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Discussion Paper Series

Water Security in
Peri-Urban South Asia
Adapting to Climate Change & Urbanization

Salinity Progression at Khulna: Anthropogenic or Climate Change Induced?

M. Rashed Jalal, M. Shahjahan Mondal, M. Shah Alam Khan, Uthpal Kumar, Rezaur Rahman and Hamidul Huq

Surface water salinity, being accentuated by the reduction in the dry season upland flows, now reaches as far as Khulna – a coastal city of Bangladesh highly exposed to climate change impacts. The projected sea level rise due to climate change would further aggravate the situation with the probability of increased spatial coverage and temporal duration of salinity. Amidst the relative lack of studies attributing to causes of salinity intrusion, this study analytically assesses the role of regional anthropogenic interventions on one hand and global climate change induced sea level rise on the other as the causes of salinity progression in Khulna. Analysis of the long-term trends in tidal water level, upland flow and river water salinity, indicates that regional human interventions, both in and outside the country, have contributed more in hydro-morphological changes in the region than the climate change induced sea level rise leading to salinity intrusion in Khulna.

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This is one of a series of Discussion Papers from the Peri Urban Project of SaciWATERs.

About the authors:

Mohammad Rashed Jalal is a graduate student at the Institute of Water and Flood Management of Bangladesh University of Engineering and Technology (BUET), Dhaka. Mr. Jalal work as a Research Assistant of the Peri-Urban Water Security Project. His current research interest is uncertainty and risk assessment for adaptation investment in coastal areas of Bangladesh.

M. Shahjahan Mondal is currently an Associate Professor at IWFM. He holds an MSc in Water Resources Engineering from BUET and a PhD from Central Queensland University in Australia. Dr. Mondal has a number of publications on water resources planning and management in leading journals. His current research interest is in the institutional aspects of water and related resources management. Professor Mondal will give necessary inputs in field work, research management and be responsible for the overall reporting and research coordination.

M. Shah Alam Khan is Director of Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET). He obtained his Ph.D from Drexel University, USA and his masters in Civil and Environmental Engineering from the University of Rhode Island, also in the US. He has a number of papers published in journals to his credit, and has contributed to several books as well. He has also taken on consultancy jobs at various points in his career for public and private enterprises. Professor Khan will provide research support, guidance and field survey and methodological inputs.

Uthpal Kumar is a graduate in Environmental Science from Khulna University, Bangladesh and a MSc in Water Resources Development from the Institute of Water and Flood Management of Bangladesh University of Engineering and Technology(BUET). His interest areas include Integrated Water Resources Management, Community Based Watershed Management and Climate Change Issues with an especial focus on southwest coastal region of Bangladesh. He is now working as research fellow in the Peri-Urban Project and also preparing for a Phd under this project.

Rezaur Rahman is currently associated with IWFM. He is a Civil Engineering graduate of BUET and did his Masters from Department of Geography and Environmental Engineering of the Johns Hopkins University, USA. Prof. Rahman holds a PhD in Environmental Engineering from University of Illinois, Urbana-Champaign, USA. At the national level, Prof Rahman has been involved in preparation of National Adaptation Program of Action (NAPA) for climate change and Climate Change Strategy and Action Plan (CCSAP) of Bangladesh. He will lend the project support and guidance to research and in field measurements.

Hamidul Huq is Founder and Chairman of Institute of Livelihoods Studies (ILS) based in Dhaka. Dr. Huq has long professional experience on livelihood studies, participatory natural resources management and gender studies. He published several article in books referred journals.

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For further information please contact:

SaciWATERs

H.No. B-87, Third Avenue,

Sainikpuri, Secunderabad - 500 094, Andhra Pradesh, India.

Telefax : +91- 04 - 27116721, 27117728

Email : periurban@saciwaters.org

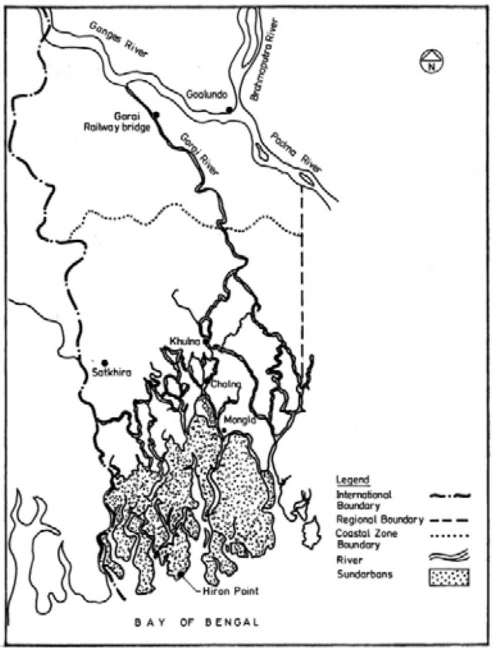
Salinity Progression at Khulna: Anthropogenic or Climate Change Induced?

M. Rashed Jalal[1], M. Shahjahan Mondal[2], M. Shah Alam Khan[2], Uthpal Kumar[1], Rezaur Rahman[2] and Hamidul Huq[3]

1. INTRODUCTION

The south-west coastal region of Bangladesh (Figure 1), being under tidal influence and dependent on sweet water supplies from upstream, is a unique brackish ecosystem. The salinity levels play an important role in shaping the socio-economic setting of this transitional zone of marine-terrestrial interface. Changes in spatial and temporal variation of salinity, a dominant factor for coastal ecosystem, fisheries and agriculture, have significant effects on the biophysical system of coastal area. Surface water salinity, being accentuated by the reduction in the flows entering the Gorai distributaries during the dry season, now reaches as far as Khulna city which is amongst the 15 most vulnerable cities of the world affected by climate change (IIED, 2009). Sea level is projected to rise between the present (1980-1999) to the end of this century (2090-2099) by 35 cm (23-47 cm) for the A1B scenario (IPCC, 2007). However, the distribution will not be uniform due to ocean density and circulation changes. The rise along the Bangladesh coast could be 0-5 cm more than the global average. The probable consequence is an expected increase in spatial coverage and temporal duration of salinity. The 5 ppt isohaline could move about 9 km further inland during the dry season due to sea level rise of 32 cm (Rahman and Rahman, 2007). The inundated areas could also increase by about 11 per cent due to the rise of sea level by 88 cm. About 84 per cent of the Sundarbans – the world's largest mangrove forest and a ramsar site – could be deeply flooded under such scenario and the mere sustenance of the Sundarbans could be at risk. Though there are several studies on the impacts of climate change on coastal areas using scenario-based model (Hasan et al., 2009; Halder, 2011), no study has been conducted on the relative attribution to the cause of salinity intrusion in and around Khulna considering the regional anthropogenic interventions on one hand, and the global climate change induced sea level rise on the other. This study attempts to analytically assess the role of human intervention, both within and outside the country, and climate change induced sea level rise as causes of salinity intrusion. This study investigates the long-term trends in tidal water level in the Khulna region using secondary data. The correlation between the Gorai flow and the salinity in the Rupsha water has been investigated in this paper. The variation in tidal water level in and around Khulna in relation to sea level rise and human intervention is also explored.

Figure 1: The south-west region of Bangladesh showing the coastal region, the Sundarbans, the Gorai River and the Rupsha-Pasur River



Source: Prepared by the project team

[1]Graduate Student, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh

[2]Professor, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh

[3]Chairman, Institute of Livelihood Studies, Dhaka, Bangladesh

2. METHODOLOGY AND DATA

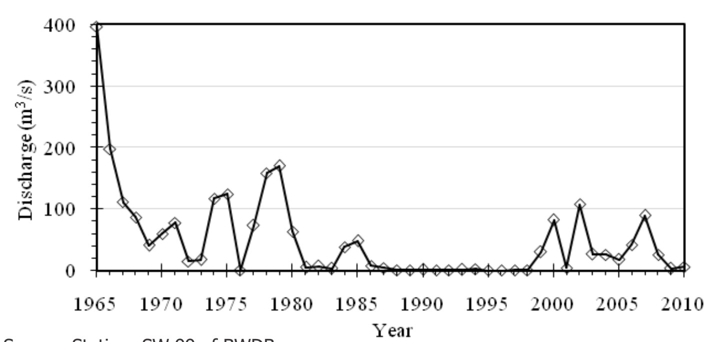
In this study, the linear, monotonic trend in a variable time period was investigated mostly at the annual, seasonal and monthly time scales. IPCC (2007) used this technique while investigating the long- and short-term trends in observed climatic and hydrologic variables. The method is based on fitting a linear line to a set of data so that the sum of squared errors becomes the least. This is the most widely used technique in trend analysis and is the most robust in case of normally distributed data in the absence of too many outliers. However, where the distribution of the variable is not Gaussian and there are many outliers in the data set, the linear but non-parametric technique may be more appropriate to investigate the trend. The latter technique is based on the ordering of a data set with no distributional assumption. The statistical significance level of the parametric trend was studied by employing a t-test. The SPSS 16.0 software was used for this purpose. The linear correlation between two variables was studied by computing Pearson's correlation coefficient, which has a parametric distributional assumption. Kendall's tau and Spearman's rho having no distributional assumption were also computed in appropriate cases to see if there is a significant difference in direction and strength of the relationship between the parametric and non-parametric techniques.

The data for this study was carefully examined before application in trend and correlation analyses. Any daily data with negative value (except for tidal water level) and absurd value was treated as missing, using a computer programme. The daily data was sorted in a chronological order with the missing dates identified. From the daily values, 10-day values were calculated for each month and year for each data set, with the condition that daily values for at least one day is available for a 10-day period. The reason for calculating the 10-day value before the monthly, seasonal and annual values was that, if the latter values were calculated directly from the daily values with some criteria, such as 80 per cent non-missing days, they might not be representative. Monthly values were calculated from the 10-day values, and the seasonal and annual values from the monthly values. River discharge, water level and water quality data were collected from the Bangladesh Water Development Board (BWDB). The tidal water level data was collected from the Bangladesh Inland Water Transport Authority (BIWTA).

3. VARIATION IN THE GORAI RIVER FLOW

The Gorai River, the principal distributary of the Ganges River at its right bank in Bangladesh, is the major source of fresh water for south-western Bangladesh during the dry season. It prevents saline water intrusion from the Bay of Bengal, prevents siltation in the regional rivers, maintains navigational depth, sustains the mangrove ecosystem of the Sundarbans and provides irrigation water for agriculture. However, due to diversion of the water from the Ganges River with the construction of a barrage at Farakka in India since 1975, the dry season flow of the Gorai River has reduced significantly. For instance, the annual minimum flow time series (Figure 2) indicates that such flow reduced to almost nil, immediately after commissioning of the barrage in 1976. However, it was not until 1981 when the effect of the withdrawal became prominent. The average lowest flow was about 110 m^3/s, till 1980 and it came down to only about 10 m^3/s during the period of 1981-1998. Due to reduction in the flow of water from the Ganges into the Gorai off-take due to the construction of the barrage, massive siltation occurred in the off-take. Towards the end of the latter part of the year 1996, Bangladesh and India signed a treaty to share the waters of the Ganges. The treaty became effective in January 1997 and established the circumstances for restoration of the flow in the Gorai. A 20-km stretch of the river from its off-take was dredged after the monsoon season of 1998 and maintenance dredging was continued for another two years. The three-year dredging removed about 18.5 million m^3 of sediment from the river (Groot and Groen, 2001). This resulted in an increase of the annual minimum flow upto a value of 45 m^3/s during the years 1999-2008. It thus appears that dredging of the river could restore only about 42 per cent of the natural minimum flow and even that was on a temporary basis. The minimum flow in the last three years became nil. Increasing demand and consequent withdrawal from the Ganges outside the country is also a major concern in sustaining availability of this minimum flow. Apart from these trans-boundary water issues, massive polderization practiced in 1960s and gradually reducing flood-plain storage and increasing siltation in the channel beds since 1980s, has also become a source of major concern

Figure 2: Time series plot of annual lowest flow of the Gorai River at Gorai Railway Bridge



Source: Station: SW 99 of BWDB

4.TREND IN TIDAL WATER LEVEL

The analysis of tidal water levels of the Rupsha River at Khulna for a period of 74 years (1937-2010) indicates that the annual maximum high tidal water levels are increasing at a rate of 18 mm per year and the annual minimum low tidal water levels are decreasing at a rate of 8 mm per year (Figures 3). Both these trends were found to be statistically significant at a confidence level of 99 per cent. The Bangladesh Water Development Board (BWDB) gage station at Khulna is located at a distance of about 125 km inland from the sea coast. To examine the trend in tidal water levels near the sea, data obtained from the Bangladesh Inland Water Transport Authority (BIWTA) station at Hiron Point, which is only 11 km inland from the coastline, over a period of 33 years (1977-2010) were also analyzed. The trend in annual maximum water level was found to be increasing at the rate of 7 mm per annum and that in minimum water level to be decreasing at 4 mm per annum (Figures 4). The increasing trend is significant at 80 per cent level of confidence and the decreasing trend at 90 per cent level of confidence. It thus clearly appears that the extremes in tidal water levels are more prominent in inland areas compared to those near the sea.

Figure 3a: Trend in annual maximum high tidal water levels at Rupsha (Station: SW 241)

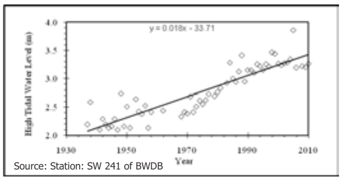


Figure 3b: Trend in annual minimum low tidal water levels at Rupsha (Station: SW 241)

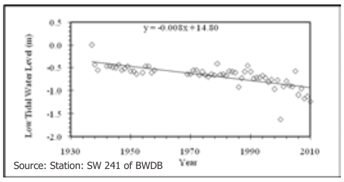


Figure 4(a): Trend in annual maximum high tidal water levels at Hiron Point

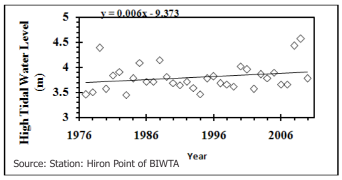
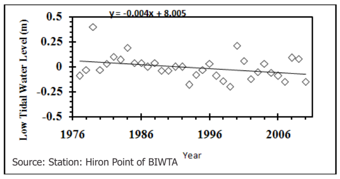


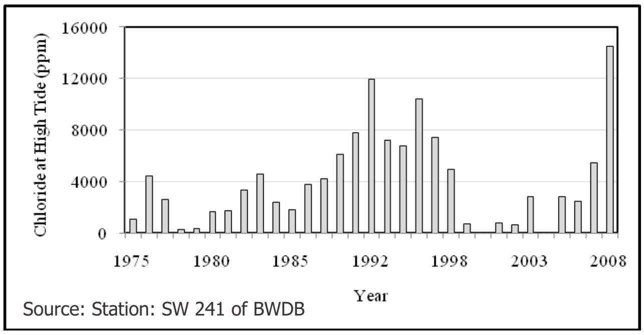
Figure 4(b): Trend in annual minimum low tidal water levels at Hiron Point



5.HISTORY AND CAUSES OF SALINITY PROGRESSION AT KHULNA

The increased intrusion of saline water into the fresh water of south-west Bangladesh is one of the most significant effects on the environment. The advancement of the saline front in the Khulna region is a matter of concern. In 1968, a salinity level of 3,800 micromhos was registered in Khulna when fresh water flow was normal in the Gorai River (Crow et al., 1997). The salinity observed at Khulna topped all the then past records, reaching 17,100 micromhos in April 1983 (Nishat, 1988). A gradual increase in annual maximum salinity was observed during the period of 1985-1992 and the maximum salinity levels of Rupsha River at Khulna remained above 5,000 ppm until 1998 when the Gorai Restoration Project was initiated (Figure 5). A sharp decline in salinity level during the years of 1999-2002 was the direct consequence of the restoration project. However, with the reduction of the Gorai flow in recent times the salinity at Khulna peaked all past records in 2008 (Figure 5).

Figure 5: Annual Maximum Salinity (Chloride, ppm) of the Rupsha River at Khulna (Station: SW 241)

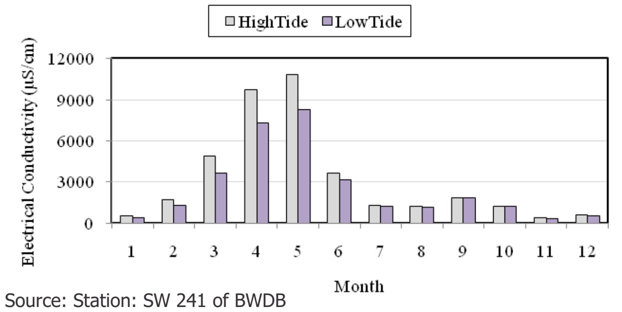


Investigation carried out since 1976 have established that the salinity intrusion length, concentration and duration in the region depend mostly upon the quantity and duration of the upland flow received in the area, from the Ganges through the Gorai-Madhumati system. Owing to the decreasing trend of dry season flow in the Ganges, the Gorai-Madhumati is receiving very low discharge in the drier months and as a result the salinity is penetrating further upwards. Crow et al., (1997) stated that the extent of saline water intrusion depends on the quantity and velocity of fresh water travelling down the river depending on the strength of tide at a given time and also on the turbulence of the river. Rahman et al., (2000) found in a study that the large scale reduction or withdrawal of the Ganges outflow greatly influences the Bhairab-Rupsha-Passur-Sibsa river complex of the south-west region as it is fed by the mighty Ganges through Gorai river. This reduction causes a drop in hydraulic head at the Ganges and its distributaries, which ultimately accelerates saline front movement or saline water intrusion towards inland fresh water zone. To maintain the Rupsha River's maximum salinity below 1,000 µS/cm the study found that the discharge in the Ganges should be 1,500 m^3/s, whereas that at Gorai basin is 10 m^3/s (Rahman et al., 2000).

The Rupsha River still has connection with the Gorai River and receives the sweet water supplies. The Gorai River flow pushes away the saline water front in the Rupsha near Khulna (Mirza, 1998). The analysis of river water salinity near Khulna using a data set of 34 years (1975-2008) shows a higher salinity during high (flood) tide compared to that during low (ebb) tide (Figure 6). There is a negative correlation between the

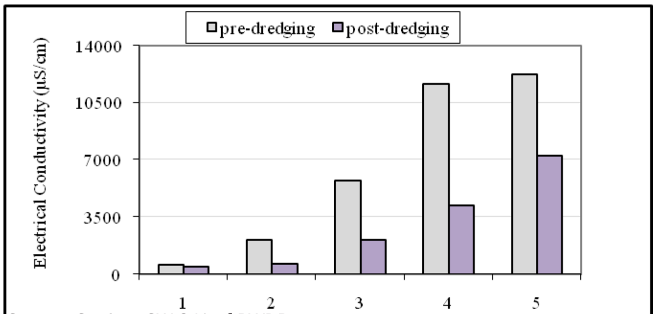
Gorai River flow and electrical conductivity (EC) in both the tidal cycles. The correlations are statistically significant at 95 per cent confidence levels during the months of February to May. The highest correlation coefficient in the high tidal cycle was found to be -0.68 in the month of March and that in the low tidal cycle was -0.64 in the month of April, both the correlations being statistically significant at 99 per cent level of confidence. Thus, when the flow was high in the Gorai River, the salinity at Khulna was low. This inference is also supported by the difference of EC values between the pre- and post-dredging situations (Figure 7). The EC values became lower due to the dredging of the Gorai River after the monsoon season of 1998.

Figure 6: Electrical Conductivity (EC, μS/cm) of the Rupsha River at Khulna



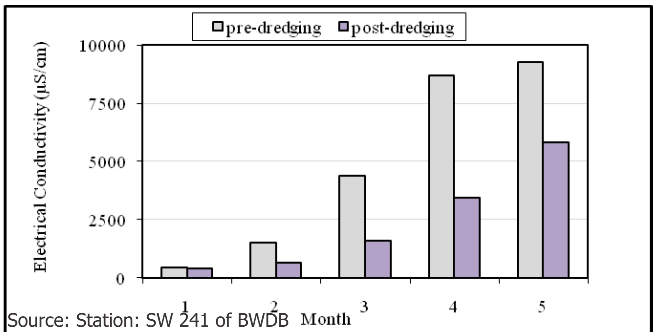
Source: Station: SW 241 of BWDB

Figure 7(a): Comparison of Electrical Conductivity of the Rupsha River at Khulna at high tide between the pre- and post-dredging situations



Source: Station: SW 241 of BWDB

Figure 7(b): Comparison of Electrical Conductivity of the Rupsha River at Khulna at low tide between the pre- and post-dredging situations



Source: Station: SW 241 of BWDB

6.CONCLUSION

The analysis of tidal water levels of the Rupsha River at Khulna and of the same river system at Hiron Point indicates similar trends. In both cases, the annual maximum high tidal water levels are increasing and the annual minimum low tidal water levels are decreasing. The possible reasons for the decreasing trends in annual minimum water levels could be the decrease in the upstream flow or the reduction in floodplain storage of tidal water or both. The increasing trends in annual maximum water levels could result either from the silting up of the rivers, reduction in flood tide propagation areas, or a rise in the sea level, or a combination of these factors. If the sea level rise were the only dominant factor, both the high and low tide levels would have rising trends. Moreover, the effect of sea level rise on water levels would gradually diminish as we move inland. However, analysis reveals that the extremes in tidal water levels are more prominent in inland areas compared to those near the sea. Thus, if sea level rise had any effect on the observed trends, the effect would be much lower than that of anthropogenic interventions as the high and low tidal levels have significantly opposing trends. The rising trend in the high tidal water level alone can be explained by a sea level rise phenomenon but not together with the falling trend in the low tidal water level.

Commissioning of the Farakka Barrage on the Ganges in India in 1975 has reduced the fresh water inflow to the region. Furthermore, construction of the coastal polders has gradually reduced the flood plain storage areas for tidal waters from the Bay of Bengal. The coastal polders and the Farakka barrage in India are found to have contributed to the gradual siltation of the coastal rivers and hence to the tidal water level extremes. The analysis of the lowest flow of the Gorai River indicates that the disruption to the natural flow regime of the Ganges in the upstream with the Farakka barrage has caused significant adverse effect on the flow regime and morphology of the Gorai. The lowest flow has now ceased to almost nil. The river salinity at Khulna has also good correlation with the Gorai flow during the months of February-May. The dredging of the Gorai during 1998-2001 contributed positively towards restoration of the sweet water flow to the south-west region and to check the level of salinity near Khulna.

It thus appears from the analysis of water salinity, tidal water level and sweet water flow data in different time periods that human interventions through upstream diversion and other means have contributed more in hydro-morphological changes in the south-west than the climate change induced sea level rise leading to salinity intrusion in Khulna.

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Adapting to Climate Change & Urbanization

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Working primarily on water security issues in Peri-Urban South Asia, across India, Bangladesh and Nepal, the project's main concerns are the rapidly changing peri-urban landscapes due to urbanisation and implications for water security in specific locations in the larger context of climate change. As an action research project, working across four locations in South Asia, it will serve as a basis for capacity-building at the grass roots level to address concerns of the poor, marginalised and other vulnerable communities to water security and seek to understand the dynamics of adaptation in the specific locations, for action and policy agenda at the regional level. It will build their capacities to cope with climate change induced water in-security.

www.saciwaters.org/periurban

Coordinating Institution:

The project is being coordinated by **SaciWATERs**, Hyderabad, India. SaciWATERs focuses on transforming water resources knowledge systems, key ideas being an interdisciplinary approach to understanding water resources issues, from a pro-poor, human development perspective, with an emphasis on exchange, interaction and collaboration at South Asia level.

Partner Institutions:

Bangladesh University of Engineering and Technology (BUET) is the oldest and leading university in Bangladesh in the area of technology. IWFM is a premier institute for the advancement of knowledge and development of human resources in water and flood management.

Nepal Engineering College (NEC) was established in 1994, as a non-profit organization under private sector initiative, to function as center for advanced learning in engineering and allied sciences. It has been offering the Interdisciplinary Water Resources Management (IWRM) Program since the beginning July, 2007 under the support of Crossing Boundaries (CB) Project funded by Government of the Netherlands.

Project Support:

This project is supported by Canada's **International Development Research Centre (IDRC)**. IDRC is one of the world's leading institutions in the generation and application of new knowledge to meet the challenges of international development. For nearly 40 years, IDRC has worked in close collaboration with researchers from the developing world in their search for the means to build healthier, more equitable, and more prosperous societies.

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