Monograph:
Carrie, R.H., Montoya Pachongo, C., Tzul, S. et al. Light-touch development and application of the MUltidimensional rISK Analysis (MUISKA) approach to produce positive water security change: A case study in Yalbac, Belize. Report. University of Leeds (Unpublished)

Light-touch development and application of the MUltidimensional rISK Analysis (MUISKA) approach to produce positive water security change

A case study in Yalbac, Belize

University of Leeds - Belize Maya Forest Trust

List of Contents

List of Tables

List of Figures

Citation: Carrie, R.H., Montoya Pachongo, C., Tzul, S., Trigg, M., Chun, R., Camargo-Valero M.A. and E. Kay (2024). *Light-touch development and application of the MUltidimensional rISK Analysis (MUISKA) approach to produce positive water security change. A case study in Yalbac, Belize.* Final Report. Leeds, UK: University of Leeds & Belize Maya Forest Trust.

Contact: Rachael Carrie, Sustainability Research Institute, University of Leeds, Leeds United Kingdom. Email: r.h.carrie@leeds.ac.uk

Light-touch development and application of the MUltidimensional rISK Analysis (MUISKA) approach to produce positive water security change. A case study in Yalbac, Belize.

Carrie, R.H., Montoya Pachongo, C., Tzul, S., Trigg, M., Chun, R., Camargo-Valero M.A. and E. Kay

Abstract

To address ongoing water insecurity, the MUISKA-tool was developed to encourage relevant parties and researchers to work together to facilitate analysis and management of water security risks in river basins. A modified version, MUISKA-light, was implemented in the Yalbac area in Belize to explore local water security concerns in a resource limited context. Workshop participants highlighted health issues linked to agricultural pesticides and inadequate water infrastructure. Analysis of water samples revealed the presence of harmful pesticides in rainwater tanks used for drinking water and in surface waters. Although pesticide concentrations were relatively low compared to international guidelines, data was limited and did not account for temporal variations. Recommendations include longer term monitoring of the range of water sources to enable the development of a fuller understanding of risks posed. MUISKA-light provided a platform for the concerns of those who identify as powerless to be heard, prioritised and documented and provides a foundation for future work.

1 Introduction/background

Two decades after the concept of water security emerged, many still face challenges linked to water insecurity. Societies remain highly affected by inadequate access to, or limits to the availability of, safe and reliable quantities of water of quality needed for health, livelihoods, productive economies and ecosystems (United Nations, 2023). A review of literature indicates assessment of water-security risks would be improved if relevant parties with multiple perspectives worked together to better understand conditions and causes of risks, the risk history in the specific context, the catastrophic potential of risks, risk distribution, and acceptability and what can be done about risk (van Asselt, 2000; Reed, 2008; Mdee et al., 2022). In light of this, Montoya-Pachongo et al. (2023; 2024) have developed an approach called the MUltidimensional rISK Analysis (MUISKA) to facilitate relevant parties and researchers to work together to encourage better management of water security risks.

The MUISKA approach can be understood as a first-order assessment of water-security risks, to be applied at the river basin scale with the participation of relevant parties during a series of workshops. MUISKA was developed in Cajibío, Colombia as part of the international project 'Water Security and Sustainable Development Hub', which comprises five collaboratories in Malaysia, India, Ethiopia, UK, and Colombia. MUISKA is a 6-step process, and the full implementation of each step can be time intensive to implement. Recognizing that resources and other constraints mean the full process may not be feasible in all contexts, this study trials a modification of MUISKA as a 'light-touch' approach in Belize. Rather than working with all relevant parties in the river basin, the modification allowed focus to be placed on one relevant party (Yalbac residents) as a result of concerns about water security raised during conservation action planning led by the Belize Maya Forest Trust (BMFT) during 2021/22. Following a scoping exercise in 2022, team members from the University of Leeds (UoL), BMFT, the Pesticide Control Board (PCB) and Yalbac Village worked together to implement MUISKA-light (outlined in Appendix 1).

2 Aim and objectives

The study aims to trial MUISKA-light to identify and explore concerns about water security from the perspective of residents in one village buffering the Belize Maya Forest. To achieve this aim, the study had the following objectives:

1) Identify and prioritize water security hazards and impacts with representatives from Yalbac Village and explore if and why there are disagreements about these.
2) Complete and communicate a preliminary and rapid risk assessment reflecting hazards prioritized by relevant parties and potential exposure based on water use patterns.

3 Study Area

The study focussed on villages buffering the southern boundary of the Belize Maya Forest (Figure 1). Covering approximately 240,000 acres of privately acquired land, the Belize Maya Forest, together with the Rio Bravo Conservation and Management Area, forms over half a million acres of lowland forest in north-western Belize. The reserve is surrounded by extensive cleared lands primarily used for large-scale, commercial agriculture, alongside some smaller traditional farming operations.

The study initially focussed on two villages along the southern boundary of the Belize Maya Forest: Yalbac and Los Tambos but ultimately focused only on Yalbac Village. Yalbac Village is located towards the boundary of the Cayo and Orange Walk Districts at approximately N 17° 24.730302 E -88° 53.404266 (16Q 299229.565 1926143.657). Yalbac Village consists of approximately 30 households, with an estimated 64 residents, some of whom are in occupation part-time. Yalbac, one of the oldest communities in Belize, is a part of the farm belt and the village and its surroundings landscape includes different scales and types of agriculture. Many local households rely on traditional, small-scale farming which is often subsistence-oriented and involves minimal mechanization and limited chemical input. In contrast, larger, commercial-scale operations, including leased agricultural lands, employ intensive farming techniques, heavy machinery, and significant chemical inputs to cultivate crops including vegetables, fruits, and rice for domestic consumption and export. These varying scales of agriculture not only shape land use but also highlight power dynamics, because larger commercial farmers often have greater ability to access resources like land and equipment. This distinction is important in discussions linking water security, land stewardship, chemical use and achieving balance between agricultural productivity and environmental and social sustainability.

At the commencement of the study, Yalbac Village lacked formal water supply infrastructure. A groundwater pump installed in the 1990s had long since fallen into disrepair. The village is located on the Black Creek (also referred to as the Yalbac Creek) in the headwaters of the Belize River Watershed. The Black Creek originates upstream of Yalbac and flows through land farmed commercially for rice and vegetables, before passing through Yalbac Village and into the Labouring Creek in the vicinity of the Cara Blanca pools on the boundary of the Belize Maya Forest Reserve.

A rapid hydrological assessment was undertaken for the Black Creek system using a wide range of mapping and hydrological data. This included: (i) mapping the hydrological stream network using digital elevation model (FABDEM) drainage analysis, validated by high resolution satellite images; (ii) identifying land use upstream within the catchment using remote sensing data of land use/land cover (WorldCover); and (iii) historical rainfall data analysis to understand the hydrological regime and seasonality of river flows. This analysis provided a transparent hydrological system mapping for the project purposes. These purposes included sharing maps with the community during workshops as illustrated in Figure 2, and supporting the identification of representative sampling locations.

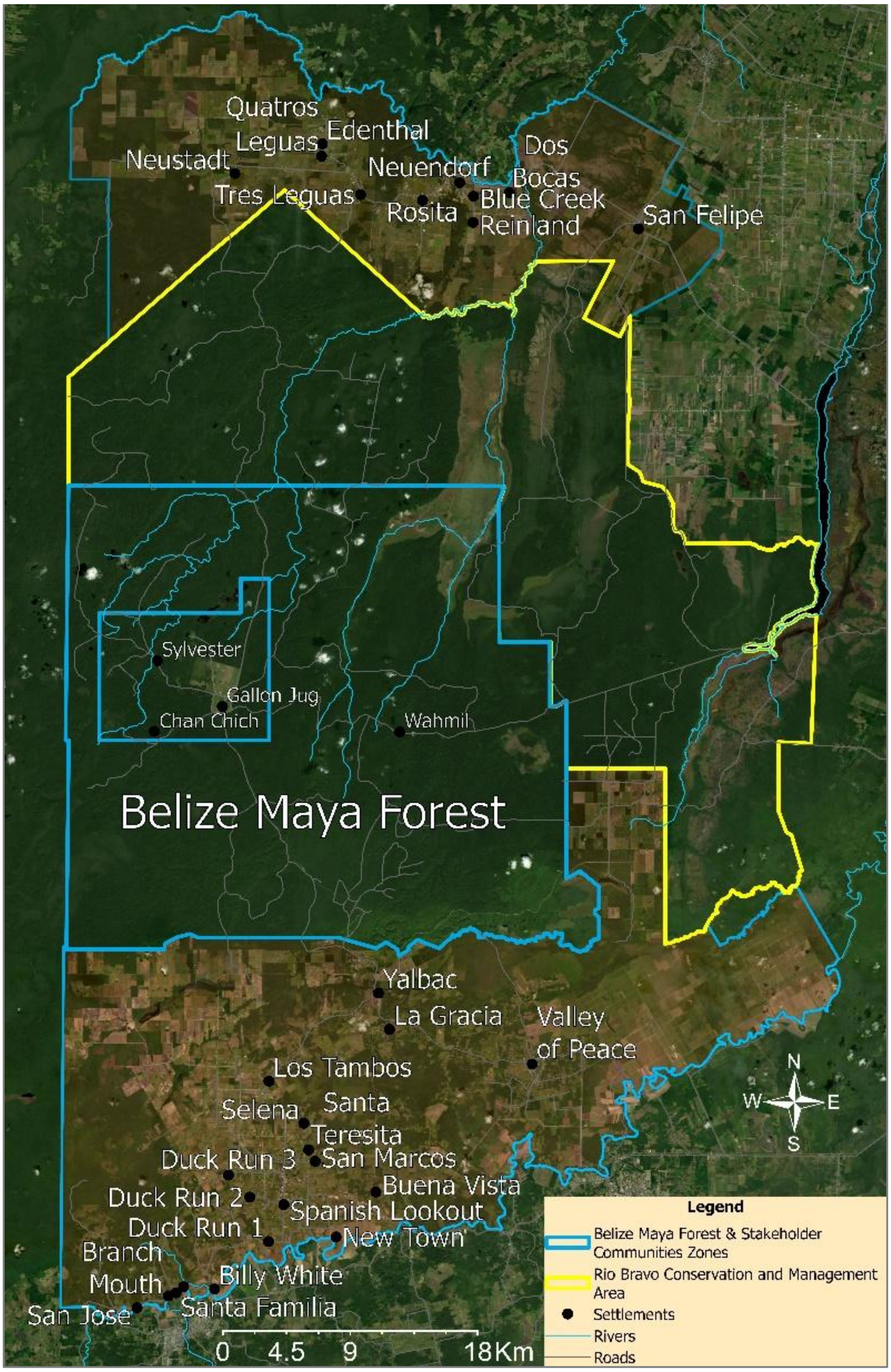

Figure 1. The Belize Maya Forest and the surrounding landscape and buffering communities

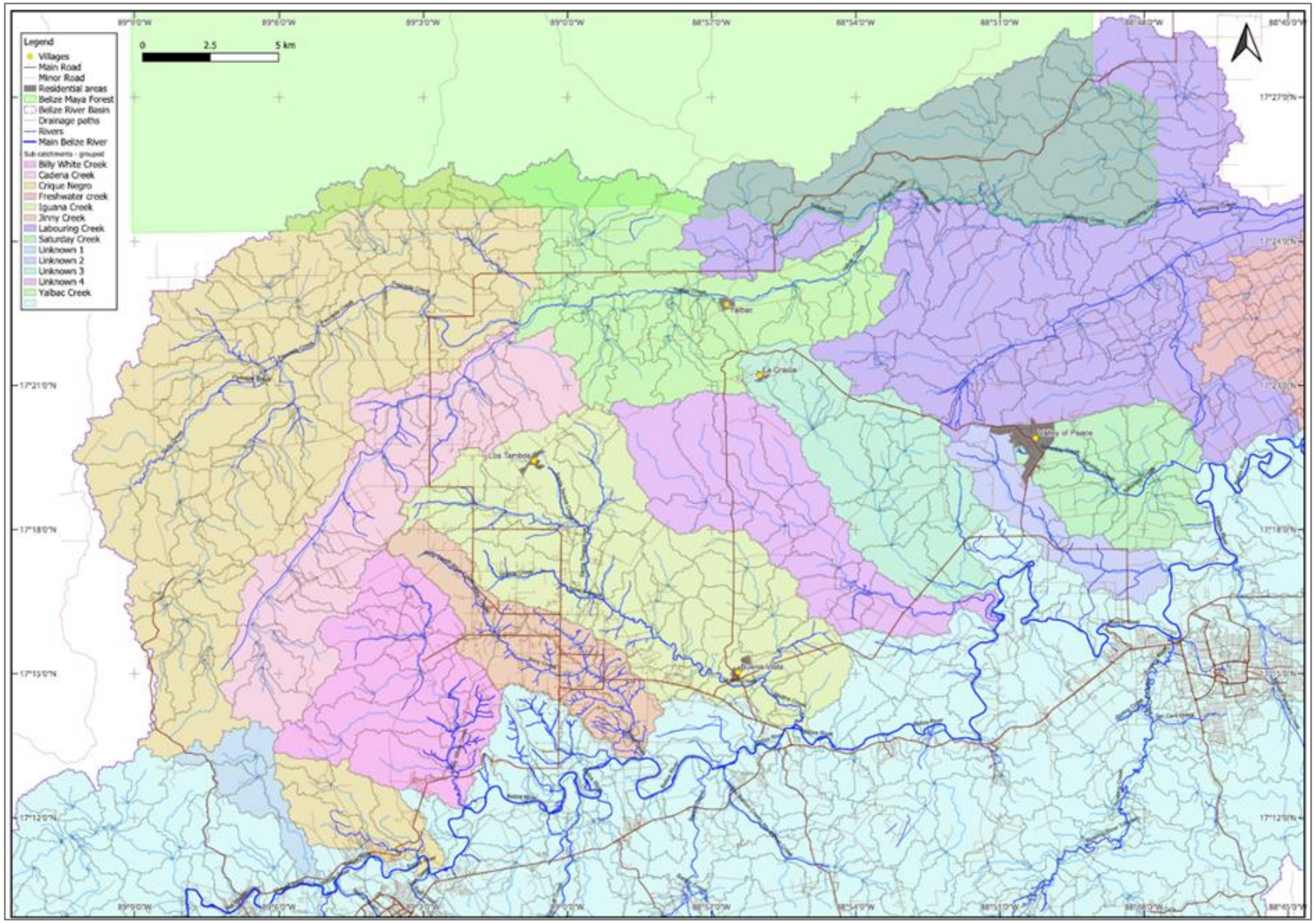

Figure 2. Example of a hydrological mapping outputs developed for and used in the project

4 Approach

The project was conducted in two fieldwork phases with the first completed in June/July 2023 and the second in May 2024. The initial phase of the research used workshops including participatory exercises to identify, understand and prioritise water security hazards from the perspective of residents, and household questionnaires to quantify trends in household water use. During Phase 1, steps 1-3 of the MUISKA-light toolkit were completed. The second phase used workshops and water quality analysis to enable a rapid preliminary risk assessment of priority hazards identified during Phase 1: pesticides in water sources. These elements align with step 4 of the MUISKA-light toolkit. Methods used and findings are described below, structured by study objectives.

5 Objective 1: Identify and prioritize water security hazards and impacts

5.1 Data collection and analysis

Two workshops were conducted with participants from Yalbac and Los Tambos. The first, lasting a full day, was held at Los Tambos school on 26/06/2023. Eight participants took part in activities to define and describe predominate water security hazards and consequences aligning with step 1 and 2 of the MUISKA-light framework (Appendix 1). Briefly, maps of the Labouring and Iguana Creek catchments were used to facilitate identification of water use activities by residents, and by others where this had a positive and/or negative impact on the ability of residents to use water, and subsequently to identify conflicts/problems for and between water users. The nature of the problems/conflicts were discussed and relationships between them mapped as a system of hazards and consequences through focus on conditions that influence the problem, cause-effect relationships and feedbacks, and benefits or further problems that may arise as a result of responses to the problems. A classification process was then used to consider who and what was affected by the problems through focussed discussion centred on five pre-defined dimensions: 1) health and wellbeing, 2) infrastructure and associated services, 3) economy and productivity, 4) ecosystem services, 5) culture, justice and peace. The scales at which effects were perceived were also considered (individual/household, community, hydrological basin, country). Following this workshop, it was agreed to work solely with Yalbac Village due to engagement with the MUISKA-light process and the nature of hazards and consequences identified.

The second workshop was a half-day event held at Yalbac school on 01/07/2023. Five participants worked to prioritise hazards and consequences for risk assessment. The prioritisation process was informed by the earlier classification based on dimensions and scale, and discussions during the workshop on the degree of power participants felt the community had to influence decision-making about the consequences identified and opportunities for empowerment. This process aligned with step 3 of the MUISKA-light framework.

Workshop outputs were collated and are summarised in the results section that follows to describe and explain water security concerns in Yalbac Village and to foreground the focus of the subsequent rapid risk assessment.

Workshops were conducted in a mix of Spanish and English, with data collected and translated into English for analysis. All data was collected and analysed in accordance with approvals from the University of Leeds ethics committee (MEEC 22-034) and the Institute for Social and Cultural Research (ISCR/ H/2/133).

5.2 Results

Workshop 1: Identifying and exploring the key water security hazards and consequences in Yalbac Village

Sources of water used by Yalbac Village identified during workshop 1 were: rainwater (in tanks and barrels), the Black Creek and tributaries, springs – some close to particular houses, others at unspecified locations in the forest, and shop purchased water. Well water was identified as available historically. However, the pump needed to extract groundwater had not been functioning for a number of years at the time of the first workshop. Water/water source uses identified were: drinking water (by households, and for livestock), washing clothes, dishes, equipment (all either at home or *in-situ*), bathing, swimming, irrigation, garbage disposal.

Participatory system mapping produced a complex socio-ecological system map focussed on problems/conflicts identified as associated with water sources, water use and the relationships between them (Figure 3). From this map and the discussions held to create it, four core hazards and linked and sometimes overlapping water security consequences were identified (Table 1).

Figure 3. Outputs produced during the participatory systems mapping (right) and consequence classification (left) activities of workshop 1

Table 1. Key hazards and first level consequences identified during workshop 1

Hazards	First-level water security consequences
Commercial rice farming	1. Suspected chemical contamination of Black Creek 2. Suspected chemical contamination of rainwater tanks 3. Lower water levels/drying of Black Creek and tributaries 4. Anxiety and powerlessness
Local farming	1. Suspected chemical contamination of Black Creek 2. Lower water levels/drying of the Black Creek and tributaries
Lack of garbage facilities	1. Pollution due to disposal of garbage in the Black Creek
Climate change	1. Lower water levels/drying of the Black Creek and tributaries 2. Over-conservative water saving behavior 3. Anxiety and powerlessness

The key narratives emerging from the mapping and subsequent classification of consequences during workshop 1 are summarised below, structured by water security consequences.

Suspected chemical contamination of the Black Creek*:* commercial-scale rice farming upstream of Yalbac Village is believed to result in the run-off of pesticides into the Black Creek, direct contamination via drainage from rice fields as they have been connected hydrologically, and drift from aerial spraying. There are anecdotal historical reports of colour, odour and taste changes to the water in the Black Creek in the vicinity of Yalbac Village, and of sickness and skin irritation after bathing in the Black Creek. This is sometimes associated with changing water levels. There were concerns about the potential impacts of chemical contamination on people in Yalbac Village who use the water for different purposes, on people downstream, on livelihoods generally, for example through impacts on cattle and crops irrigated using Black Creek water, and on the people consuming them near and far. It was also highlighted that contamination may impact wildlife and reduce desire to live in Yalbac. The conversion of forest to farmland, especially near the banks of the creek was considered a contributory factor because a buffer between farmland and the creek was understood to help reduce chemical drift and run-off. It was acknowledged that local-scale farming, including on leased land in the village by larger farmers, may also contribute to contamination, both in terms of chemical use and farming too close to the creek.

Suspected chemical contamination of rainwater tanks*:* the use of crop-duster planes in the vicinity of Yalbac Village is of particular concern. There were many reports of planes releasing chemicals close to houses and of hearing substances released from planes landing on house roofs. Rainwater tanks collect water directly from roofs and there exists concern that these tanks are being contaminated when rain drains into tanks. During the workshop, rainwater tanks were identified as the primary drinking water source for most residents. Although a water pump had been installed in Yalbac Village many years ago, this had fallen into disrepair due to drying of the well, the expense of fuel to run the pump, and the bad taste of the water. There was an indication that drinking water from rainwater tanks sometimes causes stomach pain and diarrhoea. Steps taken at the household scale to clean water included using homemade filters to remove large debris and washing tanks with chlorine at the start of the rainy season. It was felt there was a lack of willingness to work as a community to maintain a larger-scale water system.

Anxiety and powerlessness*:* Lack of knowledge and uncertainty about the extent of contamination of water in the Black Creek and in rainwater tanks was described as causing considerable anxiety and feelings of powerlessness. Workshop participants explained that testing of water from the creek had been done around the time the well/pump was installed, and this had revealed the water to be unsafe.

However, test results were not provided, thus the pollutants and their potential impacts were unknown. There was also an understanding that the quality of water at the rice fields was tested. However, data or findings were not provided to those living in Yalbac. Participants described how this lack of knowledge left community leaders powerless to take action and caused householders to be over-cautious about conserving water in rain tanks to prevent the need to use water from the Black Creek. Perceived recent increases in the use of crop dusters and concern about associated contamination of rain tanks heightened anxiety. Workshop participants made clear these anxieties left them convinced they lack a safe source of water. A clear power dynamic between resident needs and food production was described, with the impression that rice production for the country was considered more important than the health of individuals at the village-scale.

Lower water levels/drying of Black Creek and tributaries: changing patterns of rainfall and rainfall amounts, hydrological modification of channels upstream of Yalbac Village, and farming too close to the channel were identified as suspected drivers of lower water levels in the Black Creek and drying of tributaries that did not dry historically. Workshop participants described water levels in the Black Creek changing unpredictably (i.e. not in line with rainfall). The impact of climate change on rainfall added to anxieties about water availability, especially because the volume of water collected in some tanks no longer lasts the entirety of the dry season, leaving some residents with little option but to use water from the creek.

Garbage pollution: Workshop participants highlighted the disposal of garbage in the Black Creek as a water security concern. It was felt that this was done deliberately by some, including those not resident in the village, because of a lack of garbage facility, and because the creek washes garbage away. There was concern that this contributes to chemical contamination (pesticide containers have been observed in the creek) and disease, to the aesthetics of the area and desire to use the area for recreation, and to impacts on cattle and wildlife that may enter the water and/or pick up garbage.

Workshop 2: Identifying which water security consequences are a priority for rapid risk assessment and why

Consequences associated with the potential ingestion of pesticides in rainwater tanks were prioritised for preliminary rapid risk assessment during workshop 2 due to the number of links with other concerns expressed by Yalbac residents for themselves, their livelihoods, those living downstream, and wildlife using surface water sources.

Key actors believed to have the power to influence risk management actions to reduce or prevent pesticide spraying and subsequent human exposure were identified and grouped as: 1) Village (primarily the Village Council); 2) Government (the Pesticide Control Board (PCB), Department of Environment, Department of Rural Development, the Government Area Representative); 3) Mennonite farmers; and 4) the Belize Maya Forest Trust.

Discussions about power, or lack thereof, centred on actions perceived to be effective by the Department of Rural Development, PCB and village members, challenges associated with village leadership and reluctance to create tension among residents, and the belief that those with power to work with and influence large-scale farmers were reluctant to do so. It was discussed how a recent reduction in the perceived use of crop dusters may have resulted from complaints made by Yalbac to PCB and the Department of Rural Development. Ultimately however, it was felt there was a need to create unity between the village and Mennonite farmers based on a shared understanding about the negative impacts of pesticide use and farming activities more broadly, particularly those influencing water flow and water quality. Instead of effort to develop unity, it was felt financial return from commercial farming was the primary interest for farmers and Government. Some participants believe that because Mennonite farmers are the biggest rice producers in Belize and also owners of large areas of land, they hold the power, whilst residents are powerless.

The potential to use various platforms to raise the profile of water security concerns in Yalbac was discussed as a mechanism for empowerment, along with compilation of data about contamination to evidence their concerns.

Although pesticides were identified generally as the prioritised hazard of concern and contaminated drinking water as the priority consequence, it was necessary to identify a target list of specific pesticides of concern to focus subsequent assessment of risk. Data about the actual use of pesticides in the area was not available. Therefore, following workshops 1 and 2, a list of pesticides of likely concern in the Yalbac area was identified for analysis (Table 2). The list was developed by drawing on PCB prioritization of pesticides of concern nationally based on water solubility and toxicity, local farm inspection data and discussions with farmers and Yalbac residents about suspected use.

Table 2. Target pesticides prioritised based on water solubility, toxicity and suspected use in the area local to Yalbac Village

Pesticide type	Pesticide name
Insecticide	1. Cypermethrin
Herbicide	2. 2,4-D 3. Ametryne 4. Atrazine 5. Diuron 6. Glyphosate 7. Lambda-cyhalothrin 8. Nicosulfuron 9. Paraquat 10. Pendimethalin 11. Propanil 12. Topremazone
Fungicide	13. Difenoconazole 14. Propiconazole

6 Objective 2: Rapid assessment of risk associated with pesticide contamination of drinking water in residential rainwater tanks, and preliminary identification of pesticides present in surface waters.

6.1 Data collection and analysis

Questionnaires

Questionnaires were administered face-to-face with 17 households in Yalbac Village between 27/06/2023 and 06/07/2023. The purpose of this activity was to confirm water sources used and quantify trends in water use, and to collect information linked to concerns about water at the household level. The sample of 17 represents c. 85% of households with residents in occupation year-round. A copy of the questionnaire is included in Appendix 2.

A descriptive analysis of questionnaire data was undertaken to identify how those residents in Yalbac might come into contact with pesticides via water. The outputs of this analysis were used to consider potential exposure and helped to inform design of a preliminary sampling network for pesticide analysis. The network was a prompt for discussions in the third workshop.

Workshop 3: Understanding vulnerabilities and exploring risk communication

A third half-day workshop was conducted at Yalbac School on 11/05/24. It sought to explain the process of water quality testing, identify and agree sampling locations, consider different vulnerabilities, and explore meaningful ways to communicate findings. These activities align with step 4 of the MUISKA toolkit. This workshop was attended by seven participants who differed from those present during workshops in the previous year. Although animated discussions were held about the collection of water samples and communication of results, this lack of continuity increased the challenge of implementing the MUISKA process coherently.

The workshop was conducted in a mix of Spanish and English, with data collected and translated into English for analysis. All data was collected and analysed in accordance with approvals from the University of Leeds ethics committee (MEEC 22-034) and the Institute for Social and Cultural Research (ISCR/ H/2/133).

Water sampling and analysis

Drawing on outputs from the rapid hydrological assessment, workshops and questionnaire analysis, spot water samples were collected from 1) rainwater tanks (n=5), 2) the Black Creek (n=3), and 3) and cenotes/lagoons (n=2) (Figure 4). The sampling network was designed so that sampling locations were distributed spatially across rainwater tanks in Yalbac Village used for drinking water and along the Black Creek at, above, and downstream of areas known to be used for bathing/residential water use. Sampling points were also located in lagoons/cenotes close to commercial farming areas and within the Belize Maya Forest to provide an initial indication of pesticides that may be of conservation concern. Illustrative images of the different type of sampling locations are provided in Figures 5 and 6.

The final location of sampling points was influenced on the day of sampling by the volume of water in water tanks (many were dry because rains had not begun before fieldwork was conducted), low flows in the Black Creek and active wildfires in the area, which impacted ability to locate a sampling point on the Black Creek upstream of the village. Instead, a sampling point was located on a tributary of the Black Creek upstream of the village, which was believed to drain agricultural land.

Water samples were collected on 24/05/2024 in accordance with standard operating procedures for the target pesticides and a scientific research permit issued by the Belize Fisheries Department (0054-24). To summarize, 1 L of water was sampled from each location in clean amber glass bottles with PTFE-lined screw caps. The sample containers were filled to the brim. A further 50 ml of water was collected from the same location in clear plastic bottles. Samples were stored at between 2 and 8 °C in cool boxes using ice gel packs and maintained at temperature until and during export to the receiving laboratory in the UK (RPS Group Laboratories, Bedford). Samples were transported between Belize and the UK by air in cargo in cool boxes with ice gel packs and arrived at the laboratory for extraction within 10 days of sample collection.

The list of 14 priority pesticides was used as a base to identify suites of pesticides for analysis because it can be cost-effective to analyse samples for additional pesticides in the same groupings at the same time. Analysis was ultimately conducted on 63 different determinants (Appendix 3) by RPS Group laboratories using GC-MS/MS and LC-MS/MS to enable the selection of specific analytes for individual fragmentation. A few analyses were impacted by other components in the sample interfering with ability to quantify the pesticide of interest. Subsequently, reporting limits were raised from 0.02 to 0.1 for 2,3,6-trichlorobenzoic acid (2,3,6-TBA), 2-methyl-4,6-dinitrophenol (DNOC), picloram and clopyralid in isolated samples (identified in the raw data in Appendix 3).

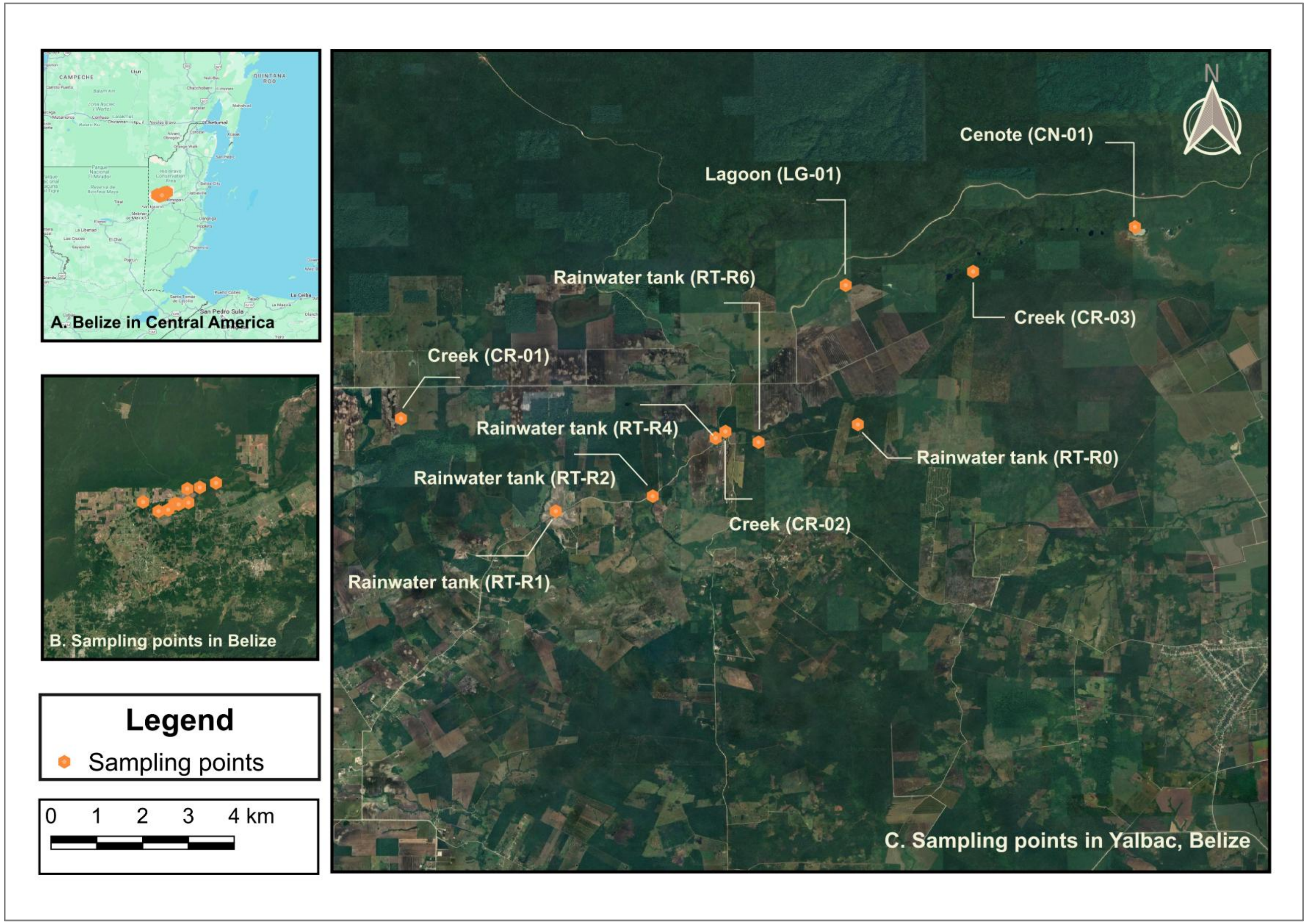

Figure 4. The location of Belize (A), the study area showing agricultural land to the south, east and west, and the Belize Maya Forest to the north (B), and pesticide sampling points (C)

Figure 5. Depictions of a typical household rainwater tank used for drinking water (A), locations on a tributary upstream of the village (B), and the Black Creek within Yalbac Village (C), and downstream of Yalbac Village just above the confluence with the Labouring Creek (D)

Figure 6. Depictions of the location sampled on the lagoon (A), the cenote (B). Image C shows the landscape upstream of Yalbac Village at the time of sampling when fires were active

The limited spatial and temporal extent of sampling meant it was not possible to determine inter-annual variation in pesticide presence or long-term concentrations for those detected as would be required to undertake a meaningful preliminary risk assessment. Instead, we analyse results of spot sampling to provide a hazard characterisation of pesticides detected. We follow, as far as possible, the steps outlined in the WHO (2021) drinking water case study to consider potential exposure to pesticides in rainwater tanks used for drinking water. We believe national guidelines for pesticides in drinking water have not been developed for Belize and we therefore draw on internationally agreed guideline values. The steps taken and resources used are described in Table 3. For other water uses, we provide results of pesticide analysis and a summary of activities that may be useful to inform the development of risk assessments in future.

It is important to re-iterate that water testing undertaken was very limited. All findings presented below are intended to focus further investigation, not to provide a comprehensive assessment of risk.

Table 3. Steps taken to characterise hazards for pesticides detected and assess potential exposure to pesticides detected in rainwater tanks used for drinking water

Hazard characterisation for all pesticides detected	
Step	**Data used**
1. What are the pesticides of concern?	Results of water quality testing to identify pesticides present in detectable concentrations at the time of sampling
2. Are the pesticides hazardous to humans and do health-based guidance values for drinking water from international organisations exist?	Pesticide properties and internationally agreed health-based guideline values were researched using the following resources: 1. World Health Organization (2022). Guidelines for drinking-water quality: fourth edition incorporating first and second addendum. https://www.who.int/publications/i/item/9789240045064 2. Internationally peer reviewed chemical safety information (INCHEM) available at https://www.inchem.org/#/ and produced by the cooperation of the International Programme on Chemical Safety (IPCS) and the Canadian Centre for Occupational Health and Safety (CCOHS) 3. The International Agency for Research on Cancer (IARC) Monographs on the Identification of Carcinogenic Hazards to Humans Available at: https://monographs.iarc.who.int/list-of-classifications The following resources were also consulted to increase understanding: 4. Lewis, K.A., Tzilivakis, J., Warner, D. and Green, A. (2016) An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment: An International Journal*, 22(4), 1050-1064 DOI: 10.1080/10807039.2015.1133242. Database available at: https://sitem.herts.ac.uk/aeru/ppdb/en/index.htm 5. Smith, C.D. & Nowell, L.H., (2024). Health-Based Screening Levels for evaluating water-quality data (3rd ed.). U.S. Geological Survey web page, accessible at https://water.usgs.gov/water-resources/hbsl/ doi:10.5066/F71C1TWP 6. The Agency of Toxic Substances and Disease Registry (ATSDR) Toxicological profiles Atrazine: (2003) https://www.ncbi.nlm.nih.gov/books/NBK597834/ Dinitrocresols: (2018) https://www.ncbi.nlm.nih.gov/books/NBK592076/ 2,4-D: (2020) https://www.ncbi.nlm.nih.gov/books/NBK590150/ Glyphosate (2020): https://www.ncbi.nlm.nih.gov/books/NBK591689/
Exposure assessment for pesticides detected in rainwater tanks used for drinking water	
3. Do assumptions underpinning health-based guidelines for drinking water reflect local conditions in Yalbac Village?	Questionnaire data about water consumption was considered alongside the assumptions underpinning health-based guidelines.
4. What is the likely duration of exposure and how much exposure is likely to occur?	The results of pesticide analysis and questionnaire data about drinking water sources and rates of consumption
5. Can health risks associated with pesticide contamination of rainwater be characterised with the data available?	Limitations of the available data were considered

6.2 Results

Pesticides are widely used in the local area, thus Yalbac residents may be exposed via other pathways in addition to water, such as air, food, soil and direct contact. Reflecting the focus of this study, only water is considered here. However, it is important to note that exposure via additional media likely occurs. Prior to presenting results of the hazard characterisation and exposure assessment we first draw on questionnaire data to describe the potential ways in which Yalbac residents use water and therefore may come into contact with pesticides via local water sources, and on discussions held during workshop 3, where participants identified their perspectives about factors that increase their vulnerability to associated risks.

6.2.1 Water Uses

The primary uses of water sources in Yalbac Village were for: drinking, cooking, bathing, washing dishes, laundry, equipment and houses, and irrigating plants and livestock. All but one of the households surveyed used a separate source of water for drinking/cooking than for other uses.

Drinking/cooking water

The majority of surveyed households (88% (15 of 17)) used rainwater tanks for drinking and cooking water, with 40% of these households supplementing this source with bottled water when the tanks run dry during the dry season and/or if there was a suspected issue with water quality. One household purchased all water consumed in the house. A second household used a spring water source located some distance from Yalbac Village, with water subject to carbon block filtration prior to drinking. This had been supplemented since 2021 on an ad hoc basis with bottled water purchased due to health concerns of a child family member. This household used the spring water source for all purposes.

Most households used a homemade filter made of cloth or mesh to remove large debris from rainwater before it enters the tank and to prevent insects and frogs entering the tank. Tanks were typically described as being cleaned thoroughly at the end of every dry season with Clorox to make them ready to collect rain once again when the wet season begins. Some reported cleaning the tank much more regularly even if rainwater remains, others reported doing so whenever the water level is low. Four households use filters donated or purchased from a store. Four households use chlorine or water tablets to treat water in their tanks. Most households identified altered taste as a reason not to do this or to do it infrequently. A few households complained of a 'stagnant' taste and that worms/larvae and frogs are a problem.

Subsequent to administration of the questionnaire, a well providing groundwater was restored for drinking water supply. Thus, at the time of writing, groundwater was also an important source of drinking water. This source was not investigated during the current study.

Other uses

The primary sources of water for other uses were the Black Creek and its tributaries. Water for these activities was typically used *in situ*, or *ex situ* at home after collection from the source.

In situ uses

Over half of households surveyed undertook *in situ* activities in the Black Creek (11 of 17, 65%). One other household had done so previously, but not in the year leading up to the survey. All of these households identified spending time in the creek for laundry and/or bathing, with one household also washing dishes. Several households indicated the creek was close to their houses, so convenient.

All households that undertook *in situ* activities in the creek identified concerns about water quality. Some identified a bad smell and/or changes in water colour, describing dirty/murky water. Sometimes this was clearly linked to periods of rainfall. However, concerns were also identified about colour changes in the dry season. One household spoke about changes in colour associated with changes in water level that were not linked to rainfall.

Ex-situ uses

Nine households collected water from the Black Creek and tributaries for use at home, for washing dishes, laundry, cleaning, bathing and irrigating livestock, pets and crops. Water was either collected and stored in barrels or, for those located in closer proximity to the creek, pumped from the source directly to the home. Three households identified Kilo 6 as the location water was collected from, others identified locations close to their homes or didn't specify.

Five households reported experiencing skin rashes and itching after using the creek, with reports of symptoms lasting from between one day to three weeks. Some described skin irritation occurring at the same time as water colour changes, with one household describing the colour as milky white. Others described feeling a residue on the skin. Two households identified a potential cause as the release of water from rice fields upstream, others potential causes included contact with the Poisonwood Tree.

To summarise, probable routes of exposure to pesticides via water in Yalbac Village include: 1) Ingestion, primarily of drinking water and water used for cooking. The most common source of water linked to this pathway was rainwater stored in tanks at home. 2) Skin absorption and skin contact whilst bathing or washing laundry, dishes etc. The most commonly used source of water for these purposes was the Black Creek (*in*- and *ex-situ* uses).

6.2.2 Vulnerabilities

During the final workshop, participants identified and/or reiterated a number of factors they felt increased and/or decreased their vulnerability to risks associated with pesticides in water sources. Factors can be summarised as 1) availability of multiple water sources, 2) the location of the house in relation to water sources, 3) tradition/habit, 4) limited livelihood options, and 5) relationships with those holding power. These factors supplemented discussions held during Phase 1 where a lack of data to evidence concerns was identified as a core vulnerability.

Multiple water sources

During the course of the study a village pump/well was restored. This increased options for accessing water and was felt to reduce vulnerability, for example if other sources dried or became contaminated. However, it was noted that different water sources come with additional problems. For example, high demand during dry periods meant the tanks storing groundwater were sometimes dry. Furthermore, pumping groundwater requires fuel which must be paid for, and is a fee not all can cover. A solar-powered generator was proposed as a solution to reduce fuel dependency, although maintenance challenges were also recognised.

Household Location

The location of the house in relation to water sources was felt to affect vulnerability. Houses close to the well were able to receive water through direct piped connection. Others had to travel to access the water. For some, this meant using rainwater and the creek was less time consuming and/or effort.

Tradition/habit

Cultural preferences held by some favour bathing in the Black Creek. Even when other water is available for bathing, some still choose to use the creek.

Limited livelihood options

Livelihood options in Yalbac are primarily agricultural and often tied to commercial farming through employment and leasing of land. This dependence can contribute to economic vulnerability and can limit autonomy for residents because they don't want to put these important relationships at risk.

Power relationships

Participants recognised the significance of supportive relationships, highlighting how they felt a change in local government had contributed to the repair of the village well and pump. This was juxtaposed against unsupportive relationships which left residents feeling their concerns are undervalued and risked their livelihoods.

6.2.3 Hazard Characterisation

What are the pesticides of concern?

Analysis of water samples indicated that five of the pesticides tested were detected at concentrations above the reporting limit. Four were included on the list of prioritised pesticides: 2,4-dichlorophenoxyacetic acid (2,4-D), atrazine, bentazone and glyphosate. One additional pesticide was detected: 2-methyl-4,6-dinitrophenol (DNOC). Two pesticides were detected in rainwater tanks used for drinking water: atrazine and DNOC. 2,4-D, bentazone and glyphosate, were detected alongside atrazine in samples collected from the Black Creek. Concentrations are reported in Table 4.

Although this report will focus on the five pesticides detected in the samples taken, the results should not be interpreted to indicate other pesticides are not present in water sources in the Yalbac area, or that the pesticides detected are not present at other locations at different time periods. These results indicate only that the five pesticides were present in detectable concentrations at the time of sample collection.

Table 4. Pesticide concentrations in spot samples taken from the Black Creek and rainwater tanks in and around Yalbac Village, and from two lagoons/cenotes. <RL= below reporting limit. Sampling site identifiers are provided in parentheses.

	Atrazine (µg/l^{-1})	**DNOC (µg/l^{-1})**	**2,4-D (µg/l^{-1})**	**Bentazone (µg/l^{-1})**	**Glyphosate (µg/l^{-1})**
Drinking Water Guideline values					
WHO Drinking Water Guidelines (WHO, 2022) *****to provide guidance in lieu of a formal value	100	Not available	30	500*	Considered unnecessary
Results					
Black Creek					
Upstream Yalbac Village (CR-01)	<RL	<RL	<RL	<RL	<RL
At Yalbac Village (Kilo 6) (CR-02)	0.06	<RL	0.05	0.16	0.13
Downstream Yalbac Village (CR-03)	<RL	<RL	<RL	0.10	<RL
Rainwater Tanks					
Rain Tank-(RT-R0)	<RL	<RL	<RL	<RL	<RL
Rain Tank (RT-R1)	0.02	<RL	<RL	<RL	<RL
Rain Tank (RT-R2)	<RL	<RL	<RL	<RL	<RL
Rain Tank (RT-R4)	<RL	0.04	<RL	<RL	<RL
Rain Tank (RT-R6)	0.05	<RL	<RL	<RL	<RL
Lagoons and Cenotes					
Lagoon 1 (LG-01)	<RL	<RL	<RL	<RL	<RL
Cenote 1 (CN-01)	<RL	<RL	<RL	<RL	<RL

Are the pesticides hazardous to humans and do health-based guidance values from international organisations exist?

**** Atrazine***

Atrazine is a triazine selective systemic herbicide used on annual broadleaf and grassy weeds. According to the IARC and INCHEM database, risk of exposure typically occurs occupationally through inhalation or skin contact. The United Nations Globally Harmonized System of Classification and Labelling of Chemicals (GHS) indicates atrazine may cause serious eye irritation if eyes are directly exposed, and damage to the liver if exposure is long-term or repeated, resulting in tissue lesions.

The International Agency for Research on Cancer (IARC) identifies atrazine as a Group 3 substance, meaning its carcinogenicity to humans is considered to be unclassifiable. The IARC note there to be sufficient evidence in experimental rats for the carcinogenicity of atrazine but conclude there is strong evidence that the mechanism by which atrazine increases the incidence of tumours in certain rat species is not relevant to humans.

Atrazine is known to be widespread in surface waters, groundwater and reservoirs (ATSDR, 2003; Lewis et al., 2016) and in drinking water supplies where concentrations rarely exceed 2 µg/l^{-1} and are commonly well below 0.1 µg/l^{-1} (WHO, 2022). Health-based guideline values for drinking water have been set at 100 $\mu g/l^{-1}$ by the WHO (2022) assuming a body weight of 60kg, consumption of 2 litres of water per day. As the presence of atrazine is likely in multiple media (e.g. air, food), the guideline value is set assuming and an allocation to water of 20% of the acceptable daily intake.

**** 2-methyl-4,6-dinitrophenol (DNOC)***

2-methyl-4,6-dinitrophenol (DNOC), also commonly referred to as 4,6-Dinitro-O-cresol, is a multiuse pesticide that was discontinued for use in many countries in the 1990s. It is not listed on the INCHEM database, nor the IARC Monographs. Lewis et al., (2016) describe DNOC as extremely toxic to humans, considering it to be genotoxic (suspected to cause genetic defects), neurotoxic, a skin sensitiser and an eye and skin irritant. It may also have reproductive/developmental impacts. Potential exposure routes are identified as inhalation, ingestion, skin absorption, and skin or eye contact.

The ATSDR (2018) recognises direct pesticide applications or run-off and leaching may result in DNOC presence in surface and groundwater. Lewis et al., (2016) identify drift to be a concern if this pesticide is applied to plants or soil because it is moderately volatile.

The ATSDR (2018) indicates ingestion of DNOC in drinking water is the most likely source of exposure in the USA, and that a lack of data means daily intake from drinking water has not been estimated. Therefore, guideline values are not reported by the WHO for drinking water quality (WHO, 2022).

**** 2,4-dichlorophenoxyacetic acid (2,4-D)***

2,4-dichlorophenoxyacetic acid (2,4-D) is a selective systemic herbicide used on broad-leaved weeds. Risk of exposure can occur by inhalation, ingestion, and skin contact. It is considered to act as an endocrine disruptor, a neurotoxicant and to have reproductive and developmental effects (Lewis et al., 2016). 2,4-D is not listed on the INCHEM database. The IARC Monographs identify 2,4-D as a Group 2B substance, meaning it is considered to have possible carcinogenicity to humans.

2,4-D degrades rapidly in the environment, and it is believed there is low potential for leaching to groundwater. Aerial application of 2,4-D may drift to surface waters and it can persist in some aquatic systems (ATSDR, 2020a). The WHO (2022) health-based guideline value for drinking water is set at 30 μgl^{-1}, assuming a body weight of 60kg, consumption of 2 litres of water per day, and a 10% allocation of the acceptable daily intake. The USEPA has set maximum contamination levels in drinking water at 70μgl^{-1} (Smith & Nowell, 2024).

**** Bentazone***

Bentazone is a selective herbicide used to control broadleaf weeds and sedges post emergence that can leach to water during heavy rainfall, and it is sometimes applied directly to water in rice fields (WHO, 2022). It is considered moderately toxic to humans and an irritant to skin and eyes (Lewis et al., 2016). Exposure pathways include direct skin contact and ingestion, although risk of dietary exposure is considered minimal (Lewis et al., 2016). Bentazone is not listed on the INCHEM database, nor on the IARC Monographs.

Bentazone photodegrades but can leach from soil into groundwater and can be present in surface water if discharged in drainage water and/or if used directly in water, for example when growing rice. Drift after application may also be a concern due to low volatility (Lewis et al., 2016).

A formal drinking water guideline value has not been established by the WHO because bentazone generally occurs in drinking-water or drinking-water sources at concentrations well below those of health concern. However, they have identified a health-based value for drinking water at 500 $\mu g/l^{-1}$ to provide guidance where there is a reason for local concern. This value assumes a body weight of 60 kg, consumption of two litres of water per day, and a 20% allocation of the acceptable daily intake. The WHO (2022) note however, that the data on which the default value of 20% is based, does not generally include information from developing countries, where exposure to bentazone via food may be higher. The USGS have established a non-enforceable benchmarks thought to be protective of chronic non-cancer effects at 900 µg/l^{-1} (Smith & Nowell, 2024).

**** Glyphosate***

Glyphosate is a broad-spectrum herbicide which can be applied directly to surface waters to control aquatic weeds (ATSDR, 2020b). It degrades microbially in soil and water to aminomethylphosphonic acid (AMPA). The WHO (2022) indicate glyphosate and AMPA are of low toxicity. However, some consider toxicity to humans to be moderate, with possible effects on the bladder, liver and endocrine system. It may also cause serious eye damage and gastrointestinal problems (Lewis et al., 2016). Potential exposure pathways include inhalation, ingestion, skin absorption and contact and eye contact. Glyphosate is listed by the IARC as a Group 2A carcinogen, meaning it is considered probably carcinogenic to humans. The USEPA and ESFA consider there to be no evidence it is a human carcinogen, or that it is unlikely (Lewis et al., 2016). Glyphosate is not listed on the INCHEM database.

Glyphosate is chemically stable in water and is not subject to photochemical degradation. AMPA the degradation product is often detected more frequently and at similar concentrations than glyphosate. Glyphosate enters surface and subsurface waters after direct use in or near aquatic environments or by runoff or leaching from terrestrial applications. The WHO (2022) do not consider a formal guideline value for glyphosate or AMPA in drinking water to be necessary because concentrations found in drinking water under normal conditions do not represent a hazard to human health. The USEPA have set a maximum contaminant level for water quality at 700 µg/l^{-1} (Smith & Nowell, 2024).

6.2.4 Exposure assessment: pesticides in rainwater tanks

Do assumptions underpinning drinking water health-based guidelines reflect local conditions in Yalbac Village?

The WHO (2021) suggest the default assumptions for water consumption rates and body weights are generally likely to be adequate because the large range in toxicological uncertainty that exists for the vast majority of chemicals exceeds them. However, questionnaire data was used to consider assumptions about the volume of water consumed. On average 0.43 L of water was estimated to be consumed per day at the house by participants. Note, the volume estimated varied markedly between households reflecting time spent at home, use of additional water sources away from home, and water conservation behaviour (standard deviation 0.47 L, min 0.06 L, max 1.9 L). Volumes estimated by some households identifying the house supply as the main source of all drinking water were occasionally far lower than seemed feasible, thus low confidence is attached to these estimates. None of the households estimated drinking more than 2 L per day, the default value on which WHO (2021) guideline values are based.

According to CAMDI (2010), average body weights in Belize vary between 70.5-74.2 kg. More up to date information was not found. In the absence of this information, the values based on an average body weight of 60 kg used by WHO (2021) are adopted.

The WHO drinking-water guideline values account for ingestion through food and are considered, in most cases, sufficient to account for intake of contaminants through inhalation and dermal absorption. As context specific exposure information is not available to indicate exposure through other media, the guideline values indicated by the WHO (2022) are the default alternative.

How much exposure is likely to occur and what is the likely duration of exposure?

The results indicate atrazine and DNOC were detected in samples taken from rainwater tanks Table 4. Ingestion of rainwater occurs year round but was generally estimated to increase in the hotter months (typically between March and June). Towards the end of this period rain tanks are often dry so consumption of purchased water increases. Therefore, long-term exposure is of concern, with exposure varying seasonally.

In addition to the properties of individual pesticides, exposure to them will also be influenced by the seasonality of their applications and the methods with which they are applied. Data describing pesticide use behaviour in the Yalbac area will help to inform future risk assessment.

Can health risks associated with pesticide contamination of rainwater be characterised with the data available?

The available data suggests exposure of Yalbac residents to atrazine and DNOC may occur through ingestion of rainwater. International health-based guideline values exist for long-term average exposure via ingestion in drinking water for atrazine.

Data for atrazine suggests the concentration recorded is considerably lower than the guideline value (with a hazard quotient between 0.0002 and 0.0005). Data is based on very limited sampling conducted on one occasion. It does not reflect seasonal variations nor long-term average exposure (which is represented in the guideline value). In order to obtain a long-term exposure hazard quotient and therefore an assessment of health risks, an estimate of long-term average concentrations of atrazine in drinking water tanks is required.

Health-based guideline values for DNOC are not available due to a lack of global data. Without formal guidelines for DNOC (and longer-term average exposure data) is not possible to assess risk. However, it is noted that DNOC has been deregulated in many countries due to toxicity.

6.2.4 Information to inform future assessment of risk linked to use of Black Creek water

How much exposure is likely to occur?

Atrazine, bentazone, 2,4-D and glyphosate were present in detectable concentrations in the Black Creek. All were detected in samples collected in the vicinity of Yalbac Village (Kilo 6), and bentazone was also detected in the sample taken downstream of the village. The concentration at the downstream site was lower than in the sample taken from the village sampling location.

No pesticides were detected at levels above reporting limits in samples taken from the Black Creek upstream of Yalbac Village. No pesticides were detected at concentrations above the reporting limit in samples taken from cenotes/lagoons.

What is the likely duration of exposure?

In-situ and *ex-situ* use of the Black Creek occurs year-round, with 6 households using Creek water both *in situ* and *ex situ,* typically in, or obtained from locations close to Kilo 6 (at Yalbac Village). Thus, long-term exposure is of concern. Exposure levels vary seasonally for some households reflecting temperature and availability of water from other sources. Creek water use increases in the dry season for some households.

In situ uses

Three households used the creek year-round. The amount of time these households estimated spending in the creek varied reflecting the activities undertaken. Two used the creek year-round and indicated spending between five and 10 minutes in the creek when visited for bathing. The third indicated spending up to as much as four hours when laundry and bathing were done at the same time.

Seven additional households used the creek in the dry season when it is hot and other sources are low or dry (variously between February and July). These households estimated spending between one and five hours in the creek depending on activity and weather.

Ex-situ uses

Eight households used creek water at home. Five used the source year-round, with volumes increasing between March and July for two of them. Three households used creek water as a back-up in the dry season (between March and July) when other sources are low/dry.

The presence of four pesticides in Black Creek samples at Yalbac Village indicates potential for dermal contact and absorption given the activities the creek is used for. Considering the several anecdotal reports of skin irritations and rashes after being in contact with creek water, long-term monitoring of pesticide concentrations in the creek is recommended to allow potential exposure to be evaluated modelled and risk assessed by pesticide exposure specialists.

6.2.5 Risk Communication

Participants indicated that in addition to the raw data, a leaflet and video summarizing the pesticides of concern would be the most effective means of communicating the results of the water quality testing and potential risk to themselves. A lengthy report was considered less accessible. Yalbac residents have been made aware of the key findings of this study during a meeting held with BMFT and are expecting the leaflet and video to be provided in the first quarter of 2025.

7 Discussion

Maintaining food availability for a growing human population is a key factor constraining global water security (Grafton et al., 2017), with achieving both objectives further exacerbated by a changing climate (Pereira, 2017). Particular concern in this context centred on potential exposure to pesticides used in food production, and the anxiety and water use behaviours resulting from lacking knowledge about their presence in water sources and potential health impacts. The United Nations (2023) have highlighted that lack of data poses a considerable risk to those living in areas where water quality is unknown. In our study, lack of evidence about pesticide contamination of water sources was identified as a key water security risk, preventing local and national-scale ability to advocate for meaningful risk management actions, and to take ownership for water security. Here we summarise and consider the results of spot sampling of rainwater tanks used for drinking, and surface waters, and make recommendations that acknowledge current data limitations, before reflecting on the future utility of ‘MUISKA-light’.

Rainwater tanks

Drinking water sourced from rainwater tanks appears to be at risk of pesticide contamination. Three of the five tanks tested revealed detectable concentrations of atrazine or DNOC.

Concentrations of atrazine, which is known to be widespread in drinking water supplies due to its low degradability (ATSDR, 2003), were within ranges reported for drinking water elsewhere. The WHO (2022) report that concentrations rarely exceed 2 $\mu g/l^{-1}$ and are commonly well below 0. 1 $\mu g/l^{-1}$. The health-based guideline value for atrazine in drinking water is 100 $\mu g/l^{-1}$ (WHO, 2022). Assessment against this value requires long-term average concentrations, rather than concentrations provided by the single sampling event in this study.

Information about DNOC in drinking water supplies elsewhere was more limited. However, it is recognised continued or historic application of the pesticide may contaminate drinking water. The ATSDR (2018) indicates ingestion of DNOC in drinking water is the most likely source of exposure in the USA and summarise data reported during the 1980/90s, that indicates concentrations of <10 $\mu g/l^{-1}$ in the Potomac River in Virginia, USA, and maximum concentrations of 35 $\mu g/l^{-1}$ in groundwater in California where DNOC had been used as a pesticide. Concentrations between 0.95 and 2.9 $\mu g/l^{-1}$ were also detected in rainwater in Switzerland. A lack of data about DNOC means daily intake from drinking water has not been estimated, and guideline values are not reported (ATSDR, 2018).

Surface waters

Surface waters also appeared to be polluted by pesticides. Atrazine, glyphosate, bentazone and 2,4-D. were detected in surface water collected from the Black Creek at Yalbac Village. These pesticides, or their derivatives, are commonly detected in surface waters where they have been tested (ATSDR, 2003; Lewis et al., 2016; ATSDR 2018; 2020a; 2020b; WHO, 2022), and the concentrations detected in the current study were within ranges reported elsewhere. For example, annual maximum concentrations of 2,4-D in over 4,000 surface water samples collected in the USA between 1992 and 2001 ranged from 0.003 to 15 $\mu g l^{-1}$, and concentrations of bentazone up to 14 $\mu g l^{-1}$ have been reported in surface water by the WHO (2022). The ATSDR (2020b) summarise data about glyphosate in surface waters, including agricultural surface waters in Argentina where concentrations range from trace to 7.6 $\mu g\ l^{-1}$. In 3 agricultural basins in the USA, concentrations between <0.02 and 430 $\mu g\ l^{-1}$ were recorded in 2007/8, with temporal trends in concentrations coinciding with seasonal applications of glyphosate, and intra-annual variation reflecting high periods of rainfall, including storm events.

All but one of the pesticides detected were present in samples taken from the stretch of the Black Creek that flows through Yalbac Village. Although concentrations detected were relatively low, the detection of multiple pesticides at this location was concerning because this section of the Black Creek, and water collected here, was most frequently identified as used by Yalbac residents for *in-situ* and *ex-situ* purposes. Given anecdotal reports of skin irritation associated with use of this water, longer term broad scan monitoring of this location would seem a sensible priority to develop a fuller picture of pesticides of concern and to inform if and how activities in the creek and use of the water should be modified. This location is used for collecting water for farming activities and for washing farming equipment. It is plausible the presence of multiple pesticides here reflects this, as much as it might reflect run-off or release from upstream. No pesticides were detected in the sample taken upstream of the village. However, the location of the sample taken upstream may not have been best placed to capture farming activities. Rather than a location on the Black Creek, a tributary believed to drain farmland was sampled. It is recommended that the upstream sections of the Black Creek and tributaries are assessed on foot in advance of future sampling campaigns to identify appropriate sampling location(s). Although this was attempted for the current study on the day of sampling, hydrological alterations to channels in the area, and low flows at the time of sampling made it difficult to locate blue lines on the map. Attempts to locate sampling points in this location were also influenced by active wildfires which constrained access.

Environmental guidelines for pesticides in surface waters have not been developed for Belize. A nationwide survey of pesticides in surface waters in Belize is imminent, to be conducted by Department of Environment, Belize and CEFAS, UK through the Ocean Country Partnership Programme with the aim of developing baseline understanding and to inform future assessment activities (Maskrey, 2024). Findings may add additional data points for the Yalbac area and should provide a useful reference for future work.

Recommendations

The findings from the current study can be useful for informing future work. For example, the detection of five pesticides from a total of 63 determinants analysed, gives some justification for analytical focus on these in future. This could be achieved through use of Enzyme-Linked Immunosorbent Assay (ELISA), a technique that offers a relatively low-cost, rapid method to detect presence of specific pesticides at levels below the limits of analytical techniques that could be conducted in-country. Although specific concentrations would need to be analysed in accredited laboratories, the ELISA technique could be a useful screening approach to rationalise analysis in this context (Maskrey, 2024).

Although the current findings may help to inform future work, it is important to remember results presented here have been generated from spot samples collected at one moment in time. Longer-term monitoring of pesticides in water sources would provide a more comprehensive understanding of pesticides of concern. This could be achieved using passive or composite sampling to detect pesticides present over a specific time period. Analysis will be logistically challenging and expensive until analytical capacity is developed locally (e.g. due to holding times and transportation needs). To facilitate future work, it would be helpful to develop a more comprehensive understanding of the seasonal use of different pesticides in the area, disaggregated by application method. Long-term monitoring of water levels in the Black Creek and comparisons of these with climate data would provide useful additional information.

Of the water sources used in Yalbac, only those indicated most frequently when the questionnaire was administered were the focus of this study (rainwater tanks and the Black Creek). Groundwater sources were also indicated (several springs located near and far from Yalbac) or became important subsequently (the community well/pump). Future assessment of risk associated with pesticide contamination of water sources, should including groundwater sources. Several pesticides, including all detected during this study with the exception of 2,4-D, have potential to leach to groundwater.

Risk of exposure through consumption of rainwater was the primary concern of this study. However, findings reinforce concerns raised locally about potential exposure to pesticides associated with using water from the Black Creek. It is recommended that future studies prioritise assessment of risk from pesticides through dermal contact and absorption.

Propanil is a pesticide commonly used to control weeds post emergence in rice fields, and it is a pesticide of concern in the Yalbac area. Propanil was not detected in this study. However, reporting limits were set at 1 μgl^{-1}, determined by laboratory facilities. Furthermore, Propanil transforms readily in water into metabolites. Thus, lack of detection is not unexpected. The WHO (2022) do not consider drinking water guidelines to be appropriate for Propanil because it does not persist. However, two metabolites (3,4-dichloroaniline and 3,3′,4,4′-tetrachloroazobenzene) are more persistent in water and toxic than Propanil (WHO, 2022). While drinking water guidelines are not available for these metabolites due to lack of data, it would be sensible for future studies to include analysis of these determinants.

MUISKA-light

Over the past two decades, evolving environmental regulations have incorporated risk-based approaches, particularly within the drinking water sector in Europe and North and South America (Bartram, 2009; Ministerio de Salud (Perú), 2011; Ministerio de Salud y Protección Social, C. and Ministerio de Vivienda Ciudad y Territorio, 2017; European Parliament, 2020; WHO, 2022; USEPA, 2024). Aligning with this, the MUISKA approach uses inclusive methodologies to undertake a first-order assessment of water-security risks, with proven effectiveness at the river basin scale, particularly to bridge risk science with local practices and concerns (Montoya Pachongo et al., 2024).

Implementing a simplified version of the MUISKA approach in Yalbac effectively created a focused space for amplifying the voices of typically marginalised parties, enabling a deeper exploration of their concerns than might have been possible otherwise. It is our belief that MUISKA-light can be a tool valuable for addressing the perspectives of a single group in a small part of a river basin, and it could be considered as a step that can provide foundation for the inclusion of marginalised concerns within a subsequent implementation of the full MUISKA approach, which aims to integrate the perspectives of a wider array of relevant parties to develop interventions to address water insecurity. In Yalbac, the use of MUISKA-light included three participatory workshops which harnessed both local knowledge and scientific insights to provide information helpful for managing water insecurity. The workshops allowed residents to reach a consensus on water security priorities and the collaborative effort resulted in the generation of primary data about pesticide contamination in local water sources. It is hoped this will provide a first step towards enhancing awareness of potential hazards and will empower future action.

Implementation of MUISKA-light was not without limitations, notably the challenge of ensuring sustained and consistent participation throughout the project lifecycle. This issue was evident in this case study, as participant continuity across workshops was not maintained meaning that some of the risk science concepts introduced and outcomes achieved in the earlier workshops may not have been fully understood or retained by participants in the final workshop, potentially influencing the robustness of the vulnerability analysis.

A broader limitation of the MUISKA approach lies in its reliance on specialised professionals to conduct risk assessments. The need for expertise may pose a barrier to its wider adoption and implementation in community settings. However, we remain optimistic that as environmental risk science becomes more integrated into the training of young professionals, this knowledge will increasingly become accessible to a broader audience, including citizens, governments and institutions. The expansion of expertise holds the potential to democratise risk assessment processes to enhance community resilience, particularly when living under water-insecurity conditions and facing climate change.

8 Conclusions

MUISKA-light has enabled a structured approach to identifying water insecurity concerns in Yalbac Village, resulting in the prioritisation of pesticide contamination of water sources. Preliminary investigations suggest there is a potential risk to those residing in Yalbac Village from exposure to pesticides based on water use behaviours and the presence of pesticides in rainwater tanks used for drinking water and in the Black Creek. Concentrations measured suggest potential exposure via drinking may be low. However, data generated in this study was extremely limited and is not sufficient for an assessment of risk from consumption of rainwater or use of other water sources.

Findings will be reported to Yalbac Village to increase their knowledge about the pesticides detected, and to enable future work to develop a fuller understanding of the risk pesticides pose to water security. It is hoped the findings reported provide a first step towards addressing the anxieties linked to data availability and powerlessness identified during workshops. Further work might focus on building understanding about long-term concentrations of the pesticides detected, and/or further broad-scan monitoring of pesticides at different time points and in the full range of water sources used. It is recommended that this is done in a way that can enable exposure both through consumption of drinking water, and dermal contact and absorption as a result of *in-* and *ex-situ* uses of the Black Creek.

The implementation of MUISKA-light created a focused space for amplifying the voices of the Yalbac community, and we consider this a valuable foundation for a fuller implementation of MUISKA with other relevant parties in the river-basin. This is a necessary step in the development of a risk-management plan that recognises and respects the broad array of perspectives, values and power dynamics influencing the implementation and effectiveness of water security interventions.

9 Acknowledgements

We are grateful to all in Yalbac Village and the surrounding area who generously shared their time, knowledge and perspectives, and for their support during fieldwork, the Pesticide Control Board for their knowledge, data and advice, and Ben Maskrey at CEFAS, UK for discussions about pesticide focussed work. We are also grateful to the Institute for Social and Cultural Research and the Fisheries Department in Belize for permitting this work. This work was supported by the Water Security and Sustainable Development Hub, funded by the UK Research and Innovation's Global Challenges Research Fund (GCRF) [grant number: ES/S008179/1], and the University of Leeds through the Sustainability Research Institute in the School of Earth and Environment, and the School of Civil Engineering.

10 References

ATSDR, 2003. Toxicological Profile for Atrazine. Agency for Toxic Substances and Disease Registry. [Online]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK597834/

ATSDR, 2018. Toxicological Profile for Dinitrocresols. Agency for Toxic Substances and Disease Registry. [Online]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK592076/

ATSDR, 2020a. Toxicological Profile for 2,4-Dichlorophenoxyacetic Acid (2,4-D). Agency for Toxic Substances and Disease Registry. [Online]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK590150/

ATSDR, 2020b. Toxicological Profile for Glyphosate. Agency for Toxic Substances and Disease Registry. [Online]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK591689/

Bartram, J., 2009. Water safety plan manual: step-by-step risk management for drinking-water suppliers. World Health Organization.

CAMDI, 2010. Survey of Diabetes, Hypertension and Chronic Disease Risk Factors. Belize, San José, San Salvador, Guatemala City, Managua and Tegucigalpa. [Online]. Available from: https://iris.paho.org/handle/10665.2/7687

European Parliament, 2020. Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption [Online]. Available from: Available from: https://eur-lex.europa.eu/eli/dir/2020/2184/oj.

Grafton, R.Q., Williams, J. and Jiang, Q., 2017. Possible pathways and tensions in the food and water nexus. Earth's Future. 5, 449–462.

Lewis, K.A., Tzilivakis, J., Warner, D.J. and Green, A., 2016. An international database for pesticide risk assessments and management. Human Ecological Risk Assessment An International Journal 22, 1050–1064.

Maskrey, B, 2024. Conversation with Rachael Carrie, 26 November.

Mdee, A., Ofori, A., Lopez-Gonzalez, G., Stringer, L., Martin-Ortega, J., Ahrari, S., Dougill, A., Evans, B., Holden, J. and Kay, P., 2022. The top 100 global water questions: Results of a scoping exercise. One Earth 5, 563–573.

Ministerio de Salud (Perú) 2011. DS N° 031-2010-SA [Online]. Available from: http://www.digesa.minsa.gob.pe/publicaciones/descargas/Reglamento_Calidad_Agua.pdf.

Ministerio de Salud y Protección Social, C. and Ministerio de Vivienda Ciudad y Territorio, C. 2017. Resolución 0549 de 2017 [Online]. Available from: http://www.minvivienda.gov.co/ResolucionesAgua/0549 - 2017.pdf.

Montoya Pachongo, C., Evans, B. and Camargo-Valero, M.A., 2023. Conceptual framework of the MUISKA approach to assess multiple water-security risks. University of Leeds. Available from: https://eprints.whiterose.ac.uk/195578/

Montoya Pachongo, C., Bayona Valderrama, Á., Camargo-Valero, M.A. and Evans, B., 2024. Desarrollo de un enfoque para el análisis multidimensional de riesgos relacionados con la inseguridad hídrica en las subcuencas hidrográficas del municipio de Cajibío–Colombia. Informe final de resultados de proyecto–Enfoque MUISKA. University of Leeds. Available from: https://eprints.whiterose.ac.uk/217301/

Pereira, L.S., 2017. Water, agriculture and food: challenges and issues. Water Resource Management 31, 2985–2999.

Reed, M.S., 2008. Stakeholder participation for environmental management: a literature review. Biological Conservation 141, 2417–2431.

Smith, C.D. and Nowell, L.H., 2024. Health-Based Screening Levels for evaluating water-quality data (3rd ed.) [WWW Document]. U.S. Geological Survey [Online]. Available from: https://www.usgs.gov/tools/health-based-screening-levels-evaluating-water-quality-data

United Nations, 2023. The Sustainable Development Goals Report. Special Edition [Online]. Available from: https://unstats.un.org/sdgs/report/2023/

USEPA, 2024. Fact sheet. Risk and Resilience Assessment and Emergency Response Plan Requirements for Drinking Water Utilities [Online]. Available from: https://www.epa.gov/waterresilience/fact-sheet-risk-and-resilience-assessment-and-emergency-response-plan-requirements

Van Asselt, M.B.A., 2013. Perspectives on uncertainty and risk: the PRIMA approach to decision support. Springer Science & Business Media.

WHO, 2021. WHO human health risk assessment toolkit: chemical hazards. World Health Organization. [Online]. Available from: https://www.who.int/publications/i/item/9789240035720

WHO, 2022. Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda. World Health Organization. [Online]. Available from: https://www.who.int/publications/i/item/9789240045064

Appendices

Appendix 1 – Outline of MUISKA-light

Appendix 2 – Questionnaire

Appendix 3 – Raw results pesticide analysis (provided as a separate attachment)

Appendix 1 MUISKA-light framework

MUISKA-light study design for Belize

MUISKA step	Objectives	Base knowledge requirement	Activities	Methods	Expected outcomes
Step 0: Stake holder analys is	Identify the river basin relevant parties to be invited to take part in the research project Identify the influencing capacity of relevant parties for water decision making	Local knowledge required to identify the relevant parties in the Labouring and Iguana Creek catchments and the existing relationships among them	Desk based analysis of secondary data and subsequent discussion with key local contacts	Stakeholder analysis using documents for the local area and the methodology of Reed et al., 2023 to analyse interest, influence, and impact of relevant parties	List of river basin relevant parties classified by their level of interest, influence, and impact in/on/over/from the research project
Step 1: Define predo minan t hazar ds for the basin	Develop a rapid, high-level understanding of the threats to water security in Yalbac and Los Tambos, based on local knowledge of individuals and representatives of institutions involved in the use and management of water resources in these sub-basins Create a network of hazards and their consequences from a community perspective and identify how they are interrelated Promote systems thinking	Local knowledge required to construct the network of hazards and their consequences	Workshop: Identification of water uses. Characterisati on of the water system	Social mapping System mapping Social networks	Identified water uses and associated values List of problems/conflicts created from water uses Network of hazards and their consequences and identification of how they are interrelated (feedback loops) List of predominant hazards in the river basin, categorised according to water quantity or quality, and characterised by the location where hazards are originated
Step 2: Qualit ative descri ption of the impac ts of hazar ds on the basin	Create the risk matrices according to the scales and dimensions of MUISKA	Expert knowledge about MUISKA is required to guide the construction of risk matrices. Local knowledge is required to populate the matrices	Workshop: Classification of water-security hazards according to the scales and dimensions of MUISKA	Participatory work to combine outputs from step 1 within a risk matrix of scale of impacts (individual, community, basin, country) against dimension (human and wellbeing, infrastructure and associated services, economy and productivity, ecosystem services, culture, justice, and peace)	Risk matrices with classification of impacts according to scales and dimensions
Step 3: Consu lt to define priorit	Prioritise the impacts according to several criteria. Recognise values associated with	Local knowledge to elaborate and apply the filters, including exploration of values and	Workshop: Determinatio n of prioritised impacts for step 4	Participatory group work to understand criteria with which to prioritise impacts, and application of	List of prioritised impacts by each relevant party group, together with water values and power influences

y impacts	prioritisation of impacts. Recognise power relationships influencing the prioritisation	power relationships		criteria to produce a prioritised list	Identified ambiguities, divergences in judgements or disagreements among relevant parties
Step 4: Assess the risk of the prioritised impacts	Conduct rapid/light touch risk assessment of select prioritised impacts Preliminary identification of exposure and vulnerabilities related to the presence of agrochemicals in the two sub-catchments	Expert/local knowledge required to gain specific data e.g. potential agrochemicals of concern and priority locations for sampling (may not be necessary for all impacts)	Determine exposure and vulnerability conditions associated with the presence of agrochemicals in the two sub-catchments Determine select water quality hazards	Exact methods/tools will depend on outputs from steps 1-3. Based on scoping visit we anticipate including water quality sampling to assess hazards, and household questionnaires to assess potential exposure and vulnerability. Questions will be based on outputs from steps 1-3. A sample questionnaire is attached	Preliminary list of exposure routes and vulnerabilities related to the hazards prioritised in step 3 Preliminary water quality data Risk assessment report
Step 5: Visualise risks	Excluded from the light-touch version of MUISKA being explored in Belize				
Step 6: Outline a risk management plan	Produce a list of potential interventions to manage prioritised water security risks in Los Tambos and Yalbac Identify values and power relationships influencing intervention implementation Characterise interventions by design, impacts and benefits, decision-making actors and implementation scenarios	Local knowledge to elaborate and analyse interventions	Workshop: Identification of potential risk management interventions and analysis of barriers to their implementation	Participatory group work to identify and qualitatively analyse potential interventions	Preliminary outline of a risk management plan Narrative description of relationships and influences associated with implementation of interventions Narrative description of consequences of interventions, including the creation or exacerbation of existing or additional risks or hazards

Appendix 2 Questionnaire used to collect data about water use behaviours

Sample ID: **Date:** **Administered by:**

HAS CONSENT FORM BEEN READ AND SIGNED? Yes (tick) No (tick) **If no, discontinue.**

Drop a pin to mark house location on google maps. Yes (tick) No (tick)

Section A: Introduction

1. Do you use the same water source(s) for drinking water as you do for all other household purposes (e.g. bathing, laundry)?
2. What water sources does your household use for all purposes?

	Yes	
e) Tank		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Barrel		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Black Creek		Identify stretch on map
e) Bought water		Shop: Truck:
e) Other sources		Describe what and where:

3. How much water is used from each source and when?

For each source, complete the overleaf table to identify:
a) if the water comes from rain, creek, underground or something else,
b) why that source is chosen
c) approximate volume **gallons** of water obtained from each source on average per household, per day in each month it is used
d) estimate % of the daily total used for drinking water

Use the gallon container as an example to estimate how many times per day it would be filled.

Reminder: Use PER HOUSEHOLD, not use per person

Record how much is USED, not how much is collected

Record number of containers and volume in gallons (1 container = 5 gallons, 1 barrel = 50 gallons)

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain tank at home												
Why this source?												
Proportion used for drinking												
Rain tank elsewhere												
Why this source?												
Proportion used for drinking												
Barrel Rain, creek, ground, other												
Why this source?												
Proportion used for drinking												
Black Creek												
Why this source?												
Proportion used for drinking												
Bought from shop/truck												
Why this source?												
Proportion used for drinking												
Other source Rain, creek, ground, other												
Why this source?												
Proportion used for drinking												

Note: Answer following questions for **each source**

4. Can you explain how this water stored at home? [each source]

5. Other than drinking, what do you use this water for? [each source]

6a. Is the water you use filtered in any way?

Yes filtered (identify which sources if more than one):

Describe what type of filter and what it filters from the water

Not filtered (identify which sources and why)

6b. Is the water you use treated in any way?

Yes treated (identify which sources if more than one):

Describe type of treatment and why

Not treated (identify which sources and why)

7. In the past year have you noticed cloudiness, sediment, bad colour, bad smell, bad taste?
   No (tick)

If yes, identify which source and describe what was noticed. Ask if they have any photos

If yes, identify when this was noticed. Describe which months

If yes, describe what source was used instead? [Open-ended question]

Go to Section E

Section C Complete only if a different source is used for drinking water

Drinking water

8. What water sources does your household use for drinking water purposes?

	Yes	
e) Tank		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Barrel		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Black Creek		Identify stretch on map
e) Bought water		Shop: Truck:
e) Other sources		Describe what and where:

9. How much water is used from each source and when?

For each source, complete the overleaf table to identify:
a) if the water comes from rain, creek, underground or something else,
b) why that source is chosen
c) approximate volume **in gallons** of water obtained from each source on average per household, per day in each month it is used

Use the gallon container as an example to estimate how many times per day it would be filled. Proportions of the barrel volume are shown below for convenience

Barrel	Volume (gallons)
¼	12.5
½	25
¾	37.5
1	50

Reminder: Use PER HOUSEHOLD, not use per person

Count how much is USED, not how much is collected

Write number of containers and volume (1 container = 5 gallons, 1 barrel = 50 gallons)

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain Tank at home												
Why this source?												
Rain Tank elsewhere												
Why this source?												
Barrel												
Why this source?												
Black Creek												
Why this source?												
Bought from shop/truck Rain, creek, ground, other												
Why this source?												
Other source Rain, creek, ground, other												
Why this source?												

Note: Answer following questions for **each source**

10. Can you explain how this water stored at home? [each source]

11. Is the water you use filtered in any way?
Yes filtered (identify which sources):

Describe what type of filter and what it filters from the water

Not filtered (identify which sources and why)

12. Is the water you use treated in any way?
Yes treated (identify which sources):

Describe type of treatment and why

Not treated (identify which sources and why)

13. In the past year have you noticed cloudiness, sediment, bad colour, bad smell, bad taste?
No (tick)

If yes, identify which source and describe what was noticed. Ask if they have any photos

If yes, identify when this was noticed. Describe which months

If yes, describe what source was used instead? [Open-ended question]

Go to Section D

Section D Complete only if a different source is used for drinking water

Non drinking water use at home

14. What is water used for other than drinking? [free text]

15. What sources are used for these purposes?

	Yes	
e) Tank		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Barrel		At home: (tick if yes) Elsewhere (tick and describe were if yes)
e) Black Creek		Identify stretch on map
e) Bought water		Shop: Truck:
e) Other sources		Describe what and where:

16. How much water is used from each source and when?

    For each source, complete the overleaf table to identify:
    a) if the water comes from rain, creek, underground or something else,
    b) why that source is chosen
    c) approximate volume **in gallons** of water obtained from each source on average per household, per day in each month it is used

Use the gallon container as an example to estimate how many times per day it would be filled. If referring to barrel, see below:

Barrel	Volume (gallons)
¼	12.5
½	25
¾	37.5
1	50

Reminder: Use PER HOUSEHOLD, not use per person

Count how much is USED, not how much is collected

Write number of containers and volume (1 container = 5 gallons, 1 barrel = 50 gallons)

Month	Ja n	Fe b	Ma r	Ap r	Ma y	Ju n	Jul y	Au g	Se p	Oc t	No v	De c
Tank at home Rain, creek, ground, other												
Why this source?												
Tank elsewhere Rain, creek, ground, other												
Why this source?												
Barrel												
Why this source?												
Black Creek												
Why this source?												
Bought from shop/truck Rain, creek, ground, other												
Why this source?												
Other source Rain, creek, ground, other												
Why this source?												

Note: Answer following questions for **each source**

17. Can you explain how this water stored at home? [each source]

18. Is the water you use filtered in any way?

Yes filtered (identify which sources):

Describe what type of filter and what it filters from the water

Not filtered (identify which sources and why)

19. Is the water you use treated in any way?
Yes treated (identify which sources):

Describe type of treatment and why

Not treated (identify which sources and why)

20. In the past year have you noticed cloudiness, sediment, bad colour, bad smell, bad taste?
No (tick)

If yes, identify which source and describe what was noticed. Ask if they have any photos

If yes, identify when this was noticed. Describe which months

If yes, describe what source was used instead? [Open-ended question]

Go to Section E

Section E: In-situ use of Creeks (i.e. water used at the creek, not taken home)

21. Do you use any Creeks for bathing/laundry/dishes/other contact uses?
    Yes — Complete Section E
    No — Go to Section F

22. Which Creeks do you use for bathing, laundry, recreation?
    a. Black Creek — identify stretch on map
    b. Other Creeks — identify stretch on map

23. How much time in minutes does your HOUSEHOLD spend in contact with creek water on average each day in each month?

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Black Creek												
Time (minutes)												
Why is this location used												
Other Creeks												
Time (minutes)												
Why is this location used?												

24. In the past year have you noticed cloudiness, sediment, bad colour, bad smell, bad taste?
    No (tick)

If yes, identify which source and describe what was noticed. Ask if they have any photos

If yes, identify when this was noticed. Describe which months

If yes, describe what source was used instead? [Open-ended question]

Go to Section F

Section F

25. Has your use of water changed in the last 5 years?

If yes, which sources, how and why? [Open-ended question].

26. Is there anything else you want to tell me about the water sources/water you use?

27. Are you aware of the names or brands of any agricultural chemicals used in this area?

28. Are any of them of particular concern to you?

If yes, which ones/ why? [Open-ended question]

29. If water sources are non-standard (i.e. not tank, barrel, Black Creek or shop bought), ask if you can photograph them.

Section G Meta Data

30. How many people live in your house?

31. What is the gender and age of residents?

Group Id	Age group	Number of people	
		Women	Men
1	0 – 6 days		
2	7 – 27 days		
3	28 – 364 days		
4	1 – 4 years		
5	5 – 9 years		
6	10 – 14 years		
7	15 – 19 years		
8	20 – 24 years		
9	25 – 29 years		
10	30 - 34 years		
11	35 – 39 years		
12	40 – 44 years		
13	44 – 49 years		
14	50 – 54 years		
15	55 – 59 years		
16	60 – 64 years		
17	65 – 69 years		
18	70 – 74 years		
19	75 – 79 years		
20	80 – 84 years		
21	85 – 89 years		
22	90 – 94 years		
23	94 – 99 years		
24	Older than 100 years		

32. What are the main occupations of household residents?

33. How many (if any) household residents use agricultural chemicals regularly?

34. Can you identify the brand(s)? [ask if they have a container and photograph it if given consent?]

That is all of our questions. Do you have any questions for us?

(make a note of questions asked)

THANK YOU FOR SHARING YOUR TIME AND INFORMATION

Appendix 3 Pesticide analysis raw data – see separate Excel sheet