RESEARCH SUMMARY

Water quality in rivers of the Red River Delta

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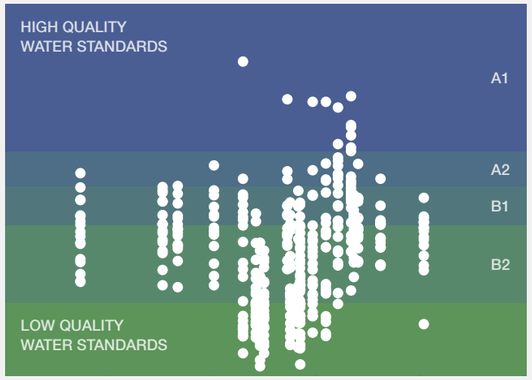
Assessment of water quality

Water quality assessment involves the measurement of physical, chemical and biological features of waters to allow their comparison with standards defined by regulatory bodies. For the Red River Delta, this is benchmarked by the National technical regulation on surface water quality (QCVN 08-MT:2015/BTNMT).

Dissolved oxygen (DO) is a key measure of water health; without oxygen nothing can live in rivers and low levels may indicate organic pollution issues. DO measured each month in 2018 and 2019 at 21 sites along the Red and Day Rivers from the reservoirs in the uplands to the coast were mostly in class B2 (moderately poor) or lower when assessed by the Vietnamese DO standards. Some sites in the heavily urbanized area around Hanoi had very lower water quality (below class B2). Only 13% of samples achieved Class A for DO.

Monthly measurements of DO across the Day and Red Rivers illustrate the difficulty in interpreting single water measurements. Seasonal variability in DO means that the timing of sampling could have a major impact on how the water is classified. Water quality would be classified as better during the wet than the dry season. Regular monitoring identifies periods when water quality issues are most prevalent, and identifies times when low DO could have detrimental implications e.g. for aquatic life or for changing the cycling of metals and nutrients.

Dissolved oxygen



For other chemical variables between 2018 and 2019, the Vietnamese limits for nitrite were exceeded in more than half of the samples, and one third were placed in class B2 or lower for ammonium. In contrast, 99% and 95% of samples for nitrate and phosphate respectively achieved good (A class) status. 37% of nitrogen is present in the reduced form of ammonium and nitrite, but the oxidized form (nitrate) is dominant in most samples.

Recommendation: *Water quality should be conducted at least monthly over the annual water cycle. Seasonal variability can provide important information for hydrology and water quality management. The most polluted river sites around Hanoi should be a priority for water quality improvement.*

Stable isotopes for tracing the Red River water cycle

The flat relief and intensive water regulation via dams, sluices and dikes poses a challenge for hydrological monitoring using conventional methods. Stable isotopes can offer a rapid and cost-effective way to evaluate regional hydrology.

Stable isotopes in water

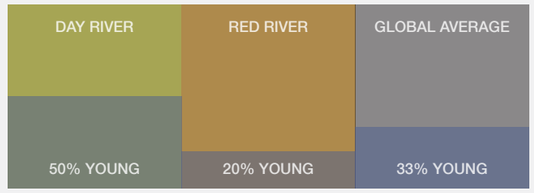
Water consists of one oxygen and two hydrogen atoms. Isotopes are a form of an element with one or more extra neutrons. Stable isotopes do not decay (they are not radioactive). Distinctive isotope signals can be incorporated into water depending on the abundance of the heavier isotopes, we therefore have a tracer of water if we measure the isotope ratios of water.

Rainwater falling on the Red River Delta has a stable isotope signature that varies seasonally, dependent on source, temperature and amount of rainfall. This distinctive seasonal pattern can be used to calculate the proportion of rainwater supplying the main river waters during different seasons.

In the Day River, stable isotope calculations indicate that around 50% of the water derives from "young rainfall" i.e. rainfall no more than 3 months old (Trinh et al 2020). This is much higher than the global average of one-third and reflects a catchment that is mostly saturated, where water passage is accelerated by artificial flow paths such as rice paddy, dikes, and hard urban surfaces.

In the Red River, only 20% of the river water is classified as "young" (Nguyen et al 2021). The presence of reservoirs in the catchment slows down the water residence time, meaning that it takes longer for water to pass through the catchment.

% Water from 'young' rainfall



Due to the larger contribution of young water in the Day River, the river water supply could be more susceptible to changes in rainfall delivery; both tropical storms and droughts are predicted to increase in the future. Longer water residence times in the Red River could mean that dilution of pollutants is more limited in this river.

Recommendation: *The Day River drainage system should be upgraded to allow faster water release during storms and infrastructure for water storage put in place to mitigate against flooding.*

Identifying sources of nitrogen pollution

Dissolved nitrate contains both oxygen and nitrogen isotopes. Distinctive isotope signatures can be found in nitrate depending on its provenance, we can therefore find the source of nitrate pollution. We demonstrate the effectiveness of applying stable isotope approaches from nitrate.

In the Day River oxygen and nitrogen isotopes act as a tracer which enables the assessment of provenance of the nitrate pollution (Luu et al 2020). The nitrate isotope data show how biological activities drive the isotopic compositions and these change along the Day River course. Inorganic urea fertilizer is a major source of nitrate, along with urban sewage, showing a clear impact especially the downstream sections especially after the confluence with the Nhue River, the main river delivering water from Hanoi City. Further down the river after the confluence with the Nhue River, the proportion of natural inputs (soil/ground and upstream Red River inflow sources) of nitrate contribute < 50% of the pollution nitrate load. The high proportion of nitrate from anthropogenic activities in the Day River is apparent.

Developing analytical capacity in Vietnam

The isotope analysis described above were conducted at the British Geological Survey in the UK and the Vietnam Atomic Energy Institute (VINATOM) in Hanoi. VINATOM has a suit of laboratories equipped for water isotope analyses via Isotope Ratio Mass Spectrometey (IRMS), it also has an Elemental Analyser Isotope Ratio Mass Spectrometer (EA-IRMS) for carbon and nitrogen isotope analysis and is procuring a Gas Chromatrographic- Isotope Ratio Mass Spectrometer (GC-IRMS) for compound specific stable isotope analysis. With the help of the International Atomic Energy Agency (IAEA) VINATOM is setting up a standard storage facility providing working standards samples for water isotope analysis.

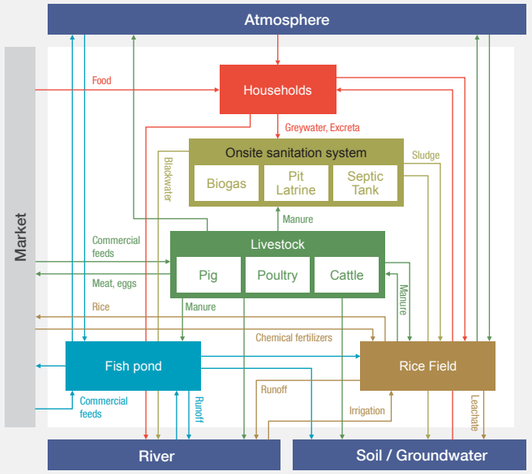
Recommendation: *The application of inorganic fertilizers to paddy fields in the Day River area should be re-evaluated to moderate application when this is an option. This is particularly important when fertilization practices are taking place in the rainy season, where rapid and large scale delivery of nitrate is demonstrated.*

Nitrogen use efficiency in the Red River Delta

Agriculture accounted for 14.85% of Vietnam's gross domestic product (GDP) in 2021. The Red River Delta (RRD) is the second biggest rice bowl in Vietnam. About 47% of landuse is agricultural and aquacultural land, of this, 90% is used for annual crops. About 80% of the delta dwellers are engaged in the agricultural sector. Pollution of water sources with nitrogen from chemical fertilizers is a major threat to environmental and human health in the delta.

Recommendation: *Improvement of nitrogen use efficiency is needed.*

Our project developed a Material Flow Analysis model (MFA) model to quantify loads of nitrogen (N) pathways from humans to the environment in the RRD and then identify potential pollution sources or intervention points (Do et al 2019). The MFA model will, therefore, provide interdisciplinary evidence to support decision-making.



The MFA model can quantify loads of nitrogen (N) pathways from humans to the environment in the RRD and identify potential pollution sources or intervention points (Do et al 2019).

RRD farmers use animal manure together with chemical fertilizers in rice production. More than half of the N load to the paddy field is from chemical fertilizers. Most rice farmers apply chemical fertilizers above the recommended rates with the hope of increased crop yield. However, fertilizer use efficiency is low at around 60% for N. Excess fertilizer enters soils and waters by percolation and runoff, causing air, water, and soil pollution.

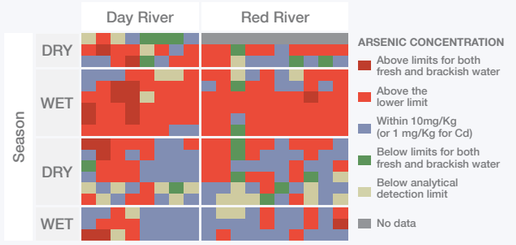
Changes in environmental policy and farming practice, for instance reductions in applied chemical fertilizers, the reuse of animal manure for producing biogas and bio-slurry, and the reuse of sludge from aquaculture and onsite sanitation systems can be explored with the MFA model to predict their effects on nitrogen pathways and loads in the RRD.

Recommendation: *The MFA model is a useful platform to quantitatively determine how changes in agricultural and domestic practices will change the flows of nitrogen in the environment. Scenarios from the MFA can help to develop policies on environmental management, raise awareness and change the behaviors of the local delta dwellers on resource efficiency.*

Pollutants in the suspended sediments of rivers

Measurements in the Red River Delta show that there has been a long-term decline in suspended sediment of the rivers since the installation of dams to create reservoirs at Thac Ba and Hoa Binh in the late 1980s. Suspended sediment can be important in influencing transport and deposition of pollutants because some elements, including metals, bind easily to suspended material carried in river clays, silts and organic matter.

Analysis of suspended matter in sediments of the Day and Red Rivers shows high pollution by chromium (Cr) and arsenic (As) which exceed the recommended Vietnamese limits (QCVN 43:2017/BTNMT) in most sites across the Red River Delta.



Cr and As concentrations of suspended sediments are higher during the wet season and further emphasized during periods of intensive rainfall and storms such as in 2018. This indicates that transport of polluted sediment from the catchment to the river is a source of As and Cr contamination and that this could get worse as storms intensify in the future.

Other pollution hotspots occurred around Hanoi where waste-waters entering the Day River via the Nhue River led to high concentrations of phosphorus, copper, chromium and arsenic.

Flux calculations indicate that a significant proportion of metal elements are deposited within the delta environment, highlighting the role of the delta in protecting coastal waters from contamination. However, this accumulation over the longer term means that deltaic sediments could pose increasing environmental and health risks in the future.

Salinisation of waters due to sea level rise and changes in the organic matter concentration of river waters can strengthen the binding of metals to sediments, adding another factor to consider in understanding metal transport from the land to coastal areas.

Recommendation: *The elemental composition of suspended solids in the RRD should be monitored, with a focus on elements such as Cr and As that exceed current regulatory limits. Further research into how these metals pass between dissolved and particulate forms in this river delta is necessary.*

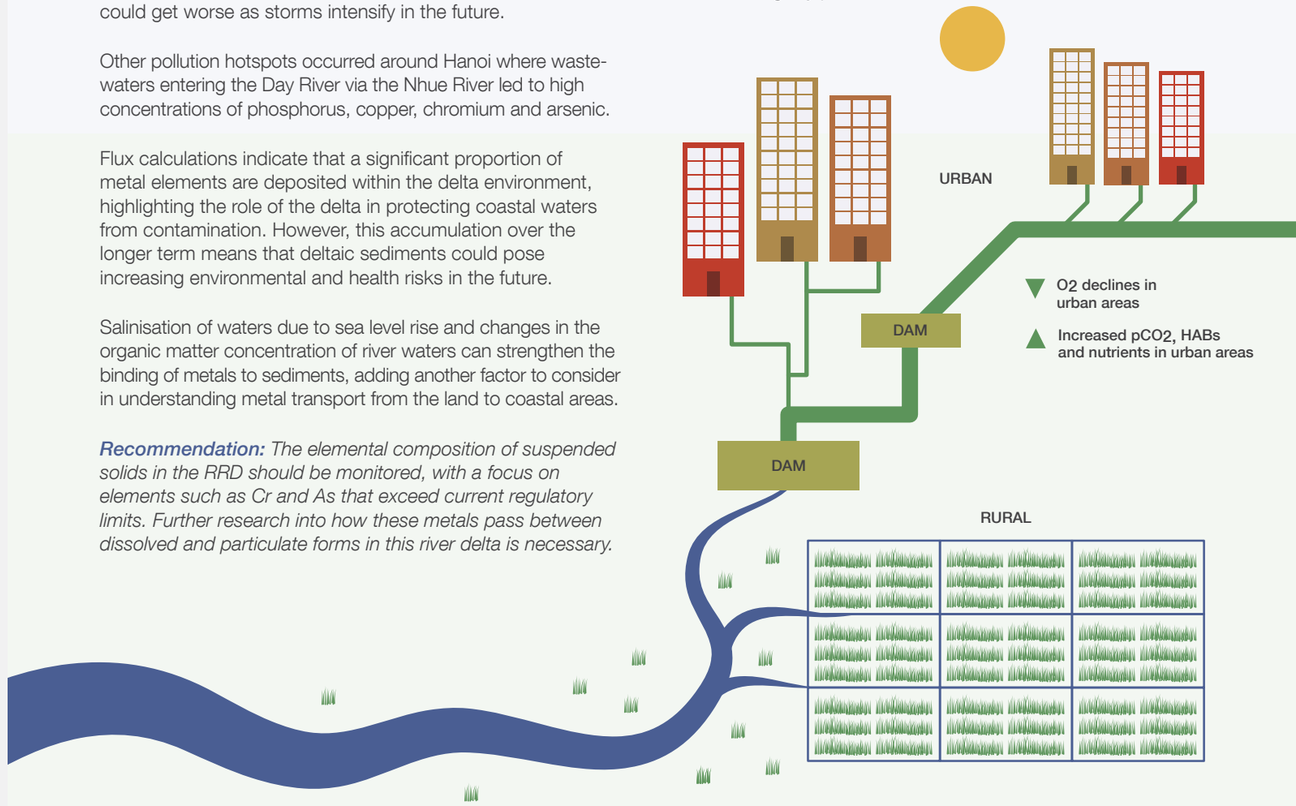
How and why do carbon dioxide concentrations vary in RRD waters?

Large tropical rivers are dynamic and shifting CO_2 sources. They receive large quantities of terrestrial organic carbon, which often can be degraded and respired elevating the partial pressure of CO_2 (pCO_2) in waters. We calculated the pCO_2 of river waters along the Day and Red Rivers upstream and downstream of Hanoi City.

In densely populated areas around Hanoi City the partial pressure of CO_2 in river waters was higher than in other parts of the river. This was due to the receipt of sewage wastes into the water containing organic matter which produces CO_2 when it decomposes. Channelisation and water demands of rivers in urban areas lead to more stagnant waters which, together with sewage-derived nutrient inputs create the conditions for cyanobacteria to bloom. Blooms of cyanobacteria produce more organic matter and reinforce the cycle for CO_2 production. Cyanobacteria blooms can also produce toxins- a "harmful algal bloom" (HAB), further degrading water quality and posing risks for water users.

In the future, increases in water demands to support urban development could intensify stagnant waters in urban rivers, which will likely strengthen the riverine CO_2 capacities of the RRD and the risk of potential associated HABs.

Recommendations: *Increases in pCO_2 and HABs risks could be mitigated through active water management to increase water flows in urban rivers during dry periods.*

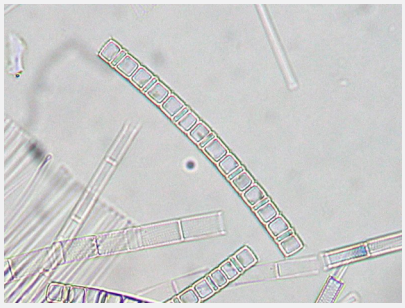


Organic pollution

The sediment quality of the Red River and associated urban waterways of Hanoi have been evaluated by comparing organic pollutants in surface samples from soils, bank and channel and shallow sediment cores.

Emerging contaminants such as antibiotics, anti-epileptics, anti-inflammatories and hormones were 3 to 15 times higher in samples from urban rivers compared to those from the Red River. The anti-inflammatory, ibuprofen was the most abundant emerging contaminant and was present at higher concentrations than many other Vietnamese Rivers. Environmental forensics using fecal steroid sewage marker compounds, revealed that urban waterways contain appreciable amounts of untreated sewage which could impact environmental health. Conversely, banned legacy polychlorinated biphenyls (PCBs) were below international sediment quality criteria and therefore not a likely to harm biota or humans. Fossil fuel hydrocarbons derived polyaromatic hydrocarbons (PAH) and petroleum hydrocarbons were present at moderate concentrations but distributed across the entire Red River system. Sediments from the urban waterways of Hanoi contained appreciable amounts of alkylated-PAH which indicated manufactured oil/crude oil inputs (e.g. moped engines) whereas those from main Red River were mainly dominated by parent forms originating from vehicular exhaust or soot from power stations. Microtox solid-phase test bioassay suggested that out of 149 sediments evaluated 4 were acutely toxic, 11 moderately toxic and 134 non-toxic.

Recommendation: *Increasing emerging contaminants (pharmaceuticals) and sewage could be mitigated through greater waste treatment processing. Hydrocarbon pollution requires greater control on urban run-off into waterways and rivers.*



Sediment retention and water quality in Hoa Binh reservoir

Hoa Binh Reservoir is located in the upper reaches of the Red River Delta and was established by damming in 1989. Sediment trapping in this site and other reservoirs has been implicated as being important for reductions in sediment supply to the delta and in modifying nutrient availability by trapping phosphorus in the sediments. Two sediment cores were collected from the centre of the reservoir to better understand how this 9 billion m^3 water body functions and changes the waters downstream.

Dating of the reservoir sediments using radioactive lead isotopes indicates a rapid sedimentation rate of around 2 g/cm^{-2} yr^{-1}. Carbon content of the sediments is mostly between 1.5% to 2.5%, which suggests that a large amount of carbon is mineralized before it reaches the sediments. The C:N ratios which are all lower than 10 suggest the organic matter in the sediments derives mostly from algae produced in the reservoir. Therefore, we can infer that the reservoir is probably not a sink for carbon delivered from the upstream catchment since much of this is mineralized before it is trapped in the sediments.

Down-core measurements indicate a possible increase in lake productivity over the past decade. This is indicated by a shift in the composition of carbon stable isotopes, and indications that the types of algae have changed. For example, remains of diatoms (silica-cased-algae) show a shift towards the nutrient-loving Aulacoseira granulata in recent sediments, and chlorophyll and carotenoid pigments from a range of algae increased. There is also an increase in microcystin toxins that derive from cyanobacteria. Together, these changes indicate that the reservoir has probably become more productive over the past 10 years.

Recommendation: *The rate of sediment infilling does not pose a short-term concern for infilling of the reservoir, but monitoring of the reservoir should be conducted to assess eutrophication.*

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