Vulnerabilities of water and sanitation at households and community levels in face of climate variability and change: trends from historical climate time series in a West African medium-sized town

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Abstract: In Kaédi, a secondary city of Mauritania with approximately 71,000 inhabitants, the analyses of historical climate time series data (1919–2010) and some projections showed a likely occurrence of more frequent heavy rains and higher risks of flooding events in the future. Vulnerability assessments, facilitated through transversal household surveys toward the end of the rainy season that covered the entire city and followed a stratified sampling approach, showed that the community’s water supply comprises more than 100 wells, 33% of households report using water from wells for drinking purposes, 12% of households have their own wells in the yard, and 69% of households have latrines in the yard. The analysis also revealed considerable spatial heterogeneity of vulnerability. Considering the risks of cross-contamination of wells water by onsite sanitation facilities during flood events, communities and local governance actors should find appropriate adaptation to climate change strategies for water and health sectors starting with thematic vulnerability maps.

Keywords: adaptation to climate change; climate change; climate variability; floods; health; Kaédi; Mauritania; secondary cities; time series analysis; vulnerability assessment; water; sanitation; West Africa.


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1 Introduction

More than 17,000 disasters have been recorded in the world from 1900 to the present, with a steady growth over time (UN/ISDR, 2005; IFRCRCS, 2010). In recent years, there was a particular increase in the frequency of disasters, with floods accounting for a growing share. For example, in 2008, over 200 major floods have been documented worldwide, affecting some 180 million people (Pitt, 2008).

The 2,200 water-related disasters that occurred between 1990 and 2001 (UNEP/GRID-Arendal, 2007a, 2007b; CRED, 2009) have been classified as follows: floods (50%), water-borne and vector disease outbreaks (28%), droughts (11%), landslide and avalanche (9%), and famine (2%). In addition to the 50% of water-related disasters, floods accounted for 15% of all deaths related to natural disasters over this 12-year period. In 2011, 67% of global hydrological disaster victims were due to floods.

Looking at the geographic distribution of disasters, the Guha-Sapir et al. (2012) report documents that Asia is the continent most often hit by natural disasters in 2011 (44.0%), followed by the USA (28.0%) and Africa (19.3%). Only relatively few such events were noted in Europe (5.4%) and Oceania (3.3%). In sub-Saharan Africa, over the past decade, an increasing number of flooding events has been reported with devastating impacts on the wellbeing and local livelihood of affected individuals and the economic development of the region more broadly (Tall et al., 2012; Cissé, 2012; UN, 2007).

Importantly, sub-Saharan Africa is considered as one of the climate hotspots, and thus particularly vulnerable to the effects of climate change and extreme events. Indeed, two-thirds of the Africa’s surface area is desert or dry land, and the region is also home to many fragile terrestrial and coastal ecosystems (World Bank, 2010).

Africa is among the regions that are particularly prone to climate change in the near future (IPCC, 2012). Several studies emphasise that increasing flooding events are due to climate variability and climate change trends in Africa, and that floods are likely to occur more frequently and with higher intensity in many regions of the continent (Hulme et al., 2001; Mbaye et al., 2004; IPCC, 2012; Sylla et al., 2010).

The short-term and long-term effects of floods on health have been documented for developed countries (Gray, 2011), but there is a paucity of studies on the health effects and impacts of flooding in the developing world. The grey literature from various non-governmental organisations (NGOs) regularly report on the short-term effects of floods on water and water-related diseases in flood-prone countries. According to these reports, the effects generally include the affected populations being moved from their
residential area, loss of assets, personal anguish, and/or mental disorders. Some outbreaks of diarrheal diseases, including cholera, have also been associated with floods.

In rural and small-sized cities in the developing world, with the predominance of no or only very simple traditional excreta disposal facilities (latrines) and traditional sources of water (e.g., unprotected wells) at household and community levels, the repeated occurrence of flooding events can negatively affect water quality and increase the burden of water-related diseases.

Damages, particularly the effects and impacts on water quality and consequently health, are currently less efficiently managed in developing countries, because of inherent institutional weaknesses at both national and local levels, exacerbating the vulnerabilities to climate variability and change at community and household levels. The challenges posed by Africa’s low institutional and financial capacities for adaptation to climate change are particularly pressing in the domains of water supply and sanitation (Cissé et al., 2011).

Considering regional climate models, the arid zone of the Sahel band is likely to face an increase in the average number of raining events and peak rainfalls (IPCC, 2012). An inherent challenge for researchers working on the likely impact of climate trends locally are related to the paucity of high-quality historical time series data. There is a lack of capacities in meteorologic and climate data collection, analysis, storage, and dissemination. The countries are facing limitations in climate data collection material and infrastructure and have insufficient capacities for climate forecasts and modelling that are necessary at the local levels. There is a pressing need for decision-makers to strengthen the evidence-base on climate changes. Hence, an analysis of historical time series of available climate data is of considerable interest.

The specific needs of small- and medium-sized cities for adaptation to climate change deserve special attention (IFRCRCS, 2010). At present, more than 50% of urban dwellers live in cities or towns with fewer than 500,000 inhabitants and, in the near future, half of the increase in urban populations is expected to occur in urban settings of this size (UNHabitat, 2008a, 2008b). The trends in ‘urbanisation’ of disasters and disaster risks merit more focused attention, particularly in secondary cities, due to the particular weaknesses and vulnerabilities of those urban contexts. Additionally, secondary cities that are located in close proximity to rivers should be studied in greater detail, because a large number of vulnerable people in such cities might be exposed to extreme events, especially floods.

The study presented here focuses on Kaédi, a secondary city of Mauritania in West Africa. The study is part of a regional project entitled ‘An ecohealth approach to water and health management in relation to climate change: adaptive strategies to cope with drought and floods in four West African countries (Côte d’Ivoire, Mauritania, Senegal, and Togo)’. The overarching goal of the study is to deepen the understanding of vulnerabilities of communities and households in this medium-sized city in face of more frequent rainfalls that could lead to flooding and affect vulnerable communities. Hence, our focus is on water- and sanitation-related vulnerabilities (Costello et al., 2009; Sherpa et al., 2014).

The following research questions were addressed:

1. What do historical time series of climate data tell us about the climate trends in the current study area?
Where are the zones and communities most physically vulnerable to and affected by floods that occurred in the recent past within the city?

What are the main water supply systems and sanitation facilities in different zones of the city?

To what extent may floods impact the water and sanitation systems in the most vulnerable areas?

In relation to these research questions, our study pursued the following specific objectives:

1. to collect historical time series of climate data and undertake analyses of the likely trends
2. to assess the vulnerability of communities in face of flood risks
3. to assess the specific vulnerabilities related to water and sanitation in face of flooding events
4. to elaborate a vulnerability map for adaptation to flooding events in the water and health sectors.

2 Materials and methods

2.1 Study site

The study focuses on the city of Kaédi, the regional capital of the Gorgol region, located in the southern part of Mauritania at the border with Senegal, marked by the Senegal River (see Figure 1; PDU, 2008). The city (geographic coordinates: 16° 09’18” N latitude, 13° 29’49” W longitude) is located about 430 km south of Nouakchott, the capital city of Mauritania. Kaédi is located where the Senegal River meets the Gorgol River.

Figure 1 Location of Kaédi, Mauritania (see online version colours)
According to the urban development program (UDP) document, the city of Kaédi consists of 11 neighbourhoods that are grouped under eight major areas covering a surface area of 815 ha (Figure 2; PDU, 2008). It counts approximately 71,000 inhabitants in 2011 (ONS, 2000; Touray et al., 2012).

Figure 2 Map of the districts (neighbourhood) in Kaédi, Mauritania (see online version for colours)

The city has no sewerage system and the families are mainly using on-site sanitation facilities. The topography is relatively flat, characterised by plains with some hills not exceeding 200 m in height. The proximity to the river puts the city at risk of two kinds of flooding:

1. river floods
2. urban floods.

In 2010, Kaédi was flooded after receiving within ten days the equivalent of an annual rainfall (data ONM) causing the displacement of over 310 households and resulting in severe disruption of the livelihoods of people in the city (Touray et al., 2012).

2.2 Study design

The study involved a literature review, a search of climate historical data, and a series of cross-sectional surveys. We combined three concomitant multidisciplinary surveys covering the entire city:

1. a cross-sectional household survey during which households were randomly selected to record a number of data following a questionnaire
2. a geographical survey, during which a number of major environmental issues were characterised, including measurement and location of specific parameters with
geographic coordinates using a hand-held global positioning system (GPS; Garmin eTrex H Handheld GPS Navigator)

3 a socioeconomic survey targeting different sectors’ actors (e.g., fishermen, farmers, and hunters) to record specific data.

2.3 Climate data

The recorded climate data in Kaédi were obtained from the National Meteorological Agency (ONM). For rainfall, the measurements cover a 90-year period from 1919 to 2010. For average monthly temperature, the measurements cover a ten-year period from 2001 to 2010 (Touray et al., 2012).

Complimentary climate data and forecast facts and figures, including past extreme events and disasters, were reconstructed based on discussions with key informants and specific searchers on the internet. Additionally, other open-access sources (e.g., climate systems analysis group of the University of Cape Town; see, http://cip.csag.uct.ac.za) were consulted for tentative projections of climate trends for Kaédi.

2.4 Baseline vulnerability assessment

We undertook baseline vulnerability surveys in Kaédi in October 2010. In a preceding participatory workshop with different local stakeholders, we divided the city into three zones according to different perceived physical vulnerabilities to flooding, considering events that occurred in the recent past (Figure 3).

**Figure 3** Overview of the flooding risk zones in Kaédi, according to past events, mapped by local partners (see online version for colours)

Notes: red = high risk; blue = medium risk; green = low risk.
Zone 1 is including settlements reported by local stakeholders as being most often affected by past flood events. This zone is composed mainly by areas in close proximity to the Senegal River. To protect the eastern part of this zone, most notably the area of Sinthiane-Kebbe, a dike has been constructed that should protect the area from flooding.

Zone 2 is the central and wealthier area of Kaédi. It is constituted by the administrative buildings area that also includes the historical built-up (i.e., Gattaga). Local stakeholders report that this zone has been least affected by flooding.

Zone 3 is the intermediary zone constituted by new and peripheral areas generally located far away from the Senegal River. This zone is located in the northern part of the city and it constitutes new settlements behind the airport (e.g., Initi and Tinzah).

While conducting our cross-sectional household survey, an effort was made to sample across the entire city, and hence, including households in all three zones mentioned above. We aimed at a random sample of 200 households in each of the three zones. The selection of the first household in each zone is done from a central location and taking a direction determined by spinning a pen and then selecting the first household along the direction pointing outwards (Winkler et al., 2012). The geographic coordinates of each household were recorded with a hand-held GPS device.

2.5 Geographic surveys

Trained field enumerators walked exhaustively along the streets and collected on elaborated specific forms a number of environmental elements: wells, open wastewater, stagnant freshwater bodies, small cleaner surface waters, solid waste dumps, health centres, major holes, animal fences, and green areas like urban agricultural fields.

2.6 Ethical considerations

The Mauritanian Ministry of Health, the Wilaya district, and the local governance authorities all gave their support to the project. They ensured official communication from the central to the regional and local levels. They made announcement of the purpose and procedures of the study to local residents. Heads of households were asked for written informed consent prior to administering the questionnaire. Participation was voluntary and people could withdraw anytime without further obligations.

3 Results

3.1 Climate features from past data and trend analyses

Information obtained from the grey literature suggests that the average temperature in Kaédi ranges between 38°C and 40°C. Rains mainly occur between June and October with an average annual precipitation of 350–400 mm before the 1970s. Considerably lower annual precipitations were observed between 1970 and 1980 (approximately 250 mm). In the following decades, annual precipitations further declined, but more recently shows an upward trend (PDU, 2000). There is a long dry season that starts in November and lasts until June. During this period, there is usually no rain and the principal sources of water in the southern parts stem from the Gorgol and Senegal rivers.
Year-to-year variations that have occurred during the last decade might render communities vulnerable and affect local economies.

From the climate time series data available for Kaédí covering the 90-year period between 1919 and 2010 (Figure 4) we find, on average, a total annual precipitation of 349 mm [95% confidence interval (CI) 321–377 mm] with a considerable inter-annual variability.

Figure 4 Total annual rainfall from 1919 to 2010 in Kaédí, Mauritania (see online version for colours)

We observed a trend toward a steady decline in the total annual precipitation over the last century and also in the first decade of the new millennium (decline of 1.8 mm per annum). A dip in annual precipitation is noted from the mid-1960s which is sustained throughout the 1970s and 1980s. However there is a gradual increase in the 1990s and the first decade of the new millennium.

A closer look at the duration and the amount of rainfall (Figure 5) shows that in the last decade (2001–2010) the duration of the rainy season (i.e., consecutive months with at least 10 mm of rainfall) has decreased significantly, while the average monthly precipitation in the rainy season increased. This observation suggests a shortening of the duration of the rainy season and concentration of precipitation within a narrower time span, during which the city experiences relatively large amounts of rainfall per unit time, while almost no rainfall occurs in the rest of the year. Regarding years in which floods occurred in the last decade (red square dots), with the exception of 2002, they occurred in years with relatively higher monthly precipitation in the rainy season (2006, 2009, and 2010).
Figure 5  Trends in duration and amount of rainfall from 2001 to 2010 in Kaédi, Mauritania (see online version for colours)

![Graph showing trends in duration and amount of rainfall, Kaédi (2001-2010)](image)

Note: Red wide square dots show years in which floods occurred in the analysed time period.

Source: ONM

As shown in Figures 3 and 4, there is a trend toward a steep increase in the average monthly precipitation in the rainy season from 2007 to 2010, placing the city at an increased risk of floods.

Figure 6  Annual cycle of monthly rainfall (in mm) for Kaédi station (1982–2000) (see online version for colours)

![Graph showing annual cycle of monthly rainfall, Kaédi station (1982–2000)](image)

Notes: Wide bars indicate the median monthly rainfall for the climate period. Narrow bars indicate the 10th to 90 percentile range of monthly rainfall for each month during the climate period.

Source: http://cip.csag.uct.ac.za
3.2 Vulnerabilities in face of flood risks at community level

During our cross-sectional survey carried out toward the end of the rainy season in October 2010, 539 households were visited. In all three zones, most of the sampled...
households were headed by a Mauritanian national. The heads of household were mostly proprietors of their houses (86%), while about 12% were tenants.

On average, a household was composed of ten individuals. Most of the houses visited had four rooms. In about 80% of the households there was at least one child under the age of five years.

The four major economic activities of the heads of households are: agriculture (29%), artisan (21%), civil servant (14%), and commerce (13%). The four major economic activities of household partners are: housewife (51%), artisan (21%), commerce (14%), and agriculture (7%).

Monthly income in about 40% of the surveyed households was below UM 30,000, which corresponds to approximately US $90, while slightly less than 20% of the household heads reported salaries above UM 50,000. One fifth of respondents were unable to give an estimate of their monthly earnings.

The households responded positively at 94% for the flooding of household courtyard after rains (without significant difference between zones); 94% for the flooding of neighbourhood after rains (no significant zone difference); 84% of households for feeling that there is more rainfall now than before. Importantly, 65% reported that their household has been affected by flooding disaster (having been victim of flood disaster), with a significant zone difference (respectively from zone 1 to zone 3: 41%, 50%, and 31%). Only 27% reported having received assistance after being affected by flooding events.

Despite the survey’s results (depending on the self-reports by the households), many key informants have reported that zone 1 is the most worrying area and that very often the people who have to be resettled during a flood event stem from this area.

### 3.3 Mapping vulnerabilities related to water, sanitation, and health

Despite the fact that Kaédi is a regional capital, the geographic surveys found more than 100 wells; 42, 15 and 53 in zones 1, 2 and 3, respectively. The household surveys found that 12% of households have their own wells in the yard and well water constitutes a major source of some families’ drinking water in the city (33%) (Table 1). In the zones most vulnerable to floods (zone 1) the figures are even higher (46%) than the average, followed by zone 3 (35%) and zone 2 (24%).

### Table 1 Wells water as source of households’ drinking water in the medium-sized city of Kaédi, Mauritania

<table>
<thead>
<tr>
<th>Zones</th>
<th>Households drinking water from wells</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Yes</td>
<td>92</td>
<td>46%</td>
</tr>
<tr>
<td>(most vulnerable)</td>
<td>No</td>
<td>110</td>
<td>54%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>202</td>
<td>100%</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Yes</td>
<td>65</td>
<td>24%</td>
</tr>
<tr>
<td>(least vulnerable)</td>
<td>No</td>
<td>211</td>
<td>76%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>276</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Source:* Cross-sectional household survey conducted in October 2010 (rainy season)
Table 1  Wells water as source of households’ drinking water in the medium-sized city of Kaédi, Mauritania (continued)

<table>
<thead>
<tr>
<th>Zones</th>
<th>Households drinking water from wells</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 3 (intermediary)</td>
<td>Yes</td>
<td>61</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>114</td>
<td>65%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>175</td>
<td>100%</td>
</tr>
<tr>
<td>City</td>
<td>Yes</td>
<td>218</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>435</td>
<td>67%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>653</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Cross-sectional household survey conducted in October 2010 (rainy season)

Latrines in household yards are predominant in the city (69%), with higher portion in the more vulnerable zone (80%) (Table 2), followed by zone 2 (70%) and zone 3 (54%).

Table 2  Households having latrines in the yard in the medium-sized city of Kaédi, Mauritania

<table>
<thead>
<tr>
<th>Zones</th>
<th>Latrines in the yard</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 (most vulnerable)</td>
<td>Yes</td>
<td>160</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>41</td>
<td>20%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>201</td>
<td>100%</td>
</tr>
<tr>
<td>Zone 2 (least vulnerable)</td>
<td>Yes</td>
<td>194</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>82</td>
<td>30%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>276</td>
<td>100%</td>
</tr>
<tr>
<td>Zone 3 (intermediary)</td>
<td>Yes</td>
<td>95</td>
<td>54%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>81</td>
<td>46%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>176</td>
<td>100%</td>
</tr>
<tr>
<td>City</td>
<td>Yes</td>
<td>449</td>
<td>69%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>204</td>
<td>31%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>653</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Cross-sectional household survey conducted in October 2010 (rainy season)

One of the first steps toward climate change mitigation in the water sector is to make communities and local governance actors aware of the areas that are physically most vulnerable to floods and require special attention to have water quality and quantity protected. This is especially true in areas characterised by traditional water and sanitation facilities.

Two thematic maps are presented here:

1. the location of existing wells, stratified by zone (Figure 8)
2. the location of health facilities (Figure 9).
Figure 8  Location of wells in rainy season in Kaédi, Mauritania (see online version for colours)

Source:  Cross-sectional household survey in October 2010

Figure 9  Location of health centres in Kaédi, Mauritania (see online version for colours)

Source:  Cross-sectional survey in October 2010
The first map is highlighting the more vulnerable wells linked to their zone, that could be used as a warning reference in case of next flooding events. The second map is highlighting the vulnerabilities of health facilities. Such information is of considerable importance in the framework of a strategic thinking about flooding disaster risk reduction plans.

4 Discussion and conclusions

An in-depth analysis of climate time series data for the medium-sized city of Kaédi in Mauritania reveals that:

1. this urban setting is likely to face increased precipitation
2. there is currently a large number of wells in close proximity to streets and in households yards that are vulnerable to flooding and contamination
3. many households are relying on wells for their drinking water
4. some households have wells and latrines in close proximity to each other in their yards.

In view of these observations, flood waters can pose health risks by contaminating drinking water and the food chain in a context of deficiencies in sanitation and wastewater disposal. It is thus not surprising that many experts warn that flooding will continue to cause more deaths and damage than any other hydro-meteorological phenomenon (Llewellyn, 2006).

While a series of case studies in high-income countries report focus on flood-related coughs, colds, bronchitis, heart attacks, and troubles in personal relationships (Gray, 2011), in the developing world, there are additional and major concerns about water contamination and the increased risk of water-related diseases specific to the social-ecological background of the affected area. The higher spatial concentration of people in poor areas of cities, compared to more rural or remote villages, explains why even small-scale flooding may have considerable negative consequences on human wellbeing through its effects on habitat, water, and sanitation.

Experts from the IPCC put forward convincing evidence that climate change is real and it does occur as we write this piece. Yet, many water and health sector professionals still have not woken up to the challenges that climate change presents (Bergkamp et al., 2003). The classical and conventional approach to water management commonly used today is not flexible enough to respond to the long-term uncertainties of climate change. Hence, there is a pressing need of increasing the resilience of water and sanitation in the face of climate change and climate variability (WHO, 2010).

One of the first steps toward climate change in the water sector is to make communities and local governance actors aware of the areas that are physically most vulnerable to floods and of the importance of protecting water quality. This is especially the case in areas characterised by traditional water and sanitation facilities. In secondary cities – like Kaédi in Mauretania that is at the centre of the current analysis – the thematic maps highlighting the threat of floods to well water quality can provide a communication tool for scientists and policy makers alike, in order to jointly develop water safety plans, disaster risk reduction plans, and local climate change adaptation strategies.
The ways the traditional wells are constructed make them vulnerable during flooding (Elliott et al., 2011) for many reasons:
1. infiltration of contaminated waters into the wells
2. collapse of the wells
3. rendering wells inaccessible.

The usual constructing of wells near traditional sanitation facilities increases the risks of contamination in case of flooding. To protect wells, technical solutions are at hand and the following recommendations should be followed:
1. promoting construction of a sanitary seal that extends at least 1–3 m below ground to prevent infiltration of contaminants
2. respecting the minimum recommended distance of 30 m between a well and any single latrine.

This study has opened opportunities for complementary research in Kaédi on further vulnerabilities assessment, including water quality, ground water sensitivity, and early warning systems, for adaptation to climate change.

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References


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