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Healthy or Unhealthy Migrants? Identifying Internal Migration Effects on Mortality in Africa using Health and Demographic Surveillance Systems of the INDEPTH Network

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Keywords: Internal Migration, sub-Saharan Africa, Mortality, Health and Demographic Surveillance System, INDEPTH Network

Abstract:

Migration has been hypothesised to be selective on health but this healthy migrant hypothesis has generally been tested at destinations, and for only one type of flow, from deprived to better-off areas. The circulatory nature of migration is rarely accounted for. This study examines the relationship between different types of internal migration and adult mortality in Health and Demographic Surveillance System (HDSS) populations in West, East, and Southern Africa, and asks how the processes of selection, adaptation and propagation explain the migration-mortality relationship experienced in these contexts. The paper uses longitudinal data representing approximately 900 000 adults living in nine sub-Saharan African HDSS sites of the INDEPTH Network. Event History Analysis techniques are employed to examine the relationship between all-cause mortality and migration status, over periods ranging from 3 to 14 years for a total of nearly 4.5 million person-years. The study confirms the importance of migration in explaining variation in mortality, and the diversity of the migration-mortality relationship over a range of rural and urban local areas in the three African regions. The results confirm that the pattern of migration-mortality relationship is not exclusively explained by selection but also by propagation and adaptation. Consequences for public health policy are drawn.

Research Highlights:

1. This study simultaneously test known hypotheses relating to migration and mortality
2. A methodological framework identifies selection, adaptation and propagation effects
3. Migration status and exposure are sufficient to identify above effects
4. HDSS data reveal important differences in selection and universal adaptation
5. Approach helps to identify target populations for local health interventions

1. Introduction

Internal migration, understood as a change in usual residence within a country, is a much more common event than other demographic phenomena such as death or birth, especially with secular fertility decline. In the mid-2000s, the median Aggregate Crude Migration Intensity (ACMI), a measure of all permanent changes of address within a country, was 7.5% for 1-year period in a range of 45 countries around the world (Bell et al. 2015), and this excludes international migrations which are estimated at only 0.12% a year, i.e. 60 times less than internal migration (Abel and Sander 2014). To give a sense of scale, the world crude birth rate was only 2% a year and the world crude death rate less than 1% (United Nations Population Division 2014). Across the 45 selected countries for which data were available, only four had an 1-year ACMI smaller than 2% (Bell et al. 2015).

Migration is not only a major demographic event, but it also has the potential to influence other demographic events. In this paper, we investigate the relationship between internal migration and health, using mortality as major indicator of health. This relationship is important because health status may both impede and stimulate migration, while migration, often motivated by economic benefits, can result in negative health outcomes, possibly leading to death (Gerritsen et al. 2013). Although studies abound on mortality and to a lesser extent on migration, their relationship has been far less investigated. Where the migration-mortality relationship has been investigated, international migration has been the focus, notably to explain the "Latino paradox" whereby migrants from Latin America have demonstrated a survival advantage in USA despite their lower socio-economic status (Abraído-Lanza et al. 1999). This paradox may or may not present in the same way in the case of internal migration but, any effect of this relationship would likely have a much higher impact on survival since internal migration is experienced by almost every person over their lifetime (Abel and Sander 2014; Bell et al. 2015).

In this paper, we revisit the theory about the migration-mortality relationship, accounting for different types of migration flow and for the level of health risk in origin and destination areas. Using information collected on migration status and duration of residence, we design a method to identify a set of hypotheses attached to the migration-mortality relationship, and apply this method to interpreting data collected in nine district populations located in West, East, and Southern Africa that present different patterns of mortality and migration. By identifying the most likely explanation for the divergent patterns seen in these different settings, we aim to better identify the categories of migrants at higher risks, in order to identify the target populations for local health interventions.

2. Literature review

The migration-mortality relationship is not foreign to the broader issue of epidemiological transition. Rather than review the role of migration in this transition, this section will build on previous reviews on the subject (Collinson et al. 2014). In the context of low- and middle-income countries (LMICs), the health transition has been at the same time spectacular in its speed and more heterogeneous than in higher-income countries (HICs) (Salomon and Murray 2002). The transition has led to a general decline in mortality but also, particularly in African countries, to a double burden of disease characterised by the emergence of non-communicable diseases (NCDs) and life-style diseases associated with urbanisation (Ezzati et al. 2005). These coexist with persistent, new and revitalised diseases, such as malaria, HIV/AIDS and TB (Boutayeb 2006). This double burden runs counter to mortality decline. Whereas urbanisation has generally contributed positively to health in the past, there are concerns that under conditions of slow economic development and weak infrastructure management it could actually drive an increase in cardio-vascular disease (CVD) (Yusuf et al. 2001) as well as in respiratory and diarrheal diseases linked to poor environmental conditions (Harpham 2009).

Migration plays an important role in sustaining livelihoods in LMIC countries. As people migrate, remittances and information circulate and help to maintain links between sending and receiving communities (White and Lindstrom 2006). However, migration may improve well-being and at the same time expose migrants to health risks. With respect to mortality, it is not clear whether the net effect of migration is positive or negative, and in which circumstances. Considering the sheer volume of migration and its high sensitivity to livelihood conditions, it is necessary to carefully examine the hypotheses relating to migration and health (for references and glossary of terms used in migrant and health analysis, see Urquia and Gagnon 2011).

The first and most-utilised hypothesis concerning migration and health is the "healthy (im)migrant" hypothesis. This hypothesis proposes that migrants are selected in their place of origin amongst the more healthy since they must prepare to adapt to their new place of residence. Positive selection on health would then operate through migration. In ordinary migration, because of a high selection effect at origin, the health of migrants can actually be better than that of non-migrants at the destination location. This *selection effect* could explain the epidemiological paradox that even if originating from places with high health risks, migrants may have better health than the non-migrants in destination areas living in superior (health) conditions (Urquia and Gagnon 2011).

This would apply provided that the migration conditions are not too stringent, as may be the case for refugees and internally displaced people. The possible effect of the migration conditions is called the *disruption effect* and is usually attributed to the conditions around the time of migration (just before and just after, the specific time span to be defined by the migration itself). This effect has been particularly studied for reproductive health (Choi 2014; Goldstein 1973; Hervitz 1985; Kulu and Steele 2013).

The migrants' health may gradually converge to that of non-migrants following exposure after migration at the destination. This *adaptation effect* (also named assimilation effect) is observed over

time, i.e. with duration of residence, and can only present if there is a difference between the health of non-migrants and the health of migrants just after their arrival. It is often presented as a loss of (negative or positive) selection effect over time (Urquia and Gagnon 2011).

Lastly, one cannot exclude that the migration may have no effect at all on the migrant's health. The health conditions acquired in the place of origin could persist after migration. This is the *socialisation effect* whereby conditions and behaviours acquired at the place of origin, in particular during childhood, persist in later life whatever the new environment the migrant is exposed to (Kulu 2005). Adaptation effect may still exist but may not be sufficient to counterbalance the socialisation effect, i.e. the persisting effect of exposure prior to migration. The two effects, adaptation and socialisation, are therefore opposed.

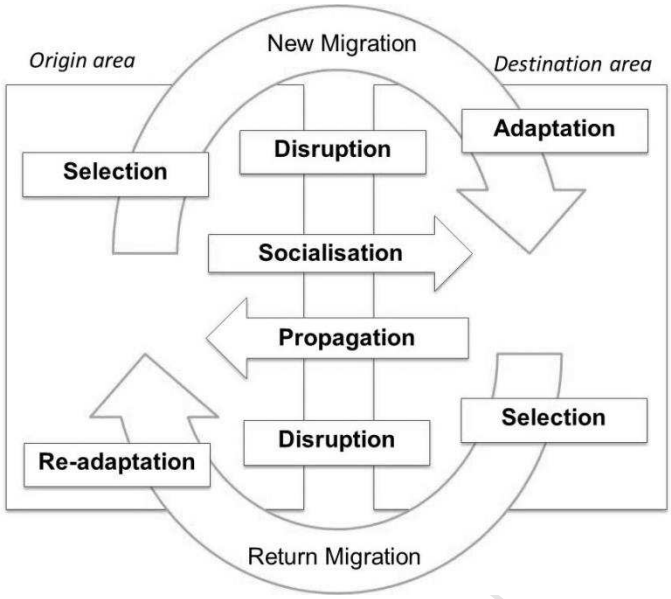
Research into the migration-health relationship often seeks to verify these four effects through empirical analysis. In the remainder of this paper we will refer to the SoSAD hypotheses to discuss the hypotheses that verify Socialisation, Selection, Adaptation and Disruption effects. To note, the SoSAD hypotheses do not only apply to the study of diseases but have been extensively used since the 1960s to analyse reproductive health in relation to migration.

The SoSAD hypotheses have been associated with migration flows from less to more affluent areas, generally from rural to urban areas. These are the most common internal migration flows generally experienced by youth at the beginning of their working lives. Other flows have sometimes been considered and these have prompted the alternative "unhealthy return migrant" hypothesis, i.e. that of negative selection on health. For example, studies in South Africa have shown that prominently rural sending areas experience an excess mortality due to people 'returning home to die' (Clark et al. 2007; Collinson et al. 2009). The assumption is that new migrants will be attracted to places with better economic opportunities and living conditions, generally in urban areas, but that some migrants may partake in high risk behaviour (smoking, drinking, unhealthy diets, risky sexual encounters, violence) and may have difficulty accessing

health services in these destinations, in particular if they reside in slums. This phenomenon is referred to as the segmented adaptation effect. As a consequence, the migrants will return to their place of origin when their health deteriorates to seek health care and support, thus contributing to higher mortality in rural areas. This return migration is also called the "midnight train" effect after a soul song by this name that tells about a failed musician in Los Angeles who takes the midnight train back to Georgia, his place of origin (Nauman et al. 2015). This return of unhealthy migrants creates the so-called "salmon bias" that leaves the healthier at destinations (Abraído-Lanza et al. 1999; Lu and Qin 2014).

The SoSAD hypotheses are usually intended for new (first-time) migration, but may apply equally to return migration, although not necessarily with the same effect on health. So, it is important to look at bi-directional migration flows between origin and destination areas. For simplicity, we present in Figure 1 the SoSAD hypotheses for two main migration flows, new migration and return migration. The selection and disruption hypotheses are generally synonymous whatever the direction of migration. However, the equivalent of socialisation, which refers mainly to behaviours and health conditions acquired during childhood, differs in the case of return migration, i.e. after the migrant spent some time at destination. We will refer to the *propagation effect* as the symmetrical effect to socialisation. This propagation (or diffusion) effect is conditional on adaptation to the place of destination and identifies the possibility that behaviour and health conditions at destinations can be spread to origin areas through return migration. After return migration, the migrant may re-adapt to its origin area, hence the *re-adaptation effect*.

Figure 1: Interaction between migration and health before and after new migration or return migration



There is an ambiguity with regards to the interplay between the environment and the behaviour of the migrants. For example, one may consider the exposure to a specific environment as fairly homogenous, while migrants may have different behaviours (segmented adaptation) that lead to negative selection by return migration or to positive selection through permanent settlement in the host area. The alternative explanation is that the environment is heterogeneous, exposing migrants to different risks depending on where they reside, while migrants may be uniformly positively selected through migration.

3. Interpreting Migration-Mortality Relationship in Local Context

3.1. Why migration matters for monitoring health at local level

Districts are often highly affected by changes in migration trends, depending on the local economic context and on the larger regional, national, or even international environment. The migratory balance can change sign from one year to the next. Epidemiological changes usually occur at a slower pace but may be dramatically affected by migration trends. A health district

officer may therefore see unexpected changes in the prevalence of mortality that do not necessarily relate to local health determinants and policy. Comparing local death statistics with regional or national estimates might not be very helpful for this district officer if she cannot attribute changes to either local or larger context. However, with simple variables on migration status and duration of exposure in and out of the district, the methodological framework proposed below will help her to identify selection, adaptation and propagation effects that might drive local public health policy towards the correct targets.

Monitoring local mortality trends can be achieved through regular vital statistics when available, i.e. in developed countries, or with a health and demographic surveillance system (HDSS) circumscribed to a local area in the case of LMICs. HDSSs have been developed in areas, usually the size of an administrative district, where population vital registration is absent or weak. The HDSS platform generates prospective, longitudinal data on demographic and health dynamics and captures all vital events such as births, death and in- or out-migrations within the surveillance population. The HDSS begins with a baseline census of the full population and subsequently tracking of individual's demographic events, on an on-going basis, at prescribed intervals within the study population (see Sankoh and Byass 2012a for more details of the HDSS methodology).

3.2. Identifying selection and exposure effects

Although HDSS platforms offer detailed longitudinal data on demographic events, information is usually lacking on the exact circumstances surrounding the in- and out-migration, as well as detail concerning the risk exposure outside of the surveillance area. However, migration status and duration of exposure can be precisely identified for each individual during the observation period in the surveillance area. This is possible since in-migration (of both new and return migrants) and out-migration is captured in prospective, longitudinal datasets that are regularly updated. Table 1 will be used to classify the expected differences in mortality risk between non-migrants (the reference category), new in-migrants, and return migrants, depending on short or longer exposure

in the HDSS, as well as longer exposure outside the HDSS in the case of return migrants. Table 1 also presents the three expected effects of propagation/socialisation, selection and adaptation/re-adaptation, evaluated net of one another.

In the absence of direct information on the selection process and on health risks exposure before and after migration, the table identifies all possible combinations of selection effect amongst migrants. Each combination of selection and exposure effects generates a particular set of relative risks. Table 1 identifies every possible combination of relative mortality risk whose direction can be negative, positive or equal to that of non-migrants.

The length of exposure (short or long) before and after a migration is important to establish the direction or presence of the effects of propagation, and (re-)adaptation. For return migrants, we can control for the exposure out of the site before return migration, in addition to short- and long-term exposure in the site after return migration. For new migrants, we control the exposure in the site following entry by migration. The only SoSAD hypothesis concerning mortality that we cannot test is that of disruption, because we cannot measure mortality before and after migration for the same individuals. Therefore, Table 1 does not include the disruption hypothesis depicted in Figure 1.

The respective effects of selection, adaptation and propagation are easier to understand for return migrants. The propagation effect is determined on the basis of a "long exposure out", i.e. the health risks brought about by exposure in the location *before* return migration, while the selection effect is determined after return migration and is expressed as the difference in mortality between return migrants and non-migrants in the location. This selection effect can be ascertained shortly after the migration event (i.e.: following a "short exposure in") and it is established by examining the differences in mortality risk between return migrants and non-migrants in the population. The re-adaptation effect is ascertained after a longer duration following the migration event (the

effect of "long exposure in"). This effect is established by examining whether mortality of return migrants has gradually converged to that of non-migrants.

For new migrants to the HDSS, the effect of adaptation and selection are the same as in the case of return migration. However, since we do not have information on the exposure before the new migration, captured as the socialisation effect, we have to consider the possible differences in health risk exposure before and after the migration. We use these to infer a socialisation effect which we view as being synonymous to the propagation effect in return migrants.

3.3. Interpreting results

As explained above, Table 1 shows the expected direction of the relationship between migrants and non-migrants with respect to mortality risk when different situations obtain. Any of the theoretical premises described above can be present and this table provides an interpretative device that indicates which theoretical premise, or combinations thereof, would be most likely to provide the observed results. More description is given below for return migrants and for new in-migrants.

For Return Migrants

Columns 1-6 present the possible combinations of exposure effects that may be present where return migrants are negatively selected on health. Negative selection is identified when a return migrant's risk of mortality, following a short exposure in the HDSS, is greater than that of a permanent resident. This is attributed to conditions acquired at the migration destination. Following a longer exposure in the HDSS, the risk of mortality for return migrants might remain higher or might converge to the same risk as that of the permanent residents. This re-adaptation effect is deemed either negative or positive accordingly. For return migrants, the relative risk of mortality following a long exposure outside the HDSS can be contrasted with the risk of mortality following an exposure outside the HDSS of shorter duration. Following a longer

exposure outside the HDSS, the risk of mortality amongst return migrants may be the same, greater than or less than that of return migrants with a shorter outside exposure. This is the propagation effect that would be deemed 'not present', 'positive' or 'negative' accordingly.

Columns 7-9 present the possible combinations of effects where no selection is identified (i.e. the mortality risk of return migrants with a short exposure in the HDSS equal to the mortality risk of permanent residents in the HDSS). In the case of no selection effect, the re-adaptation effect is not testable by definition. The effect of long versus short exposure outside the HDSS for return migrants is determined in the same way as previously. Longer versus shorter exposure may result in mortality risk that is equal, less than or greater than permanent residents, and the propagation effect determined as 'no effect', 'positive effect' or 'negative effect'.

The final set of expected combinations for return migrants are presented in Columns 10-15. These relate to the instances where return migrants are positively selected on health (i.e. their risk of mortality following a short exposure in the HDSS is lower than that of the permanent residents). After a longer exposure in the HDSS, the risk of mortality may either converge to, or remain lower than, that of the permanent residents. Re-adaptation is present only in the case of the risk following a longer exposure in the HDSS being equal to that of permanent residents (i.e. where the risk of mortality remains lower amongst return migrants, re-adaptation is assumed to not have taken place). The propagation effect is determined in the same way as described for other cases.

For new in-migrants

The above approach differs in the case of new (in-)migrants to the HDSS, because the exposure prior to entering the HDSS is long and its effect cannot be measured directly. Therefore, only the effect of short and long exposure following migration into the HDSS is available to identify the three hypotheses for in-migrants. The interpretation of exposure in the site is conditional on knowledge of the difference in health risks before migration (labelled 'B') and after migration

(labelled 'A'). The expected direction of the difference in health risks before and after migration for new migrants is the same as the effect of long exposure outside for return migrants. Therefore, for in-migrants, both the "short exposure in" and "long exposure in" effects are the compound of the selection effect and the difference in health risks before and after migration i.e. the selection and adaptation effects are not discriminated from the socialisation effect.

Where health environments are assumed equal (i.e. B=A), there is no expected socialisation effect and the effect of short and long exposure in the HDSS site on health risk is the same as that described for return migrants. Where migrants are negatively selected on health (columns 1 and 2), their risk of mortality following a short exposure in the HDSS is expected to be greater than that of permanent residents. After a long exposure in the HDSS, a migrant's mortality risk may converge to that of permanent residents or remain higher (corresponding to a presence or absence of adaptation effect). Where no selection effect is present (column 7), a short or long exposure in the HDSS predicts no differences in mortality risk between in-migrants and permanent residents, and adaptation is not testable. In the case of positive selection (columns 10 and 11), the mortality risk amongst in-migrants can be expected to be lower than the resident population following a short exposure in the HDSS. Following a longer exposure the mortality risk is expected to converge to that of the resident population (an adaptation effect) or remain lower (no adaptation effect).

Where the environment before migration carries lower mortality risks than the destination environment (i.e. B<A), a positive socialisation effect can be inferred. In cases where the selection effect of new in-migrants is negative (columns 3 and 4) the mortality risk of in-migrants after a short exposure in the HDSS will equate to that of permanent residents, i.e. the effects of a better prior health environment and negative selection will equalise the risk. A longer exposure can result in either equal mortality risks across both groups (where no adaptation effect is inferred) or lower mortality risk amongst the in-migrant group (where adaptation is assumed to

have cancelled out the selection effect leaving the environment effect only). In cases of no selection (column 8), the migrant's better health environment before migration creates a lower mortality risk for in-migrants following a short and long exposure in the HDSS compared to permanent residents and the adaptation effect is not testable. Where in-migrants are positively selected on health, and the prior health environment is better (columns 12 and 13), the mortality risks following a short and long exposure in the HDSS will be lower than the resident population. However, where the degree/magnitude of risk following a longer exposure is reduced an adaptation effect can be inferred (column 12).

Finally, if the health environment prior to migration carries higher mortality risks than the destination environment (i.e., B>A), a negative socialisation effect is inferred. Where this is coupled with negative selection (columns 5 and 6), the mortality risk amongst migrants following both a short and a long exposure in the HDSS will be higher than for the resident population. Where the degree/magnitude of higher risk is reduced over time, an adaptation effect may be inferred (column 5). In the case of no selection effect amongst in-migrants (column 9), the mortality risks relative to permanent residents of the HDSS will be higher after both a short and a long exposure in the HDSS, and the adaptation effect is not testable. In the case of a positive selection effect amongst in-migrants, the relative mortality risk amongst migrants is assumed to be equal following a short exposure in the HDSS, i.e. the effects of a worse prior health environment and positive selection will even out the risk. The mortality risk will either remain equal following a migrant's longer exposure in the HDSS, in which case no adaptation effect is inferred, or migrants' mortality risks may be higher than the resident population, in which case adaptation is assumed to have cancelled out the selection effect leaving the environment effect only.

3.4. Limits to interpretation

It is reasonable to assume that in relation to rural HDSSs, new migrants generally come from neighbouring areas with the same level of health risks as the HDSS area. In this case, the assumption of no difference in health risks before and after migration (i.e. B=A), is sensible. The combination of selection and adaptation hypotheses can thus be uniquely identified in columns 1, 2, 7, 10, and 11. However, in urban areas, the assumption is less valid because new migrants may come either from rural areas or from urban areas, which are very heterogeneous. Consequently health risks exposure may be higher before migration (B>A), risks may be equal (B=A), or health risks exposure may be lower prior to migration (B<A).

The literature on new migration (Urquia and Gagnon 2011) has largely assumed the combination of positive selection of migrants (healthy migrant hypothesis) moving to better-off areas from areas with adverse health conditions (negative socialisation hypothesis) and integrating after some time to become undistinguishable from non-migrants (convergence hypothesis) (column 14). Return migration is assumed to be associated with positive propagation effect, re-adaptation and negative selection in the "midnight train" case (column 3) or with positive selection in the opposite case (column 12). However, there are potentially twelve other combinations, when one considers the possibilities of no selection effect, no socialisation/propagation, and no (re-)adaptation (as outlined in Table 1). The observed patterns are expected to be much more diverse than those in the literature.

It is possible that the migration-mortality relationships are not only generated by the combination of selection and exposure, but also by other processes unaddressed, and therefore uncontrolled for in this paper. In addition, Table 1 only indicates the direction of the effects, not their magnitude. Any departure from the proposed patterns in Table 1 will be interpreted as a failure to explain the migration-mortality relationships with selection and exposure effects using the proposed theoretical framework.

Consequently, the specific objectives of the study are as follows:

- To confirm the diversity of the migration-mortality relationships over a range of countries and residence types in Western, Eastern and Southern parts of Africa;
- To confirm that the pattern of migration-mortality relationships is mainly generated by the combination of three processes: selection, adaptation, and socialisation/propagation;
- To identify the most likely explanation for the patterns of mortality in contexts characterised by high mobility, and to check whether they conform to the well-known healthy migrant and unhealthy return migrant hypotheses;
- To help local health authorities to identify the categories of migrants for targeted interventions.

346 **Table 1: Expected mortality differences between migrants and non-migrants for different combinations of selection and exposure effects**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
CASE OF RETURN MIGRANTS															
Expected difference in mortality risk between return migrants and non-migrants:															
Short exposure in	>	>	>	>	>	>	=	=	=	<	<	<	<	<	<
Long exposure in	=	>	=	>	=	>	=	=	=	=	<	=	<	=	<
long exposure outside	=	=	<	<	>	>	=	<	>	=	=	<	<	>	>
Selection Effect	neg	neg	neg	neg	neg	neg	none	none	none	pos	pos	pos	pos	pos	pos
Re-adaptation effect (i.e. convergence with non-migrants)	yes	no	yes	no	yes	no	n.t.	n.t.	n.t.	yes	no	yes	no	yes	no
Propagation effect (i.e. origin conditions persist at destination)	no	no	pos	pos	neg	neg	no	pos	neg	no	no	pos	pos	neg	neg
CASE OF NEW MIGRANTS															
Assumed difference in health risks exposure before (B) and after (A) migration	**B=A**	**B=A**	B<A	B<A	B>A	B>A	**B=A**	B<A	B>A	**B=A**	**B=A**	B<A	B<A	B>A	B>A
Expected difference in mortality risk after migration between new migrants and non-migrants:															
Short exposure in	**>**	**>**	=	=	>>	>>	**=**	<	>	**<**	**<**	<<	<<	=	=
Long exposure in	**=**	**>**	<	=	>	>>	**=**	<	>	**=**	**<**	<	<<	>	=
Selection Effect	**neg**	**neg**	neg	neg	neg	neg	**none**	none	none	**pos**	**pos**	pos	pos	pos	pos
Inferred adaptation effect (i.e. convergence with non-migrants)	**yes**	**no**	yes	no	yes	no	**n.t.**	n.t.	n.t.	**yes**	**no**	yes	no	yes	no
Inferred socialisation effect (i.e. persistence of exposure B)	**no**	**no**	pos	pos	neg	neg	**no**	pos	neg	**no**	**no**	pos	pos	neg	neg

347 n.t.: not testable. pos: positive. neg: negative. In bold: assumption of no difference in health risks before and after migration in rural areas

4. Data and Methods

4.1. Study Population

The paper uses data from nine HDSS sites that are members of the International Network for the Demographic Evaluation of Populations and Their Health (INDEPTH). The INDEPTH network brings together HDSS member centres located in LMICs, and provides a streamlined, standardised approach to addressing health-related research questions using the HDSS platform (for more details concerning the methods and objectives of the INDEPTH organisation see Sankoh and Byass 2012b). The HDSS sites included in this study are located in in four sub-Saharan African countries in the Western, Eastern and Southern regions of the continent, and they represent a mix of settlement types across the urban rural continuum. The sites are Nanoro, Nouna and Ouagadougou in Burkina Faso; Kilifi, Kisumu and Nairobi in Kenya; Manhiça in Mozambique; Agincourt and Africa Centre in South Africa. To note, the present study does not aim to cover all existing situations on the continent, nor does it pretend to be representative. The situations are as illustrative as they can be considering the available data. Our hope is that these situations are diverse enough to inspire the analysis of other health issues in local areas where migration is important.

The HDSS sites included in this study were selected to present a set of illustrative contexts across the Western, Eastern and Southern regions of the continent and comprised those sites that met the eligibility criteria for participation in the study. These sites represent one or more sub-district populations of their countries, in relation to which a detailed examination of migration and mortality dynamics across different contexts can be conducted. This study follows from an investigation of the patterns of migration by age and sex and an exploration of education as a determinant of migration in these HDSS populations (see Ginsburg et al. 2016). Exhaustive migration and mortality data are collected through a standardised system of continuous

372 registration of events (Sankoh and Byass 2012a). Internal and external consistency checks were
373 performed on dates, order of events, frequency of events, rates, etc. Data from all sites were
374 processed using the same procedures thus ensuring strict comparability from data collection to
375 data analysis. The characteristics of the HDSS sites included in the study are outlined in
376 Appendix 1. Seven of the sites are rural or mostly rural, while the Nairobi HDSS and the
377 Ouagadougou HDSS, comprising non-contiguous areas, are urban.

378 ### *4.2. Data and variables*

379 As part of the routine HDSS data collection activities, conducted at least once, on average twice a
380 year, reliable dates of all events representing entry into, or exit from households within the
381 geographical boundaries of the HDSS are gathered. These events include enumeration at the
382 inception of the HDSS (through a baseline census or subsequent expansion of the study area),
383 births, deaths, in-migration, out-migration, internal moves (i.e. moves within the boundaries of
384 the study area involving changes of residence from one household to another), and end of
385 observation (an event signalling the last round of reliable data collection). In an HDSS each and
386 every individual that has once been documented as a resident can be traced from any entry event
387 (enumeration, birth, in-migration) to any exit event (death, out-migration, end of observation)
388 allowing the construction of complete migratory histories from first entry event to last exit event.
389 Individuals can exit and re-enter the HDSS as they are traced with a unique identifier. Standard
390 statistical techniques can now easily handle left-censoring and observation gaps.

391 In this study, the focus is on migration events that involve the crossing the geographical
392 boundaries of the HDSS site (in either an inward or an outward direction). Moves that are
393 internal to the HDSS are excluded from the migration definition, as are moves that take place
394 between areas outside of the boundaries of the HDSS. Across HDSS sites, definitions of in- and
395 out- migration may differ in relation to the time threshold used to determine HDSS membership
396 (varying from 3 to 6 months of residence within the boundaries of the HDSS). In this study, a

consistent residency threshold of 6 months was selected to determine residency across all HDSS sites. A new in-migrant is an individual who has entered and resided in the HDSS area for at least 6 months, while an out-migrant is a resident who moved away from the HDSS area for at least 6 months. For both new in-migrants and return migrants, exposure time following entry into the HDSS is categorised into durations of 6 - 24 months; 25 - 59 months and 60+ months. Return migrant exposure outside the HDSS discriminates between long exposure (taken at >36 months) and short exposure (<36 months).

4.3. Statistical Analysis

The study uses Event History Analysis (EHA) techniques to analyse the relationship between migration and mortality. This technique requires that the data be checked for consistency and transformed into a biographical "residency episode" structure (Gerritsen et al. 2013). This structure implies that all events (such as births, deaths, in- and out-migration) for individuals are recorded sequentially with dates attached to each event. The models treat time continuously and allow for the analysis of repeatable migration events per individual. The analyses presented in this paper are based on data starting in 1998 or the earliest reliable year for migration analysis until 2012 (see Appendix 2 for the different periods covered for each site).

Cox semi-parametric proportional hazards models were produced for each site to examine in-migration and return migration status as a determinant of death. These models control for age in the non- parametric part of the Cox model, and migration status, grouped calendar years and education as covariates. Models were stratified by sex to control for gender compositional effects. All analyses were performed using Stata version 14.

Table 2 Migration-related characteristics of the analytical sample by HDSS site over the respective analysis periods

	Nanoro HDSS		Nouna HDSS		Ouagadougou HDSS		Kilifi HDSS		Kisumu HDSS		Nairobi HDSS		Africa Centre HDSS		Agincourt HDSS		Manhiça HDSS	
	% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Permanent Resident	32 179	53 491	168 474	144 158	58 798	56 165	318 513	412 786	294 542	360 534	86 579	56 708	118 221	172 872	100 591	146 649	99 371	180 212
	87%	87%	67%	57%	84%	81%	57%	57%	75%	75%	44%	41%	66%	69%	56%	53%	58%	67%
In-Migrant																		
6 - 24 months in HDSS	3 422	6 163	18 244	29 353	8 771	9 941	77 490	95 949	26 746	39 179	43 899	32 375	13 353	16 774	15 845	31 433	13 070	16 352
	9%	10%	7%	12%	12%	14%	14%	13%	7%	8%	22%	24%	7%	7%	9%	11%	8%	6%
25 - 59 months in HDSS	1 208	2 152	23 245	36 835	2 843	3 215	77 762	102 454	27 287	35 804	34 295	24 273	15 060	19 870	21 935	42 405	16 287	20 589
	3%	3%	9%	15%	4%	5%	14%	14%	7%	7%	17%	18%	8%	8%	12%	15%	10%	8%
60+ months in HDSS	n.a.	n.a.	19 171	28 895	n.a.	n.a.	48 866	71 873	12 555	14 781	12 177	8 730	11 388	15 922	24 304	42 167	13 359	17 842
			8%	11%			9%	10%	3%	3%	6%	6%	6%	6%	13%	15%	8%	7%
Return Migrant																		
6 - 24 months in HDSS	n.a.	n.a.	7 356	4 710	n.a.	n.a.	17 693	18 773	15 197	15 733	9 027	6 665	9 295	10 658	6 966	4 759	10 901	12 258
			3%	2%			3%	3%	4%	3%	5%	5%	5%	4%	4%	2%	6%	5%
25 - 59 months in HDSS	n.a.	n.a.	9 232	4 989	n.a.	n.a.	13 919	15 409	13 692	13 172	8 348	6 037	8 457	10 464	6 615	4 808	11 552	14 286
			4%	2%			2%	2%	3%	3%	4%	4%	5%	4%	4%	2%	7%	5%
60+ months in HDSS	n.a.	n.a.	6 262	3 244	n.a.	n.a.	3 658	4 920	3 902	3 733	2 922	2 173	3 559	4 855	4 563	3 435	6 714	9 148
			2%	1%			1%	1%	1%	1%	1%	2%	2%	2%	3%	1%	4%	3%
Exposure 36+ months for return migrants only	n.a.	n.a.	5 979	3 668	n.a.	n.a.	9 752	8 738	5 282	4 666	2 299	1 485	5 039	5 602	11 470	6 777	6 741	7 265
			2%	1%			2%	1%	1%	1%	1%	1%	3%	2%	6%	2%	4%	3%

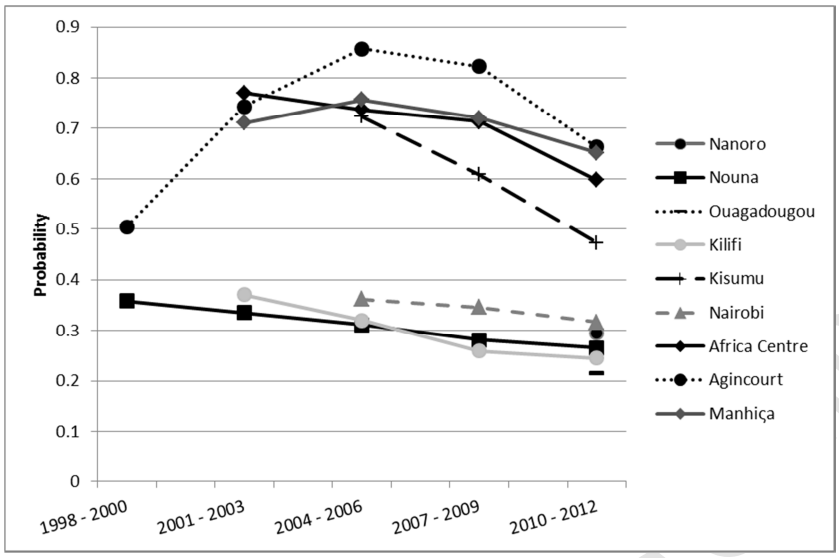
5. Results

5.1. Descriptive results

The rates of out-migration by site were analysed and reported on in a previous study (see Ginsburg et al. 2016). Across the same group of HDSS sites, between 7 and 21 per 100 PYAR of these HDSS populations were found to have out-migrated between years 2009-2011, while between 7 and 27 per 100 PYAR of individuals in-migrated over this period. Both in- and out-migration rates were found to vary by age group with the highest rates observed in early adult years (ages 15-29) for both males and females across all HDSS sites (Ginsburg et al. 2016).

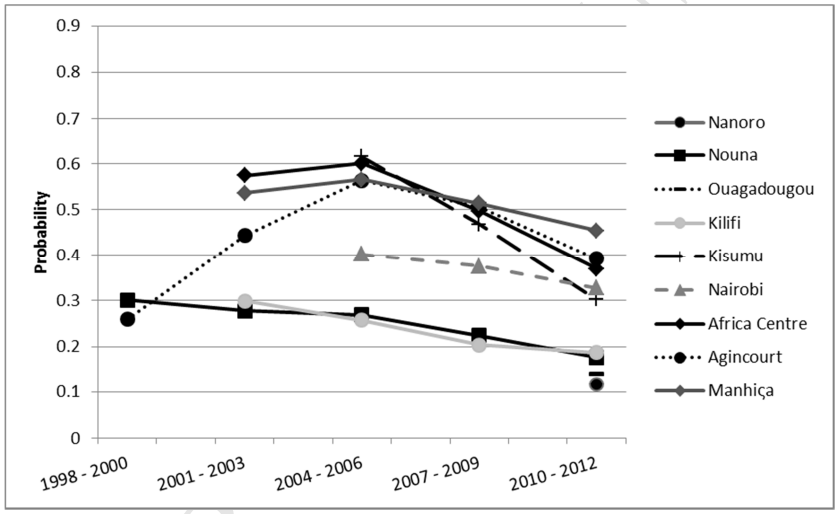
The probability to die between ages 15 and 60 (45q15) for males and females is presented for each HDSS site by period in Figures 2 and 3. In the 2010-2012 period, for which data is available for all sites, Southern Africa sites experience the highest probability of male adult mortality over time, with probabilities between ages 15 and 60 being 0.66 and 0.65 for Agincourt and Manhiça, closely followed by the Africa Centre at 0.60. Similarly, Southern African sites report the highest probabilities of mortality in females: 0.45 for Manhiça, 0.39 for Agincourt and 0.37 for the Africa Centre. Lowest probabilities of mortality are evident within the Burkina Faso HDSS sites and Kilifi in East Africa. In all sites for which data is available from the year 2000 onwards the probability is declining for both males and females.

443 **Figure 2: Probability of Death between Ages 15 and 60 ($_{45}q_{15}$) by HDSS Site for Males**



444

445 **Figure 3: Probability of Death between Ages 15 and 60 ($_{45}q_{15}$) by HDSS Site for Females**



446

447 ## *5.2. Regression results*

448 **Rural Southern Africa**

449 With respect to the Agincourt HDSS, significant differences are observed between permanent
450 residents and first time entering in-migrants in the initial two years following in-migration.
451 Similarly, in the case of both male and female return migrants, the probability of death in the
452 HDSS is 4.99 times higher for males and 5.39 times higher for females within two years following
453 return, as compared with permanent residents. Conversely in the Africa Centre HDSS, the effect
454 of return migration is far less in magnitude for females (1.36 times higher between 6 and 24

455 months following return to the HDSS) and not apparent amongst males. The higher relative risk
456 of mortality for female return migrants reduces the longer the duration spent in Africa Centre
457 HDSS. Results from the Manhiça HDSS indicate that male and female first time in-migrants to
458 the HDSS have a significantly higher risk of death within two years following their entry in the
459 HDSS (1.41 times the risk for males and 1.45 times for females); however this risk reduces with
460 length of stay in the HDSS. To note, risks within the first two years following return do not differ
461 by gender for Agincourt and Manhiça HDSSs, but they do differ for the Africa Centre.

462 The only case where a socialisation/propagation effect can be seen is amongst return migrants to
463 the Agincourt HDSS. All other HDSSs in the sample show no evidence of these effects. The
464 propagation effect in combination with the negative selection effect results in particularly high
465 mortality for return migrants as compared to non-migrants. This stands in sharp contrast to the
466 absence of any migration effect for in-migrants. Here the "midnight train" or negative selection
467 effect (unhealthy return migrant) is compounded with a propagation effect resulting in migrants
468 returning home with higher health risks acquired outside the study area.

469 The results of the Africa Centre HDSS reveal no migration effect whatsoever for males. This
470 means that both in-migrant and return migrant males are moving from areas with similar
471 exposures to the HDSS resident population and there is no selection effect. Female return
472 migrants, however, show a negative selection effect. Female in-migrants in Africa Centre HDSS
473 are the only group amongst all the African HDSS under study that present a pattern that does not
474 conform to any combination displayed in Table 1. This group experiences lower mortality for
475 short exposure in the site but higher mortality after 5 years of residence: this reversal of trends
476 after long exposure in the site is not predicted by our hypotheses and would therefore need
477 further investigation.

478 In the Manhiça HDSS in Mozambique, the dominant pattern is that of negative selection with
479 (re-)adaptation, and no socialisation/propagation effect. The "unhealthy migrant" hypothesis

applies in Manhiça to both in-migrants and return migrants. The number of female return migrants was too low to compute meaningful regression analysis coefficients.

Rural East Africa

The results from the Kisumu HDSS reveal both first time in-migrants and return migrants have a higher risk of mortality within the first two years following entry into the HDSS as compared with non-migrants, with the risk for females being higher than for males (for first-time in-migrants 1.80 and 1.35 times the risk respectively). The risk of mortality declines with duration of residence in the HDSS. Conversely, in-migrants and return migrants to the Kilifi HDSS are positively selected on health with lower risk of mortality within two years following entry to the HDSS (male return migrants have 0.56 and females 0.62 times the risk of death during this period).

The gender difference in mortality pattern is negligible in these two sites. The difference by migration status is also absent: the effects are the same for in-migrants and return migrants. Both sites show (re-)adaptation effect but no socialization/propagation effect, meaning that migrants faced similar health risks where they migrated from to the non-migrants in the site. However Kisumu and Kilifi HDSS differ markedly in terms of the selection hypothesis: it is positive in the case of Kilifi (conforming to the "healthy migrant" hypothesis) and negative in the case of Kisumu (conforming to the "unhealthy migrant" hypothesis). The situation in Kisumu HDSS in Kenya is very similar to that of Manhiça HDSS in Mozambique, while the Kilifi HDSS situation is unique among the African sites under study.

Rural West Africa

In Burkina Faso, males returning to the Nouna HDSS, or entering the Nouna HDSS for the first time are positively selected on health with their risk of mortality being 0.61 and 0.75 times the risk of non-migrants respectively. For females, no significant relationship between mortality and migrant status is observed.

505 There is a sharp contrast between males and females in Nouna HDSS: females show no
506 migration effect, whereas males show a positive selection effect that persists over time, i.e. with
507 no (re-)adaptation effect. In Nanoro, there is no selection effect for both males and females and
508 therefore adaptation is not testable.

509 **Urban Sites: Ouagadougou and Nairobi**

510 With respect to the Ouagadougou HDSS, male first time entering migrants have 0.61 times the
511 risk of death within two years following entry to the HDSS as compared to non-migrants. The
512 risk converges to that of non-migrants after some years. This pattern is only compatible with no
513 difference in health risks before and after migration, i.e. with positive selection, adaptation and no
514 socialisation effect. This is also the case for male in-migrants in Nairobi HDSS (relative risks of
515 0.77 times that of non-migrants within two years of entry).

516 The number of return migrants is too low in the Ouagadougou HDSS to include in an analysis
517 due to the site's more recent inception date. Males returning to the Nairobi HDSS present the
518 opposite risks to in-migrants: their risk of death is 1.31 times higher than non-migrants in the
519 HDSS, while the risk converges to that of non-migrants thereafter. This pattern is compatible
520 with negative selection, re-adaptation and no propagation effect.

521 To note, for both males in Ouagadougou and Nairobi, the observed patterns are only compatible
522 with no difference in health risks before and after migration. In other words, migrants faced
523 similar health risks where they migrated from as the non-migrants in these two sites. This is also
524 the case of females in Nairobi but there exists a doubt about females in Ouagadougou: the
525 absence of migration effect for female in-migrants is compatible with all situations of difference
526 in health risks before and after migration. However, there is little reason to believe that female
527 migrants were subjected to very different health risks than male migrants. Therefore, assuming no
528 socialisation, the pattern of female in-migration is compatible with no selection effect, and
529 therefore not testable adaptation effect.

530 Contrary to males, female in-migrants in Nairobi HDSS show a negative selection effect, the risk
531 of mortality within the first two years is 1.25 times the risk for a permanent resident, but their
532 risk converge to that of non-migrants thereafter (adaptation effect).

533 **Table 3 Cox proportional hazards models – Southern African Rural HDSSs**

	Africa Centre HDSS		Agincourt HDSS		Manhiça HDSS	
	All Deaths		All Deaths		All Deaths	
	Male	Female	Male	Female	Male	Female
Permanent Resident (Ref)	1	1	1	1	1	1
In-Migrant						
6 - 24 months in HDSS	0.94	0.85**	1.37***	1.26***	1.41***	1.45***
	(0.83 - 1.05)	(0.75 - 0.97)	(1.20 - 1.56)	(1.12 - 1.43)	(1.26 - 1.58)	(1.27 - 1.65)
25 - 59 months in HDSS	0.86**	1.09	1.08	1.14**	1.12**	1.19***
	(0.76 - 0.97)	(0.97 - 1.23)	(0.95 - 1.23)	(1.02 - 1.27)	(1.01 - 1.25)	(1.06 - 1.35)
60+ months in HDSS	1.02	1.19**	0.88*	1.03	0.97	1.11
	(0.88 - 1.18)	(1.03 - 1.38)	(0.77 - 1.01)	(0.92 - 1.15)	(0.86 - 1.09)	(0.98 - 1.27)
Return Migrant						
6 - 24 months in HDSS	1.18*	1.36***	4.99***	5.39***	1.27***	1.58***
	(1.00 - 1.40)	(1.14 - 1.62)	(4.36 - 5.70)	(4.55 - 6.37)	(1.10 - 1.48)	(1.36 - 1.84)
25 - 59 months in HDSS	1.08	1.23**	1.23**	1.53***	1	1.47***
	(0.91 - 1.29)	(1.03 - 1.48)	(1.04 - 1.45)	(1.22 - 1.92)	(0.86 - 1.15)	(1.28 - 1.69)
60+ months in HDSS	0.98	1.22	0.97	0.85	1.08	1.05
	(0.75 - 1.27)	(0.95 - 1.58)	(0.81 - 1.17)	(0.62 - 1.16)	(0.91 - 1.29)	(0.87 - 1.27)
Return Migrant Exposure <36months (Ref)	1	1	1	1	1	1
36+ months away	0.98	1.14	1.40***	1.33***	1.16*	1.17
	(0.78 - 1.24)	(0.90 - 1.45)	(1.23 - 1.59)	(1.11 - 1.59)	(0.98 - 1.39)	(0.96 - 1.42)
Period						
1 Jan 1998 - 1 Jan 2001 (1998)	n.a.	n.a.	0.78***	0.74***	n.a.	n.a.
			(0.69 - 0.90)	(0.65 - 0.85)		
1 Jan 2001 - 1 Jan 2004 (2001)	1.06	1.34***	1.44***	1.20***	1.12**	1.29***
	(0.95 - 1.18)	(1.21 - 1.50)	(1.28 - 1.61)	(1.07 - 1.35)	(1.02 - 1.23)	(1.17 - 1.42)
1 Jan 2004 - 1 Jan 2007 (2004)	1.31***	1.75***	1.91***	1.56***	1.24***	1.39***
	(1.18 - 1.45)	(1.58 - 1.93)	(1.72 - 2.13)	(1.40 - 1.74)	(1.14 - 1.36)	(1.27 - 1.51)
1 Jan 2007 - 1 Jan 2010 (2007)	1.25***	1.41***	1.70***	1.30***	1.13***	1.20***
	(1.13 - 1.38)	(1.27 - 1.56)	(1.53 - 1.89)	(1.17 - 1.45)	(1.04 - 1.23)	(1.10 - 1.31)
1 Jan 2010 - 1 Jan 2013 (2010) (Ref)	1	1	1	1	1	1
Education						
No Formal (Ref)	1	1	1	1	1	1
Some Primary	1.19***	1.03	0.96	0.90*	0.83***	1.02
	(1.06 - 1.34)	(0.92 - 1.15)	(0.87 - 1.06)	(0.82 - 1.00)	(0.77 - 0.90)	(0.95 - 1.10)
Some Secondary	0.85**	0.88**	0.85***	0.89**	0.59***	0.53***
	(0.75 - 0.96)	(0.78 - 0.99)	(0.76 - 0.94)	(0.80 - 1.00)	(0.52 - 0.68)	(0.43 - 0.65)
Some Tertiary	0.36***	0.30***	0.41***	0.51***	n.a.	n.a.
	(0.31 - 0.41)	(0.26 - 0.35)	(0.33 - 0.50)	(0.41 - 0.62)		
Unknown	7.02***	10.60***	3.08***	3.00***	0	0
	(6.12 - 8.05)	(9.26 - 12.14)	(2.49 - 3.81)	(2.34 - 3.84)	(0.00 - 0.00)	(0.00 - 0.00)
Observations	132 397	178 581	334 011	486 753	161 391	254 925
Wald Chi-square	1793	2238	2067	970.8	195.2	237
Log Likelihood	-26421	-30511	-22910	-25463	-30180	-34677
Subjects	38234	46303	40818	55904	37663	48787
Time at risk	179333	251414	180818	275656	171254	270686
Failures	3593	3860	3198	3143	3966	4203

*** p<0.01, ** p<0.05, * p<0.1
n.a. = not applicable

534 **Table 4 Cox proportional hazards models – East African Rural HDSSs**

	Kilifi HDSS		Kisumu HDSS	
	All Deaths		All Deaths	
	Male	Female	Male	Female
Permanent Resident (Ref)	1	1	1	1
In-Migrant				
6 - 24 months in HDSS	0.59***	0.58***	1.35***	1.80***
	(0.53 - 0.66)	(0.52 - 0.64)	(1.23 - 1.49)	(1.64 - 1.97)
25 - 59 months in HDSS	0.67***	0.74***	1.12**	1.26***
	(0.60 - 0.74)	(0.67 - 0.82)	(1.01 - 1.24)	(1.13 - 1.40)
60+ months in HDSS	0.96	1.12*	0.95	1.17*
	(0.85 - 1.08)	(1.00 - 1.25)	(0.81 - 1.12)	(0.99 - 1.39)
Return Migrant				
6 - 24 months in HDSS	0.56***	0.62***	1.36***	1.53***
	(0.44 - 0.71)	(0.49 - 0.77)	(1.17 - 1.57)	(1.31 - 1.79)
25 - 59 months in HDSS	0.76**	0.86	1.40***	1.13
	(0.61 - 0.96)	(0.68 - 1.07)	(1.21 - 1.62)	(0.94 - 1.36)
60+ months in HDSS	0.75	0.92	1.15	1.12
	(0.49 - 1.13)	(0.63 - 1.34)	(0.87 - 1.52)	(0.79 - 1.60)
Return Migrant Exposure <36months (Ref)	1	1	1	1
36+ months away	0.96	1.11	1.04	0.88
	(0.71 - 1.29)	(0.83 - 1.48)	(0.81 - 1.33)	(0.64 - 1.23)
Period				
1 Jan 1998 - 1 Jan 2001 (1998)	n.a.	n.a.	n.a.	n.a.
1 Jan 2001 - 1 Jan 2004 (2001)	0.97	1.06	n.a.	n.a.
	(0.88 - 1.07)	(0.96 - 1.16)		
1 Jan 2004 - 1 Jan 2007 (2004)	1.16***	1.31***	1.80***	2.21***
	(1.06 - 1.27)	(1.20 - 1.42)	(1.68 - 1.92)	(2.07 - 2.36)
1 Jan 2007 - 1 Jan 2010 (2007)	1.00	0.98	1.39***	1.57***
	(0.91 - 1.09)	(0.90 - 1.06)	(1.31 - 1.48)	(1.48 - 1.68)
1 Jan 2010 - 1 Jan 2013 (2010) (Ref)	1	1	1	1
Education				
No Formal (Ref)	1	1	1	1
Some Primary	0.89**	1.05	0.70***	0.81***
	(0.81 - 0.99)	(0.94 - 1.17)	(0.63 - 0.78)	(0.75 - 0.87)
Some Secondary	0.83**	0.91	0.53***	0.55***
	(0.71 - 0.96)	(0.73 - 1.14)	(0.47 - 0.60)	(0.49 - 0.62)
Some Tertiary	0.72**	0.66*	0.36***	0.32***
	(0.56 - 0.93)	(0.42 - 1.06)	(0.30 - 0.43)	(0.24 - 0.43)
Unknown	4.10***	8.38***	0.75***	0.92*
	(3.77 - 4.47)	(7.80 - 9.01)	(0.66 - 0.85)	(0.84 - 1.01)
Observations	2 382 427	3 097 890	292 304	352 742
Wald Chi-square	2033	3974	623.3	969
Log Likelihood	-34689	-39304	-53320	-56146
Subjects	145669	168010	98838	123054
Time at risk	557901	722164	393920	482936
Failures	4145	4548	6345	6396

*** p<0.01, ** p<0.05, * p<0.1

n.a. = not applicable

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Table 5 Cox proportional hazards models – West African Rural HDSSs

	Nanoro HDSS		Nouna HDSS	
	All Deaths		All Deaths	
	Male	Female	Male	Female
Permanent Resident (Ref)	1	1	1	1
In-Migrant				
6 - 24 months in HDSS	1.11	0.96	0.75***	0.92
	(0.69 - 1.79)	(0.56 - 1.67)	(0.60 - 0.93)	(0.77 - 1.10)
25 - 59 months in HDSS	1.34	0.53	0.85*	0.97
	(0.66 - 2.71)	(0.19 - 1.51)	(0.71 - 1.02)	(0.83 - 1.13)
60+ months in HDSS	n.a.	n.a.	0.86	0.87
			(0.71 - 1.03)	(0.72 - 1.04)
Return Migrant				
6 - 24 months in HDSS	n.a.	n.a.	0.61**	0.89
			(0.42 - 0.90)	(0.63 - 1.26)
25 - 59 months in HDSS	n.a.	n.a.	0.56***	0.57***
			(0.40 - 0.78)	(0.38 - 0.84)
60+ months in HDSS	n.a.	n.a.	0.51***	0.73
			(0.36 - 0.73)	(0.49 - 1.08)
Return Migrant Exposure <36months (Ref)	1	1	1	1
36+ months away	n.a.	n.a.	1.11	1.17
			(0.76 - 1.63)	(0.78 - 1.75)
Period				
1 Jan 1998 - 1 Jan 2001 (1998)	n.a.	n.a.	0.83**	1.02
			(0.71 - 0.96)	(0.87 - 1.19)
1 Jan 2001 - 1 Jan 2004 (2001)	n.a.	n.a.	0.83***	1.10
			(0.72 - 0.95)	(0.95 - 1.27)
1 Jan 2004 - 1 Jan 2007 (2004)	n.a.	n.a.	0.92	1.17**
			(0.81 - 1.05)	(1.02 - 1.35)
1 Jan 2007 - 1 Jan 2010 (2007)	n.a.	n.a.	1.04	1.12
			(0.91 - 1.18)	(0.97 - 1.30)
1 Jan 2010 - 1 Jan 2013 (2010) (Ref)	1	1	1	1
Education				
No Formal (Ref)	1	1	1	1
Some Primary	0.99	1.03	1.37***	1.23
	(0.60 - 1.63)	(0.47 - 2.29)	(1.15 - 1.63)	(0.94 - 1.60)
Some Secondary	0.22***	0.63	1.17	0.79
	(0.07 - 0.69)	(0.19 - 2.03)	(0.87 - 1.57)	(0.47 - 1.32)
Some Tertiary	0.94	0	0.61	0.00
	(0.23 - 3.84)	(0.00 - 0.00)	(0.15 - 2.46)	(0.00 - 0.00)
Unknown	1.47	3.11***	4.64***	4.55***
	(0.71 - 3.07)	(1.73 - 5.58)	(4.20 - 5.12)	(4.13 - 5.03)
Observations	48 198	85 165	369 512	383 136
Wald Chi-square	13.95	14.92	1035	1056
Log Likelihood	-1607	-1532	-16135	-14960
Subjects	14863	24204	45864	51906
Time at risk	36808	61807	251985	252185
Failures	272	238	2130	1948

*** p<0.01, ** p<0.05, * p<0.1

n.a. = not applicable

546 **Table 6: Cox proportional hazards models – Urban HDSSs**

	Ouagadougou HDSS		Nairobi HDSS	
	All Deaths		All Deaths	
	Male	Female	Male	Female
Permanent Resident (Ref)	1	1	1	1
In-Migrant				
6 - 24 months in HDSS	0.61**	0.93	0.77***	1.25**
	(0.38 - 0.97)	(0.59 - 1.47)	(0.65 - 0.90)	(1.05 - 1.50)
25 - 59 months in HDSS	1.12	0.96	0.91	1.01
	(0.62 - 2.00)	(0.45 - 2.04)	(0.78 - 1.07)	(0.83 - 1.24)
60+ months in HDSS	n.a.	n.a.	0.81*	0.91
			(0.63 - 1.03)	(0.67 - 1.23)
Return Migrant				
6 - 24 months in HDSS	n.a.	n.a.	1.31**	1.16
			(1.04 - 1.65)	(0.85 - 1.58)
25 - 59 months in HDSS	n.a.	n.a.	1.10	0.98
			(0.86 - 1.40)	(0.70 - 1.35)
60+ months in HDSS	n.a.	n.a.	1.32	1.39
			(0.92 - 1.89)	(0.91 - 2.14)
Return Migrant Exposure <36months (Ref)	1	1	1	1
36+ months away	n.a.	n.a.	1.46*	1.36
			(0.99 - 2.15)	(0.77 - 2.40)
Period				
1 Jan 1998 - 1 Jan 2001 (1998)	n.a.	n.a.	n.a.	n.a.
1 Jan 2001 - 1 Jan 2004 (2001)	n.a.	n.a.	n.a.	n.a.
1 Jan 2004 - 1 Jan 2007 (2004)	n.a.	n.a.	1.05	1.33***
			(0.91 - 1.20)	(1.13 - 1.57)
1 Jan 2007 - 1 Jan 2010 (2007)	n.a.	n.a.	1.07	1.03
			(0.94 - 1.21)	(0.88 - 1.20)
1 Jan 2010 - 1 Jan 2013 (2010) (Ref)	1	1	1	1
Education				
No Formal (Ref)	1	1	1	1
Some Primary	1.13	1.13	0.95	0.90
	(0.84 - 1.51)	(0.75 - 1.69)	(0.76 - 1.19)	(0.73 - 1.11)
Some Secondary	1.14	0.7	0.62***	0.55***
	(0.82 - 1.58)	(0.41 - 1.19)	(0.49 - 0.79)	(0.43 - 0.70)
Some Tertiary	0.96	0.36	0.60*	0.15*
	(0.52 - 1.80)	(0.05 - 2.60)	(0.33 - 1.08)	(0.02 - 1.07)
Unknown	1.43	1.59*	1.70**	1.69*
	(0.93 - 2.20)	(0.99 - 2.54)	(1.08 - 2.69)	(0.95 - 3.03)
Observations	40 696	40 882	370 927	266 241
Wald Chi-square	7.587	8.546	105.7	82.57
Log Likelihood	-2050	-1268	-12214	-7698
Subjects	33377	34174	67859	50049
Time at risk	70412	69321	197246	136962
Failures	317	195	1511	992

*** p<0.01, ** p<0.05, * p<0.1

n.a. = not applicable

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Table 7: Summary of the empirical findings of the effects of selection, (re)-adaptation and socialisation/propagation in rural areas

Socialisation/ Propagation	Adaptation	Negative selection	No selection	Positive selection
Negative	**Yes**	Agincourt ♂ ♀ R	n.a.	
	No		n.a.	
	Not testable	n.a.		n.a.
None	**Yes**	Agincourt ♂ ♀ I Manhiça ♂ ♀ I R Kisumu ♂ ♀ I R Africa Centre ♀ R	n.a.	Kilifi ♂ ♀ I R
	No		n.a.	Nouna ♂ I R
	Not testable	n.a.	Africa Centre ♂ I R Nouna ♀ I R Nanoro ♂ ♀ I	n.a.
Positive	**Yes**		n.a.	
	No		n.a.	
	Not testable	n.a.		n.a.

Only "Africa Centre ♀ I" do not fit into this table of expected combination of selection and exposure. n.a.: not applicable. I: in-migrants. R: return migrants. ♂: males. ♀: females.

Table 8: Summary of the empirical findings of the effects of selection, (re)-adaptation and socialisation/propagation in urban areas

Socialisation/ Propagation	Adaptation	Negative selection	No selection	Positive selection
Negative	**Yes**		n.a.	
	No		n.a.	
	Not testable	n.a.		n.a.
None	**Yes**	Nairobi ♀ I Nairobi ♂ R	n.a.	Ouagadougou ♂ I Nairobi ♂ I
	No		n.a.	
	Not testable	n.a.	Ouagadougou ♀ I Nairobi ♀ R	n.a.
Positive	**Yes**		n.a.	
	No		n.a.	
	Not testable	n.a.		n.a.

n.a.: not applicable. I: in-migrants. R: return migrants. ♂: males. ♀: females

6. Discussion and conclusion

The results confirm the diversity of the migration-mortality relationship over a range of rural and urban local areas in three African regions (South, East and West). The selection and exposure effects are very diverse across the continent and within each country. No single pattern fits all situations: only two sites (Manhiça and Kisumu HDSS) present with similar situations although being very distant. Gender differences are absent in about half the sites. The results also confirm that the pattern of migration-mortality relationship is mainly generated by the combination of three processes: selection, adaptation and propagation. Out of 30 observed patterns there is only one (female in-migrants in Africa Centre HDSS) that does not conform to the expected combination. Therefore, the proposed theoretical framework proves valid. A limited set of variables easily extracted from longitudinal data (migration status and duration of residence in and out of the study site) is sufficient and quite effective in interpreting the data at hand. However, an important limitation is that for in-migrants into rural HDSSs, prior knowledge of origin areas (assumed difference in health risks before and after first in-migration) is necessary for interpreting data that are covering destination, but not origin.

With regards to the selection hypothesis, the results present a range of situations summarized in Table 7 for rural HDSSs and in Table 8 for urban HDSSs. The healthy in-migrant hypothesis is confirmed in four sites out of eight for males (Kilifi, Nouna, Ouagadougou and Nairobi HDSSs) and in only one site for females (Kilifi HDSS). It is contradicted in three sites (Agincourt, Manhiça and Kisumu HDSSs, for both males and females) while migration has no effect for in-migrants in one site for males (Africa Centre HDSS), and one site for females (Nouna HDSS).

The pattern amongst return migrants corresponds exactly to that of in-migrants in all sites but the Africa Centre HDSS for females (where the pattern is not consistent with our theoretical framework), as well as the Nairobi HDSS, where male return migrants are negatively selected (as opposed to positive selection observed amongst in-migrants) and female return migrants are not

583 selected (as opposed to negative selection observed amongst in-migrants). The similar patterns
584 for in-migrants and return migrants found in most sites show that the nature of the migration
585 does not markedly influence the interplay between selection and exposure effects. In particular,
586 the "healthy migrant" does not oppose the "unhealthy return migrant" in the same site, except
587 for males in one urban site, the Nairobi HDSS.

588 Whether positive or negative, selection is always associated with adaptation, except for males in
589 Nouna who experience positive selection and no adaptation. In one case, return migrants in
590 Agincourt, negative selection is associated with negative propagation, making return migration
591 particularly associated with high mortality. At the opposite, 12 out of 30 observed patterns show
592 no effect of migration on mortality, i.e. no selection, adaptation, or socialisation effects.

593 How might these results impact on the administration of public health services in these HDSS
594 sites, in particular as relating to migrants? Two effects call for particular attention: negative
595 selection and negative socialisation/propagation. Migrants who are negatively selected on health
596 are clearly a concern in Manhiça and Kisumu, whatever the migration status (in- or return
597 migrant) and gender. In the Agincourt HDSS, male and female return migrants should be also
598 targeted, especially since they are vectors of negative propagation in the site. In the Africa Centre
599 HDSS, female return migrants' health calls for more investigation on why it departs from other
600 patterns. In Nairobi HDSS, the concern is for male return migrants and for female in-migrants.
601 In all these cases but females in Africa Centre, the migrants should be targeted in the first 2 or 3
602 years after their arrival to the HDSS. After some years, migrants' risks tend to converge with
603 those of non-migrants. The public health intervention would then help to reduce the risks upon
604 arrival and accelerate the convergence.

605 Conditional on the validity of our assumption in rural areas of no difference in health risks before
606 and after first in-migration, the negative socialisation/propagation effect is not a concern in any
607 of the rural sites under study, except in Agincourt HDSS for return migrants. The Agincourt

608 HDSS situation probably reflects the propagation of the AIDS epidemic that affected this rural
609 area particularly severely in the years 2000 (Bocquier et al. 2014). There, in the absence of a
610 means to reduce health risks at migrants' destinations, prevention targeted towards residents who
611 intend to migrate could help reduce health risks taken in these destinations through raising
612 awareness to potential health risks. Contrary to the expected, return migrants to rural areas
613 (presumably returning from more affluent areas, in cities or abroad) do not appear to be vectors
614 of positive propagation, as this effect is not evident in these data. Seeking support for return
615 migrants with long exposure out of the site in the form of local public health policy
616 implementation would be a less effective direction for interventions. Gathering information
617 about health risks at migrants' destinations would be a more fruitful approach.

618

619 ## 7. References

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686 **Appendix 1: HDSS sites included in this multi-centre analysis**

HDSS Site	Population Size (approximate)	Size of Site (km^2)	Settlement Type	Population Density Estimate (persons per km^2)	Inception Year	Contiguity and Location
WEST AFRICA						
Nanoro HDSS Burkina Faso	61 000	594.3	Rural	102.6	2009	Contiguous site situated in centre of Burkina Faso, 85km from capital, Ouagadougou
Nouna HDSS Burkina Faso	84 336	1 756	(Mostly) Rural	48	1992	Contiguous site situated north west of Burkina Faso, 300km from capital, Ouagadougou
Ouagadougou HDSS Burkina Faso	81 717	14.73	Urban	5 547.7	2008	Non-contiguous site comprising three informal areas: Nonghin, Polesgo and Nioko 2, and two formal areas: Kilwin and Tanghin, north of city.
EAST AFRICA						
Kilifi HDSS Kenya	261 919	900	(Mostly) Rural	291	2000	Contiguous site situated north of Mombasa on Indian Ocean coast of Kenya
Kisumu HDSS Kenya	223 406	700	(Mostly) Rural	319.2	2001	Contiguous site located in Rarieda, Siaya and Gem districts, northeast of Lake Victoria, Nyanza Province, western Kenya
Nairobi HDSS Kenya	71 000	0.97	Urban	73 195.9	2002	Non-contiguous site comprising Viwandani and Korogocho slum settlements (7km apart) in capital, Nairobi
SOUTHERN AFRICA						
Africa Centre HDSS South Africa	85 000	438	Rural	194.1	1997	Contiguous site in the Umkanyakude district of KwaZulu-Natal
Agincourt HDSS South Africa	91 178	420	(Mostly) Rural	217.1	1992	Contiguous site situated in northeast South Africa close to border with Mozambique
Manhiça HDSS Mozambique	90 000	500	Rural	180	1996	Contiguous site located in southern Mozambique, 80 km north of capital, Maputo

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688 **Appendix 2: Non-migration characteristics of the analytical sample by HDSS site over the respective analysis periods**

	Nanoro HDSS		Nouna HDSS		Ouagadougou HDSS		Kilifi HDSS		Kisumu HDSS		Nairobi HDSS		Africa Centre HDSS		Agincourt HDSS		Manhiça HDSS	
	% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years		% Person Years	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Period																		
1 Jan 1998 - 1 Jan 2001	n.a.	n.a.	29 518	29 762	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	39 433	55 500	n.a.	n.a.
			11.71%	11.80%											22%	20%		
1 Jan 2001 - 1 Jan 2004	n.a.	n.a.	44 704	44 527	n.a.	n.a.	107 781	137 179	n.a.	n.a.	n.a.	n.a.	43 779	61 698	32 956	52 442	33 108	49 855
			17.74%	17.66%			19%	19%					24%	25%	18%	19%	19%	18%
1 Jan 2004 - 1 Jan 2007	n.a.	n.a.	54 232	54 325	n.a.	n.a.	135 271	177 188	93 066	114 869	60 031	40 031	43 210	61 482	32 713	52 597	44 296	70 090
			21.52%	21.54%			24%	25%	24%	24%	30%	29%	24%	24%	18%	19%	26%	26%
1 Jan 2007 - 1 Jan 2010	n.a.	n.a.	59 190	59 471	n.a.	n.a.	149 931	195 821	141 468	172 354	64 977	45 185	44 969	63 771	35 327	55 600	44 556	73 172
			23.49%	23.58%			27%	27%	36%	36%	33%	33%	25%	25%	20%	20%	26%	27%
1 Jan 2010 - 1 Jan 2013	36 808	61 807	64 341	64 100	70 412	69 321	164 918	211 977	159 386	195 713	72 238	51 746	47 375	64 463	40 389	59 518	49 294	77 569
	100%	100%	26%	25%	100%	100%	30%	29%	40%	41%	37%	38%	26%	26%	22%	22%	29%	29%
Education																		
No Formal	24 135	50 961	119 727	149 753	21 348	29 179	66 760	292 929	7 640	52 595	6 237	9 468	8 916	19 976	18 910	55 734	26 841	111 548
	66%	82%	48%	59%	30%	42%	12%	41%	2%	11%	3%	7%	5%	8%	10%	20%	16%	41%
Some Primary	5 453	4 235	37 542	20 998	18 497	14 720	283 779	254 246	243 840	299 926	110 180	86 218	23 215	47 039	38 862	50 950	116 683	136 597
	15%	7%	15%	8%	26%	21%	51%	35%	62%	62%	56%	63%	13%	19%	21%	18%	68%	50%
Some Secondary	5 510	3 438	18 734	10 806	20 253	16 188	65 220	39 569	89 834	71 840	76 577	39 389	98 220	125 451	113 129	152 609	26 136	20 570
	15%	6%	7%	4%	29%	23%	12%	5%	23%	15%	39%	29%	55%	50%	63%	55%	15%	8%
Some Tertiary	357	67	852	150	3 778	1 554	12 911	8 291	16 186	8 441	2 733	1 037	46 617	56 347	8 317	14 155	n.a.	n.a.
	1%	0%	0%	0%	5%	2%	2%	1%	4%	2%	1%	1%	26%	22%	5%	5%		
Unknown	1 354	3 107	75 131	70 478	6 536	7 681	129 231	127 129	36 418	50 133	1 520	849	2 364	2 600	1 600	2 208	1 594	1 971
	4%	5%	30%	28%	9%	11%	23%	18%	9%	10%	1%	1%	1%	1%	1%	1%	1%	1%

689 n.a. = not applicable

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