interesting approaches?