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Climate Risk Assessment for Water Resources Development in the Niger River Basin Part II: Runoff Elasticity and Probabilistic Analysis

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Additional information is available at the end of the chapter

1. Introduction

The preceding chapter presented the context and overview of the climate risk assessment (CRA) for the Niger River Basin (NRB). It also discussed the climate change estimation methodology and the impact of potential runoff changes on the performance indicators of the Niger Basin Sustainable Development Action Plan (SDAP). In this chapter, we describe the methodology used in estimating the runoff response to climate change, followed by the quantitative assessment of climate risks for key water related sectors, and a discussion of the major findings.

2. Runoff response to climate change

For this study, the primary goal is to determine the relative changes (in %) in annual runoff and various performance criteria such as hydro-energy and irrigated agriculture production, due to relative changes (in %) in annual climate parameters (notably the precipitation, P, and temperature, T) caused by projected future climate changes. The task, then, is to determine the response of runoff to changes in climate parameters, i.e. to estimate the climate elasticity of runoff. A precipitation elasticity of runoff of, for example, 2.5 implies that a 10% increase in precipitation causes a 25% increase in runoff; a temperature elasticity of -0.5 implies that a 10% increase in temperature causes a 5% decrease in runoff. For this purpose we have extensively

reviewed available literature on climate elasticity of basin runoff, *inter alia* Wigley and Jones (1985), Gleick (1986, 1987), Karl and Riebsame (1989), Risbey and Entekhabi (1996), Vogel et al (1999), Arora (2002), Legates et al (2005), including the estimation of climate change impacts on runoff through hydrological modeling studies for similar river basins in Africa, *inter alia* Deksyos Tarekegn (2006), Strzepek and McCluskey (2006) and SNC Lavalin (2007). We also applied linear and log-linear regression models to the available rainfall, temperature and runoff data for various sub-catchments of the Niger Basin (Grijsen and Brown, 2013). The data used were spatially aggregated (gridded) annual precipitation and temperature data for the period 1948-2002 for major sub-catchments of the Niger Basin (Hirabayashi, 2008) and annual stream flow data from the data base of the Niger Basin Observatory of the Niger Basin Authority (NBA). The Basin's network of hydrometric stations is shown in Fig. 1. In the preceding chapter, we showed that the projected changes in annual precipitation and temperature were well represented by the normal distribution.
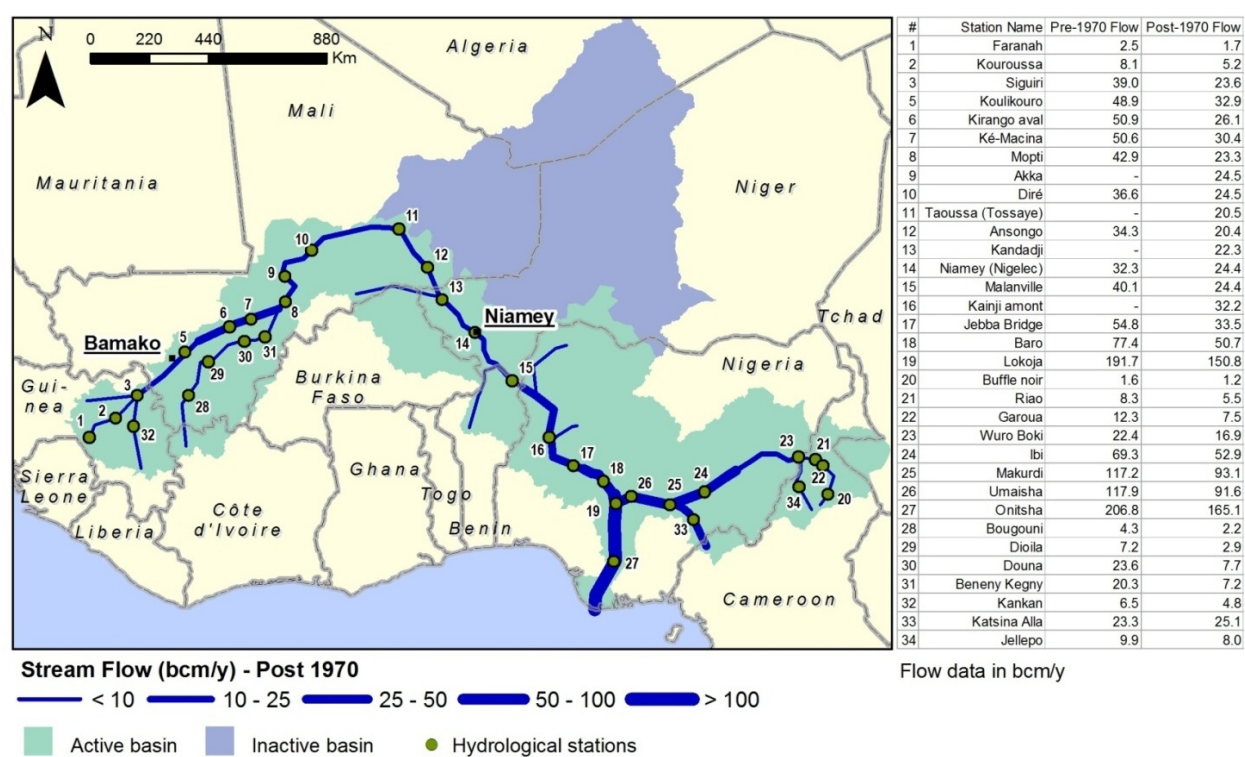

#	Station Name	Pre-1970 Flow	Post-1970 Flow
1	Faranah	2.5	1.7
2	Kouroussa	8.1	5.2
3	Siguiri	39.0	23.6
5	Koulikouro	48.9	32.9
6	Kirango aval	50.9	26.1
7	Ké-Macina	50.6	30.4
8	Mopti	42.9	23.3
9	Akka	-	24.5
10	Diré	36.6	24.5
11	Taoussa (Tossaye)	-	20.5
12	Ansongo	34.3	20.4
13	Kandadji	-	22.3
14	Niamey (Nigelec)	32.3	24.4
15	Malanville	40.1	24.4
16	Kainji amont	-	32.2
17	Jebba Bridge	54.8	33.5
18	Baro	77.4	50.7
19	Lokoja	191.7	150.8
20	Buffle noir	1.6	1.2
21	Riao	8.3	5.5
22	Garoua	12.3	7.5
23	Wuro Boki	22.4	16.9
24	Ibi	69.3	52.9
25	Makurdi	117.2	93.1
26	Umaisha	117.9	91.6
27	Onitsha	206.8	165.1
28	Bougouni	4.3	2.2
29	Dioila	7.2	2.9
30	Douna	23.6	7.7
31	Beneny Kegny	20.3	7.2
32	Kankan	6.5	4.8
33	Katsina Alla	23.3	25.1
34	Jellepo	9.9	8.0

Flow data in bcm/y

Stream Flow (bcm/y) - Post 1970

— < 10   — 10 - 25   — 25 - 50   — 50 - 100   — > 100

Active basin   Inactive basin   • Hydrological stations

Figure 1. Niger Basin river network of hydrometric stations (Note: flow data are shown in billion m^3/year)

Arora (2002) used the aridity index, $\varphi = E_0/P$, i.e. the ratio of annual potential evapotranspiration (E_0) to precipitation (P), to assess climate change impacts on annual runoff. Simple analytic expressions based solely on the aridity index of a basin are used to estimate changes in runoff due to changes in precipitation and (temperature driven) changes in potential evapotranspiration, as a first order estimate of the effect of climate change on annual runoff. The aridity index, φ, has been shown to describe the actual evaporation ratio E/P and the runoff ratio Q/P (= 1-E/P) of catchments for a range of climatic regimes. Arora (2002) used the aridity index to obtain analytic equations, which can be used to estimate relative changes in annual runoff

due to relative changes in annual precipitation and available energy, i.e. the precipitation elasticity ε_P (= [dQ/Q]/[dP/P]) and the evaporation elasticity ε_{E0} (= [dQ/Q]/[dE$_0$/E$_0$]) of runoff. The latter is used to derive the temperature elasticity of runoff, ε_T = [dQ/Q]/[dT/T]. Because of its mathematical convenience, we used the functional form introduced by Turc (1954) and Pike (1964), as follows:

E/P = [1+ φ^{-2}]$^{-0.5}$ (actual evaporation ratio)

Q/P = 1 – E/P (runoff coefficient)

dQ/Q = (1 + β) dP/P – β dE$_0$/E$_0$

ε_P = [dQ/Q] / [dP/P] = 1 + β (precipitation elasticity of runoff)

ε_{E0} = [dQ/Q] / [dE$_0$/E$_0$] = -β (potential evapotranspiration elasticity of runoff)

ε_T = [dQ/Q]/[dT/T] = ε_{E0} T/(T+17.8) = -0.60β (temp. elasticity of runoff; T=26.6^{0}C; Hargreaves, 1982, 1985)

β = [1 + φ^2]$^{-1}$ / {[1 + φ^{-2}]$^{0.5}$ – 1} = (1 + E/P) E/P = 2 – 3 Q/P + (Q/P)^2

Thus, the (observed) runoff coefficient provides a simple initial estimator for the climate elasticities of runoff for the Niger Basin (T=26.6^{0}C), i.e.:

ε_P = 3 – 3 Q/P + (Q/P)^2

ε_T = -1.2 + 1.8 Q/P – 0.6 (Q/P)^2

2.1. Results of runoff elasticity analysis

We applied linear regression analysis on the historical relative variations (in %) in annual precipitation and runoff for multiple sub-catchments of the Niger Basin, and compared actual and theoretical values of the aridity index φ and precipitation elasticity ε_P based on the runoff coefficient Q/P (Fig. 2). Overall the runoff regime of the Niger Basin (i.e. for the runoff generating sub-catchment in the Upper Niger and Benue Basins) is well represented by a runoff coefficient Q/P = 0.2, which corresponds to a precipitation elasticity of runoff ε_P = 2.44 and temperature elasticity ε_T = -0.86. The former value agrees well with the results of our regression analyses, and we have thus adopted the precipitation elasticity ε_P = +2.5 for our study.

Hydrological modeling studies for similar basins in Africa generally showed lower values for the temperature elasticity of runoff, and we have thus adopted ε_T = -0.75[1]. Thus, a 10% (2.7^{0}C) increase in temperature (causing a 7.5% decline in runoff) and a concomitant 3% increase in precipitation (causing a 7.5% increase in runoff) would yield no net change in runoff. Projections of future precipitation and temperature were subsequently translated into annual basin runoff for the ensemble of 38 climate projections for the 21st century, centered on 2030, 2050 and 2070 (Fig. 2), by using the precipitation - temperature - runoff regression model of the form:

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1 The temperature elasticity of -0.75 corresponds to a temperature sensitivity of run equal to -0.75/T, or approximately -3% runoff per 0C temperature increase.
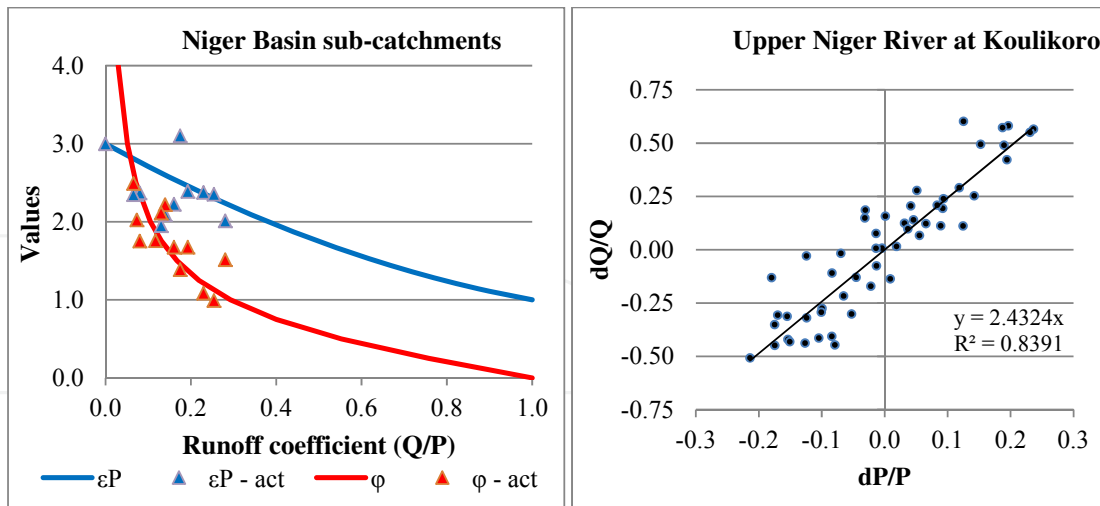
Figure 2. Theoretical and actual ε_P and φ parameter values for NRB sub-catchments, based on the runoff coefficient (left panel; blue and red lines represent theoretical values) and linear regression of historical changes in annual precipitation and runoff for the Upper Niger River at Koulikoro (right panel)
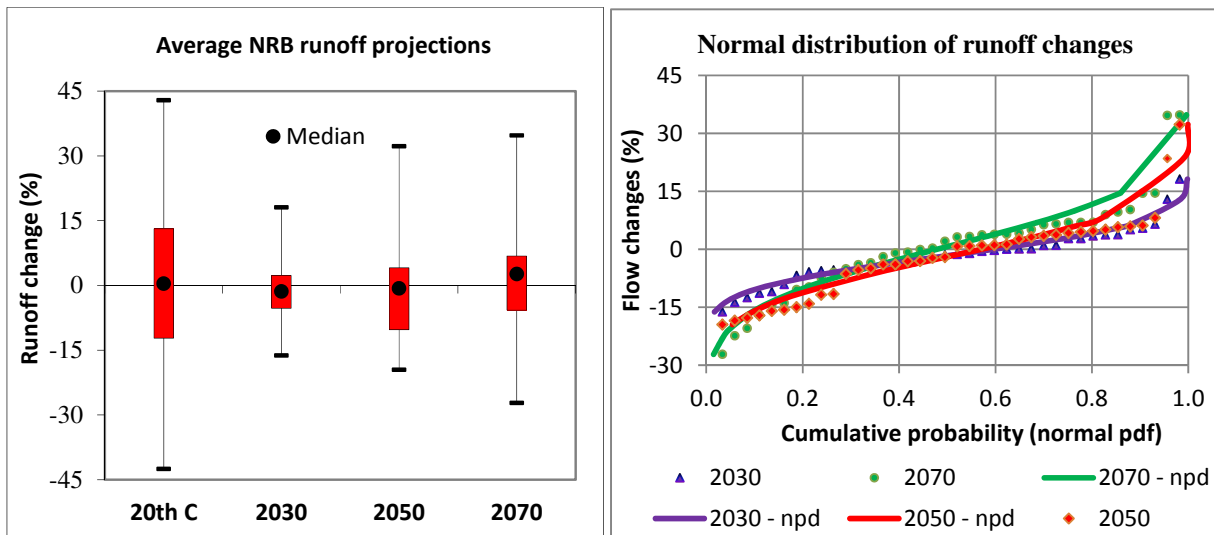

Figure 3. Runoff quartiles and probability distributions for projected runoff changes (2030, 2050 and 2070)

$$dQ/Q_0 = \varepsilon_P \, P/P_0 + \varepsilon_T \, dT/T_0$$

The projected mean flows are essentially constant over the 21st century at an average of 2% below the 20th century mean till 2050, with an insignificant increase of 1% by 2070; the standard deviation of projected mean flows is 7% by 2030 and 13% by 2070, reflecting the increasing uncertainty in climate projections for the distant future. The probability of a decrease in average annual runoff is just over 50%. The probability of a 20% decrease in average runoff by 2050 is minimal, which could be considered as a worst case scenario for standard project economic analyses for SDAP, with 2050 as an investment horizon. The projected mean flows adhere well to the normal probability distribution (Fig. 3, right panel).

By 2050 the projected temperature increase (8% or 2.1^{0}C) causes an average decrease of 6% in runoff due to increased evapotranspiration, which is partially compensated by a projected 4% additional runoff due to increased rainfall, yielding a net decrease in mean runoff of only about 2%. Since annual rainfall, temperature and runoff adhere to the normal distribution, we can estimate the distribution of projected changes in runoff from the expected average changes in rainfall and temperature, and the variances of these changes (as for example available from the Climate Portal and Climate Wizard), as follows:

$E\{dQ/\mu_Q\} = \varepsilon_P E\{dP/\mu_P\} + \varepsilon_T E\{dT/\mu_T\}$; E{...} denotes the expected/projected shift in means of P and T

$CV^2(dQ/\mu_Q) = \varepsilon_P^2 CV^2(dP/\mu_P) + \varepsilon_T^2 CV^2(dT/\mu_T)$; CV(...) denotes coefficients of variation of projections

The contribution of temperature variations to the variance of runoff is negligible due to its small CV compared to the CV of changes in precipitation. This further explains that the temperature elasticity cannot be estimated through regression analysis. Probability distributions of future annual runoff can thus be based on an estimation of the average change in runoff - based on projected changes in annual precipitation and temperature and climate elasticities of runoff - and a commensurate shift of the historical distribution of annual runoff, as long as the inter-annual variability of precipitation does not change.

While all analyses pointed to a precipitation elasticity of about +2.5, the choice of the temperature elasticity or sensitivity is less certain, yet critical for the outcome of climate risk assessment. Therefore, a sensitivity analysis was done for a precipitation elasticity of +2.5 and a temperature elasticity of -1.25^2 (instead of -0.75). Results indicate that by 2050 the increase of 8% in temperature (2.1^{0}C) would cause indeed an additional decrease of runoff by 4% due to the difference in temperature elasticities.

3. Quantitative climate risks for key water related sectors

Climate risks to key sectors are estimated on the basis of projected future runoff changes, where climate risk is defined based on probabilities of selected percentage changes in performance metrics relative to baseline operations. Recall that the baseline development scenario was defined in the preceding chapter as the scenario in which the Fomi (FO), Toussa (TA) and Kandaji (KD) dams and associated irrigation infrastructure are fully implemented. As previously discussed, the relationships between relative changes in runoff and relative changes in selected performance criteria at basin level were derived from numerous Mike-Basin runs for variations in runoff between -30% and + 10% of the 20th century baseline conditions, and water demands with a 5% increase compared to the 20th century baseline (Table 3, preceding chapter). The runoff changes required to cause specific changes in selected performance indicators are shown in Fig. 11 (preceding chapter). The results shown in Fig.

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2 The temperature elasticity of -1.25 corresponds to a temperature sensitivity of runoff equal to -1.25/T, or approximately 5% decrease in runoff per 0C increase in temperature, which is well above the values mostly found in literature.

11 for minimum flows are less realistic than the other results, since minimum flows are impacted mainly by changes in dry season flows and irrigation abstractions, rather than by changes in annual flows. They are indicative nonetheless of the sensitivity of minimum flows to climate changes.

Figure 4 shows probabilities of risks for the average (A) and 1/5 years (20% dry) performance of selected indicators (risk levels defined as shown in Fig. 3 of the preceding chapter), estimated as follows. The relationships between specific changes in the performance indicators and changes in the runoff required to generate those specific changes in most indicators is nearly linear in the most relevant domain of -20% to 0% of change in runoff (Fig. 11 of the preceding chapter). Thus, the performance indicators will also be distributed according to the normal probability distribution, similar to the projected changes in runoff. When we find e.g. a 25% probability that future mean flows (averaged over many years) will at least be 10% less than the present long-term mean flows, we also assume there is 25% probability that a specific performance indicator is at least xy% less than the historic indicator values; the xy% value is derived from the column '-10%R' in the performance matrix of Table 3 (preceding chapter). In reverse, to estimate the probability that e.g. projected hydro-energy generation will at least be 20% less than at present, we determine the runoff reduction required to cause 20% less hydro-energy (16% per Fig. 11 of the preceding chapter), and estimate the probability of such runoff reduction based on the normal distribution for the projected future runoff (2% in 2030 and 10% in 2070).

Figure 4 shows specific percentiles (5, 25, 50, 75 and 95%) of the selected performance indicators. The concerned percentiles of runoff changes were first determined from the normal probability distribution of projected future runoff changes; then the corresponding percentiles of each performance indicator were interpolated from the performance matrix in Table 3 of the preceding chapter.

The probability that by 2050 or 2070 one may see decreases of more than 20% (significant risk) in the various performance criteria is only 5 to 15% or less, other than for the minimum environmental flow conditions in the Inner Delta and Middle Niger, which are under severe risk. The probability that one may not be able to maintain the required minimum flows under the fully developed FO-TA-KD scenario is 100%. This will be primarily caused by (projected) increased water abstractions for irrigation at the large Office du Niger irrigation scheme in Mali. Hydro-energy, navigation and flooding of the Inner Delta vary similar to runoff variations, with runoff elasticities of about 1 to 1.2. There is 25 - 35% probability that by 2050 these sectors could suffer performance decreases above 10% (moderate risk). The probability that the performance decreases in these sectors would be between 10 and 20% is about 20% and the probability of performance decreases exceeding 20% is between 5 and 15%. Impacts on irrigated agriculture are minimal under the prevailing priority of water allocation to agriculture. Figures 3 and 4 serve to illustrate the main findings and conclusions of this CRA, as highlighted in the following.
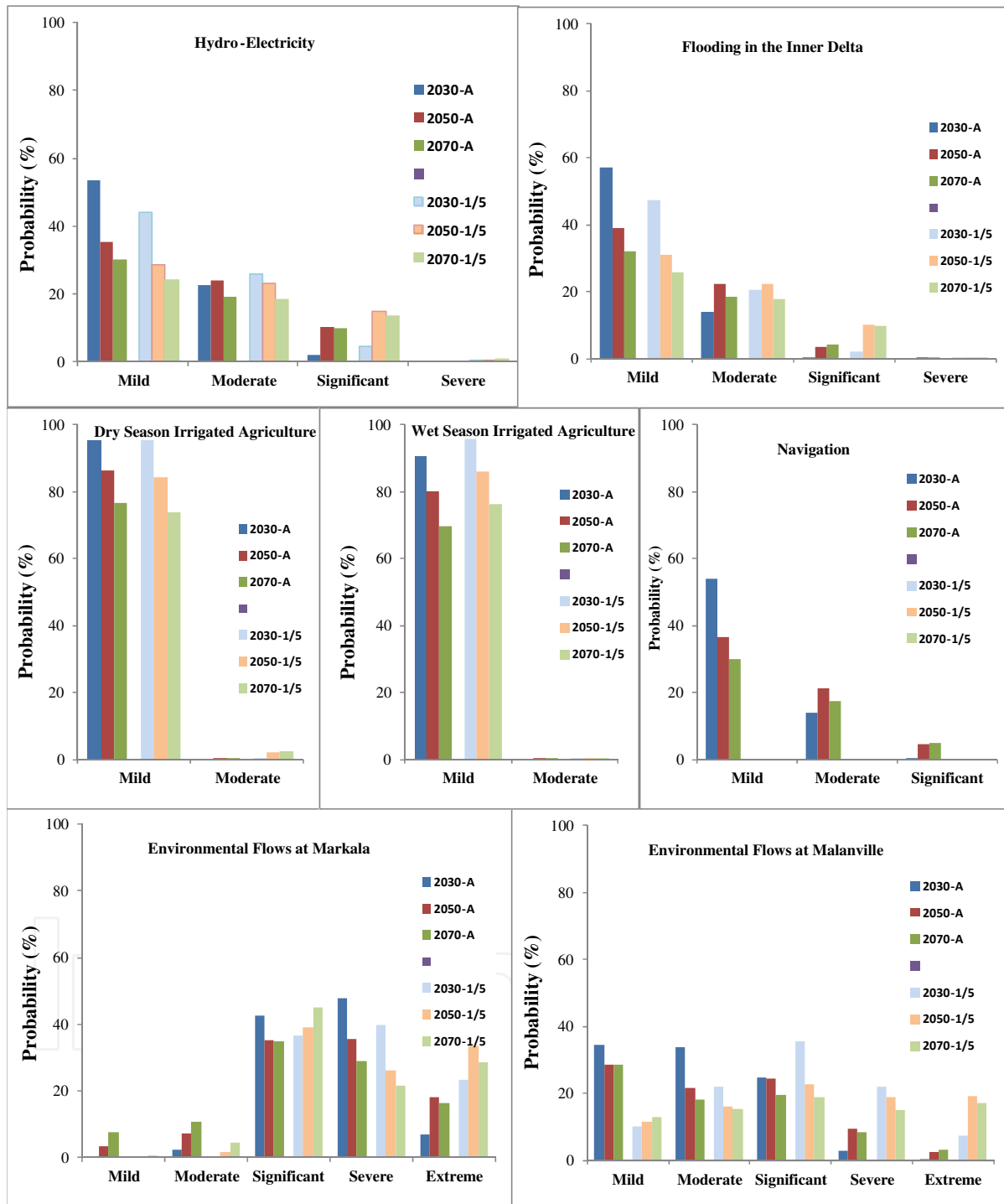
Figure 4. Probabilities of risks for average (A) and 1/5 years (20% dry) performance of selected indicators; risk levels are defined in Fig. 3 of the preceding chapter.
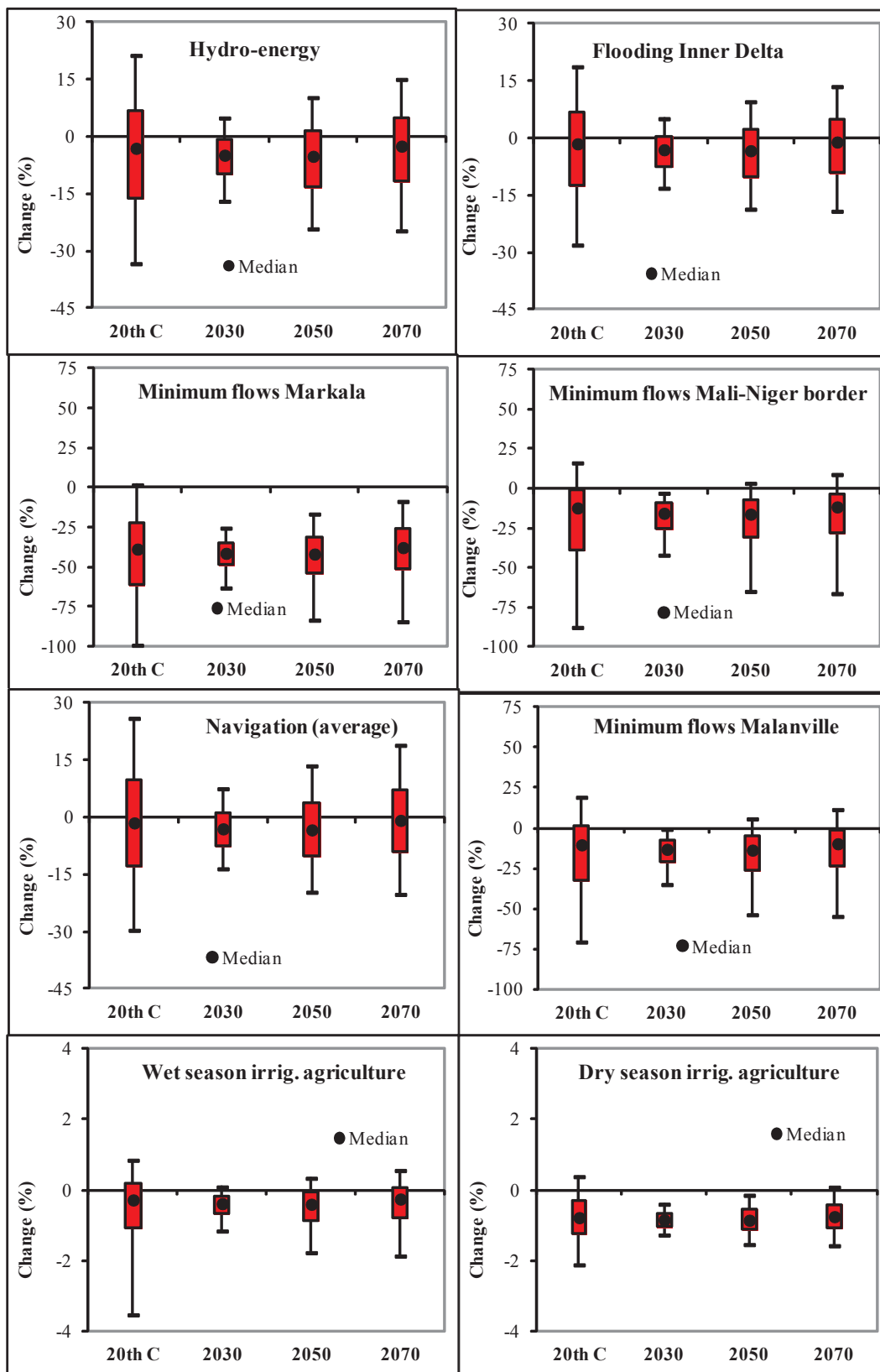
Figure 5. Percentiles (5, 25, 50, 75 and 95%) of selected performance indicators for an average year (Note: Minimum flow data refer to 10-day average flows)

3.1. Sensitivity of selected sectors to climate change

Irrigated agriculture is insensitive to projected climate changes; SDAP and particularly the construction of Fomi dam is an effective adaptation measure. Under SDAP total agricultural output in the NRB is projected to increase by nearly 450%. The current water allocation rules prioritize irrigation water demands in order to secure food production and alleviate poverty in the long term. This makes irrigated agriculture in the NRB insensitive to decreased runoff as a result of the projected climate changes, but it places pressures on the existing reservoir systems to provide a reliable water supply for hydro-electricity production, navigation, and environmental flows. These sectors are found to be more vulnerable to the risk of decreased runoff. Under the current water allocation rules, mild agricultural production decreases are likely to occur, but would generally be less than a few percentage points. As long as reservoirs can be fully replenished during the rainy season, climate change has little impact on the supply side of irrigation during the dry season. Indeed, by regulating the variability of the Upper Niger flow, SDAP and particularly the construction of Fomi dam will be good insurance for the protection of irrigated agriculture against the potential negative impacts of climate change.

Climate change impacts on hydro-energy, navigation, and Inner Delta Flooding are projected to be mild to moderate (less than 20% decrease). Hydro-energy, navigation and flooding of the Inner Delta vary similar to runoff variations, with runoff elasticities of about 1 to 1.2[2]. There is 25 to 35% probability that by 2050 these sectors could suffer performance decreases more than 10%, and the probability of performance decreases exceeding 20% is only between 5 and 15%. Hence, risks of climate change impacts on these sectors will be mild to moderate. These impacts are similar to the declines in navigation and Inner Delta flooding caused by the full implementation of the FO-TA-KD development scenario (10-20%).

Climate change impacts on minimum flows can be severe. Minimum flows entering the Inner Delta (downstream of the Office du Niger irrigation scheme in Mali) are sensitive to an increase in water demands by for example 5% at the Office du Niger (ON) irrigation scheme, due to increased future temperatures and evapotranspiration. The design of SDAP has planned irrigation development and abstractions during dry season irrigation at the ON such that minimum flows at Markala dam can just be maintained at the present ON water demands per hectare for dry season irrigation. The probability that by 2050 - under the FO-TA-KD development scenario - one may not be able to maintain the required minimum flows through the Inner Delta and the Middle Niger to Malanville at the Niger-Nigeria border is 100%.

Minimum environmental flows during the dry season are the most sensitive to climate change (particularly with increased irrigation water demands) under the present water allocation rules, with runoff elasticities on the order of 2.5 to 4.0[3]. By 2050 there is a 50% probability that once in 5 years the 10-day average minimum inflow to the Inner Delta will be less than 25 m^3/s; i.e. less than 60% of the adopted norm of 40 m^3/s. Relative decreases of minimum flows at the Mali-Niger border, Niamey and Malanville are slightly less severe.

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3 The large runoff elasticities of minimum flows indicate that moderate decreases in annual runoff can cause severe reductions in the minimum flows at Markala and further downstream on the Middle Niger.

Adaptations required for enhancing minimum Niger River flows. Minimum flows are severely impacted by increased water demands of the Office du Niger (ON) irrigation scheme due to increased evapotranspiration. Should higher priority be accorded to the sustenance of minimum flows, as per the Water Charter agreed between the NBA member countries - dry season irrigated agriculture could become moderately sensitive to climate change impacts, since the abstractions for irrigation at ON – as planned under the FO-TA-KD scenario - would need to be reduced in favor of releasing more water into the Inner Delta. This potential problem can be addressed by measures to increase the present low dry season irrigation efficiency at ON (about 30%), and/or by slightly reducing the future dry season irrigated areas, such that minimum flows can also be maintained in the future. Future abstractions during the critical low flow period February to May would by 2050 amount on average to 425 m^3/s, and would need to be reduced by about 25 m^3/s (6%) to avoid unacceptable minimum environmental flows passing Markala dam. This can be achieved by implementing irrigation system rehabilitations and water management measures aimed at increasing the dry season irrigation efficiency at ON by about 2%; presently the dry season irrigation efficiency at ON is less than 30%. Other options to reduce abstractions by at least 6% during the dry season would be to reduce the acreage projected to be cropped in the dry season by 6%, or to reduce dry season rice planting in favor of an extension of less water demanding horticulture and other non-rice crops.

Worst case scenario for project economic analysis. The probability of a 20% decrease in average runoff in the Niger Basin is minimal, which could thus be considered a worst case scenario for the standard economic analysis of infrastructure projects under SDAP. For example, a detailed economic analysis of the Kandadji hydro-power and irrigation project - located on the Niger River in Niger near the Malian border - was performed as part of project appraisal (World Bank, 2012), yielding an Economic Internal Rate of Return (EIRR) of 13.5% for the base case (2005 hydrology). Sensitivity analyses showed that the EIRR would reduce to 12.4% for an overall decline of 20% in the runoff of the upstream basin, still above the World Bank's financing threshold rate of 12%. The runoff elasticity of EIRR was assessed at about 0.4, i.e. a 20% decrease in runoff causes an 8% decrease in the EIRR (1.1 percentage points down from 13.5%). Thus a 30% decline in average runoff would push the EIRR below the threshold rate of 12%.

3.2. Economic analysis of SDAP under climate change conditions

Potential climate change impacts on the economic performance of SDAP are modest. The economic analysis of climate change impacts on the full SDAP investment plan has focused on hydro-power development with associated irrigation development as the main drivers for SDAP. Various proposed Run-of-River (R-o-R) hydropower schemes were also included. Primary economic benefits from the FO-TA-KD Program and R-o-R schemes will accrue from the combination of hydropower generation and new schemes brought under irrigation. Secondary benefits include provision of water supply (particularly for towns and villages along the Middle Niger River), environmental benefits of wetlands (reservoir surface areas and newly irrigated rice planted areas), fish production in the new reservoirs, ecosystem regeneration in the Niger Valley, and livestock production. Economic and environmental losses will occur in

the Inner Delta (rice production, environmental benefits of wetlands, fisheries and livestock), related to navigation in the Middle and Lower Niger, and due to reduced hydro-energy generation at Kainji and Jebba dams in Nigeria caused by upstream water diversions for irrigation and evaporation losses from the new reservoirs. Losses due to climate changes, which would also occur under the prevailing (2005) "natural conditions", such as losses of Inner delta flooded areas and losses of hydro-energy at Kainji and Jebba dams due to climate change, have been excluded from the analysis of climate change impacts on the SDAP Program. Results of the economic analysis for the SDAP, in terms of EIRR, are shown in Table 1, for the baseline (2005) hydrological conditions and for the situation with a 20% flow reduction due to climate change during the entire life of the SDAP project components (2015 – 2050).

Development scenario	EIRR (2005 hydrology)	EIRR under 20% runoff reduction	Runoff elasticity of EIRR
FO-TA-KD + R-o-R	13.0	11.3	0.64
FO-KD + R-o-R	14.6	13.0	0.55
FO-TA-KD; no R-o-R	9.5	7.9	0.84
FO-KD; no R-o-R	11.7	10.2	0.64
FO-TA-KD + R-o-R; no irrigation development	14.1	12.3	0.64
FO-TA-KD; no R-o-R; no irrigation development	10.1	8.0	1.0
KD + 45,000 ha irrigation (no R-o-R)	13.5	12.4	0.42

Table 1. Estimated EIRR for various SDAP development scenarios, with/without impacts of climate change

Potential climate change impacts on the economic performance of the SDAP Program are assessed as mild (<10%) to moderate (<20%). Under the above 'worst case' scenario of 20% reduction in the long-term average basin runoff, the projected climate change impacts on irrigated agriculture, navigation, minimum flows and flooding of the Inner Delta have only a minor impact on the overall economic performance of the SDAP. In economic terms the only significant impact of reduced runoff due to climate changes would stem from its direct impact on hydro-energy production. In the 'worst case scenario', with the 20% flow reduction imposed as from 2015, one can expect a 1.7% reduction in the EIRR of 13% for the SDAP under the base case (2005) hydrological conditions. The runoff elasticity of the EIRR for the SDAP is about 0.6, compared to 0.4 for the Kandadji (stand-alone) Program. The investment in Run-of-River hydropower schemes appears to be the most beneficial component of the SDAP, since it increases the EIRR of the FO-TA-KD scheme by 3.5%. It allows the SDAP to maintain a robust EIRR above 12%, and even more than 11% in the 'worst case' scenario. Without R-o-R schemes the EIRR drops well below 10% under conditions of 20% reduction in average runoff due to climate change.

Irrigated agriculture achieves an adequate EIRR as long as the cost of the new dams are treated as sunk cost, i.e. are fully charged to hydropower development. Losses to dry season irrigated agriculture under climate change, estimated at 8% for an average runoff reduction of 20%, cause only a loss of 0.1% of the EIRR under the 'worst case' runoff scenario. Similarly, the impacts of losses due to reduced flooding of the Inner Delta (including losses to wetlands, fisheries, floating rice production and livestock) caused by Fomi dam and the planned large extensions of the Office du Niger irrigation schemes have no significant impact on the EIRR, causing only a loss of 0.2% in the EIRR. Impacts of climate change on these losses are similar under the present (2005) as well as future (FO-TA-KD) hydrological conditions, and were thus excluded from the SDAP economic analysis. Finally, losses to navigation under the FO-TA-KD scenario cause only a reduction of 0.2% of the EIRR.

4. Conclusions

While the risk of climate change has generated many policy and adaptation initiatives aimed at combating it, few of these initiatives are based on quantitative assessments of expected impacts to specific sectors. We argue that such assessments are necessary to convince decision makers and as a means of prioritizing and targeting scarce resources at the most vulnerable sectors or those sectors likely to create the largest domino effect. This study represents an important contribution towards that goal. Beginning with a bottom-up definition of risk, we estimated the expected magnitude of climate change, principally precipitation and temperature changes, translated those changes into runoff changes, and then estimated the impacts of projected runoff changes on key development sectors in the Niger Basin with respect to thresholds of changes in specific performance indicators.

The results show that climate change impacts in the Niger Basin will be generally mild (<10%) to moderate (<20%). By 2050, average annual temperatures in the Niger Basin would rise by 2.1^0C, an 8% increase over baseline values. The increase in temperature will increase evapo-transpiration, leading to an average decrease of 6% in runoff. However, a projected 4% additional runoff due to increased rainfall will partially offset the decreased runoff, producing a net decrease in mean runoff of only about 2%. It is notable that the magnitude of these changes pale in comparison to the historical patterns of variability in precipitation and runoff, observed over the NRB in the 20th century. Even so, the results should be interpreted cautiously. In general, while climate projections do a good job on simulating the mean, they are generally incapable of reproducing variability around that mean. Thus, whereas the change in the mean may be small, variability around the mean may trigger shocks to economic and agro-ecological systems disproportionate to the change in mean conditions.

With specific respect to the Niger Basin SDAP and under the current water allocation rules, irrigated rainy season agriculture ('hivernage') remains insensitive to climate change even under severe reductions of runoff (e.g. up to 30%). Dry season irrigated agriculture ('contre-saison') and the sustenance of environmental flows during the low flow season are interlinked and respectively mildly and extremely vulnerable to severe reductions of runoff. However,

with (i) the implementation of Fomi, Taoussa and Kandadji dams, along with (ii) optimal basin-wide reservoir management, (iii) increased irrigation efficiencies, particularly at the Office du Niger, (iv) gradual shifts from dry season rice to less water demanding non-rice dry season crops, and (v) other similar adaptation measures to improve water use efficiencies in particularly dry season irrigated agriculture, these 'sectors' can be well protected from the impacts of significant climate change.

Severe reductions in runoff would cause equally severe reductions in generated hydro-energy, navigation and flooding of the Inner Delta (projected to be mild to moderate under the present climate change projections). Such severe future impacts on (particularly) hydro-energy generation can only be minimized by reducing rainy season irrigated agriculture in the basin and/or by the construction of additional storage reservoirs along with hydro-energy generation facilities in the Upper Niger Basin and in Nigeria, particularly in the Benue Basin, which has mostly untapped hydro-power potential.

It is important to emphasize that in this report the risks are calculated based on the long term (i.e. 30 years) shift in mean precipitation and temperature values; they do not account for inter-annual or decadal variability. We do not consider this a serious limitation since the baseline period (1966-1988) - used also for the design of the FO-TA-KD scenario and simulated with the Mike Basin model - comprises arguably the most variable period in the historical data. It is noteworthy that the NRB has historically experienced runoff shortages greater than the projected levels. Thus, the historical experience provides an analogue for dealing with future climate; for water managers and farmers who do not know what to expect in the upcoming rainy season, managing the impacts of intra-seasonal, inter-annual variability of climate would be the priority to start with. Managing the near-term climate variability has also the potential to better prepare for dealing with long term-climate change impacts. Therefore, the use of seasonal to inter-annual hydrologic forecasts in reservoir operations and planning could be an important adaptation opportunity.

Acknowledgements

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