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Modelling for river basin planning: a demonstration in the Brahmani Basin, India: Synthesis report

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Modelling for river basin planning: a demonstration in the Brahmani Basin, India

Agriculture makes a vital contribution to the Indian economy. While it contributes close to 16% of GDP it also underpins livelihoods, with 60% of the population being dependent on this sector. The agriculture sector is intrinsically linked to water resources. India's water resources are under pressure, as evidenced by drought, poor water quality and low crop yields. Sufficient and clean water resources are vital for supporting people and their livelihoods and the environment. Water scarcity is driven by seasonal variation in climate and a lack of investment in water resources either constraining development or alternatively promoting overuse.

Water assessment and management at river basin scales promotes solutions at a system-level. It is a participatory process underpinned by a scientific evidence base. This report documents the findings of a study, utilising an evidence-based approach to support a Basin Planning process, in the Brahmani Basin (north-east India). The focus is on improving irrigated crop production and the impact on other water sectors by exploring current distribution and use of Basin water resources as well as investments in existing and new water infrastructure and in changed cropping practices. The model reports outcomes at state and basin scales.

Background

The focus of this project was on capacity building in water resource management and basin planning. Project activities included delivering a capacity building program and undertaking a demonstration case, on the Brahmani Basin. This demonstration uses a water resources modelling approach to explore the current water availability, as well as potential investments in water management with a view to improving agricultural production, and thus livelihoods in the Basin. We also explore potential impacts of climate change across water sectors. A web-based scenario visualisation tool is used to explore the outcomes of the demonstration case.

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Photos are courtesy of project staff.

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Basin planning framework

Water resource management supports people's livelihoods by underpinning food and energy production, supporting industry and maintaining the environment. Basin Planning is a process used to manage water resources at a basin scale. The approach seeks to:

- be participatory
- set out a clear and transparent process for decision making
- streamline and standardise planning processes
- promote intergovernmental cooperation
- balance outcomes for industry, people and the environment
- be refined as new knowledge is gained.

River System models are an analytical tool used to support basin planning. The particular form of the model depends on objectives of basin stakeholders and available information – and can provide a tool to explore interactions between the river system, environmental forces and human water use and infrastructure, under current and possible future conditions.

The Brahmani Basin

The Brahmani Basin is located in the north eastern part of India (Figure 1) and crosses three Indian states – Chhattisgarh, Jharkhand and Odisha. The Basin is bounded by the Chhotanagpur Plateau on the north, by the ridge separating it from Mahanadi Basin on the west and the south, and by the Bay of Bengal on the east. The physiography of the Basin is defined by four regions – the northern plateau, the eastern ghats, the coastal plains and the central table land. The first two regions are hilly and forested, and the coastal plains consist of a fertile delta area. The main soil types found in the Basin are red and yellow soils, red sandy and loamy soils, mixed red and black soils and coastal alluvium.

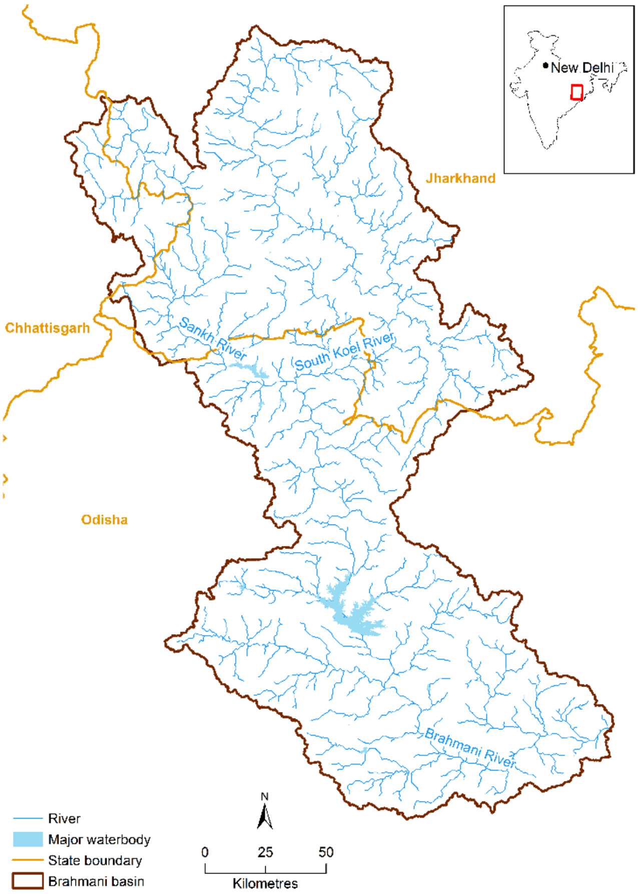

Figure 1 The Brahmani Basin showing state boundaries; and the insert shows the Basin's location within India

The Brahmani River is formed by the confluence of the South Koel and Sankh Rivers. The neighbouring basin is the Baitarni Basin. The Brahmani Basin has a total area of is 34,614 sq km (3.46 million ha) and the Brahmani River, with its constituent rivers, is 799 km long.

The Basin has a tropical monsoonal climate. Rainfall is dominated by the monsoon, between June to October, with 80% of annual precipitation occurring during these months.

In 2011, the Basin population was about 3.8 million with approximately 80% in rural areas. The landuse of the Basin is a mix of forest and agriculture (Figure 2).

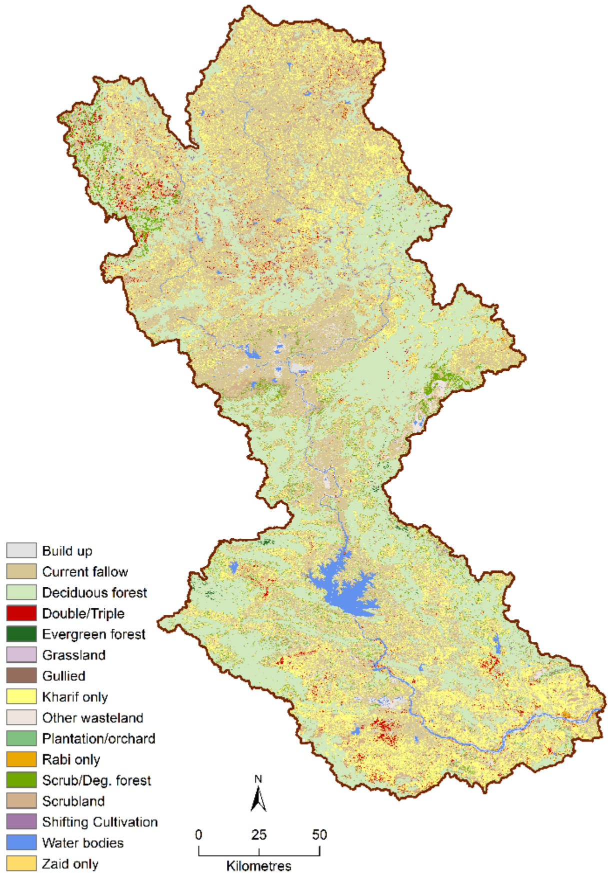

Figure 2 Landuse mapping for the Brahmani Basin (2007–2008)

Description of Basin agriculture

Agricultural land covers approximately 52% of the Basin. Agriculture plays a critical role in the economy and livelihood of people in the Basin, particularly in Odisha. Throughout the Basin, agriculture is critical to the food security and socioeconomic development of its people.

The major cropping seasons in the Basin are Kharif (July to October) and Rabi (November to February). In this report, we also define rice as double/triple cropping, representing multiple rice seasons in a year.

Agricultural districts are located through the Basin, and cross Basin boundaries. These districts contain both irrigated and rainfed agriculture.

Together, Odisha, Chhattisgarh and Jharkhand cover 20% (8.65 million ha) of the total cultivated area of India, growing about 14% of total rice production. Only 6% of the total rice production is irrigated.

An analysis of the Basin districts using cropping intensity (i.e. the number of times a crop is planted per year in a given area) found that cropping intensity is lower in the northern part of the Basin, relative to the south (Figure 3).

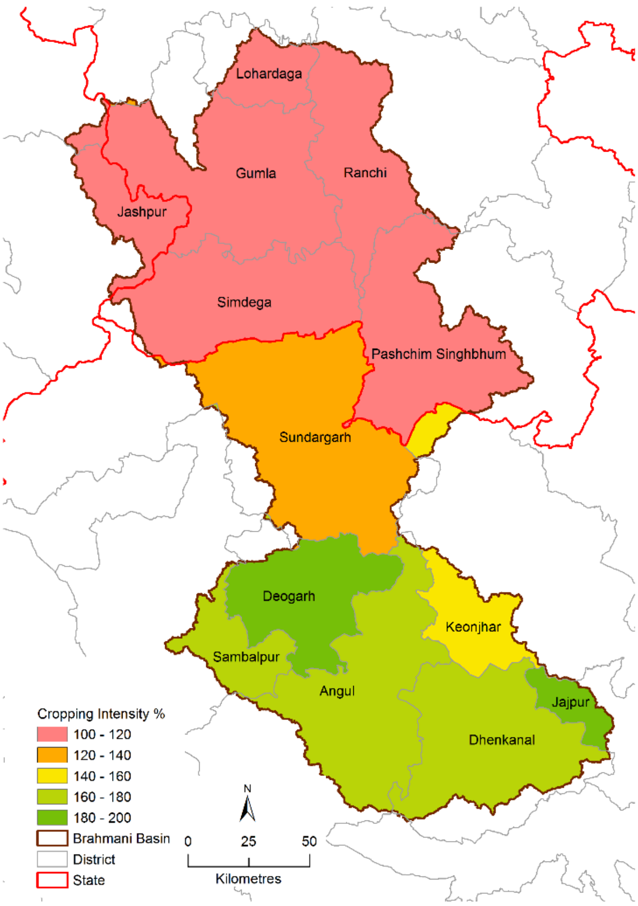

Figure 3 Cropping intensity at the district level (2007–2008)

Whilst this district analysis is based on data from 2007 to 2008, our analysis using more recent data shows a similar trend, but with increasing crop intensity in the south. The main reason for this is low rice yields in the upper part of the Basin due to a lack of supplementary irrigation. Other constraints are likely to include low yielding crop varieties, lack of nutrients and farming practices.

Irrigated agriculture in the Basin

Irrigated areas in the Basin are predominantly located in command areas. Associated with a typical command area is a water storage. The Brahmani Basin demonstration considers 20 medium/major storages (10 in Jharkhand and 10 in Odisha), servicing approximately 500,000 hectares of irrigated land, of which approximately 427,000 hectares are in Odisha.

The total available water storage (assuming storages at 100%) is approximately 4850 MCM, with 4000 MCM (80% of total Basin storage) in Odisha.

The Brahmani Basin model

A River System model for the Brahmani Basin was developed in the eWater Source modelling platform. This Brahmani model can be used to represent current water availability and use in the Basin (as a baseline scenario). It can then also be used to explore potential consequences of alternative water infrastructure, water use and climate change as new scenarios to the baseline conditions.

The river system is represented as 6 reaches, defined using Central Water Commission streamflow gauges. Each reach includes, inflows (upstream and residual catchment area), current infrastructure (medium and major irrigation storages across both Jharkhand and Odisha), irrigation demands and demands for livestock, domestic and industry. Major storages, including new modelled storages, have hydropower and environmental demands included. Locations are shown in (Figure 4).

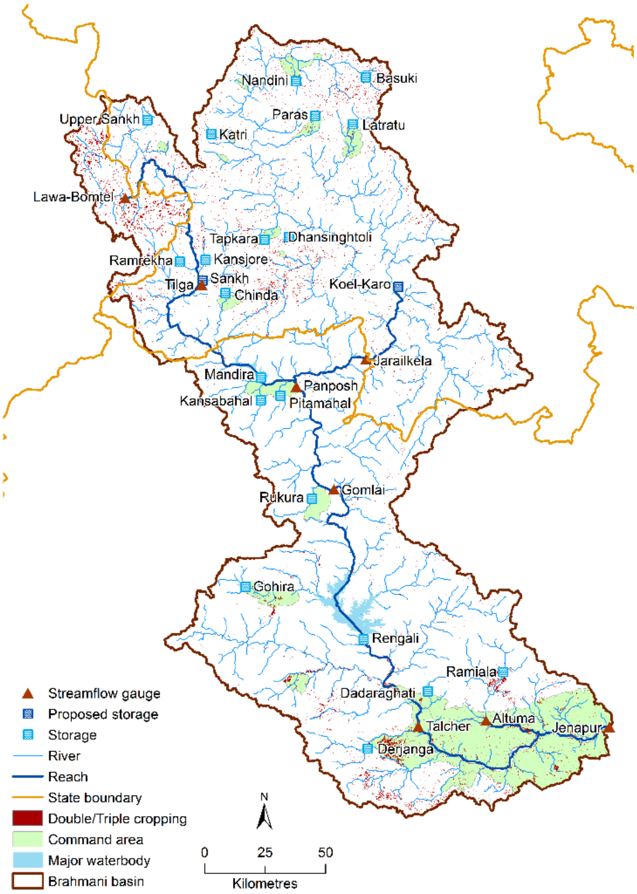

Figure 4 The Brahmani Basin, showing state boundaries, command areas (and associated irrigation projects and storages) and streamflow gauges

Inflows were calibrated to the downstream gauge of each reach, taking into account the current development and water use on the reach. For each command area, the irrigator demand model has been used to represent the irrigation requirements of crops.

Scenarios for Basin Planning

We evaluated 12 scenarios:

- a Baseline scenario that represents the Basin with its most recent level of development
- a Without Development scenario that represents the Basin without infrastructure and extractions
- three sets of development scenarios (Table 1).

Table 1 Description of scenario sets (CA = Command Areas)

Set 1 (3 scenarios) – improved current practices
• CA developed to their maximum spatial extent with existing cropping practices (S1) • Water to the CA delivered more efficiently (80%) (S1-80) • CA planted with rice (double/triple) (S1-80-DT)
Set 2 (4 scenarios) – new storages scenarios
Two new schemes added and their: • New CA planted with rice (double/triple) (S2) • Water to the new CA delivered more efficiently (80%) (S2-80) • All major storages operated to provide water for agriculture and flood mitigation (S2-80-OR) • All major storages operated for agriculture, flood mitigation and environmental flows (S2-80-OR-E)
Set 3 (3 scenarios) – combination (practices and storages)
Two new schemes added: • All CA (existing and new) planted to maximum extent with rice (double/triple) and water delivered more efficiently (80%) (S3-80-DT) • All CA planted to maximum extent with rice (double/triple) and all storages operated to provide for agriculture and flood mitigation (S3-80-DT-OR) • All CA planted to maximum extent with rice (double/triple) and all storages operated to provide for agriculture, flood mitigation and environmental flows (S3-80-DT-OR-E)

Scenario analysis

A series of questions guided our approach to the analysis of scenario analysis.

How is water currently distributed through the Brahmani Basin?

The Baseline scenario shows that annual water availability in the Basin is dominated by monsoonal flows with low flows in the dry (non-monsoon) period (Figure 5).

The highest flow volumes in the system are below the confluence of the Sankh and South Koel Rivers in Odisha, where the Brahmani River is formed.

To what extent has current water use changed the availability of the Brahmani Basin water resources?

Water use is minimal in the upper Basin, with only minimal differences in flows in the system between the Baseline and the Without Development scenarios, and annual flows being unchanged (Figure 6, Panposh). The Baseline scenario shows reduced flows at the end of the system (Figure 6, Jenapur), reflecting greater water use for consumptive purposes.

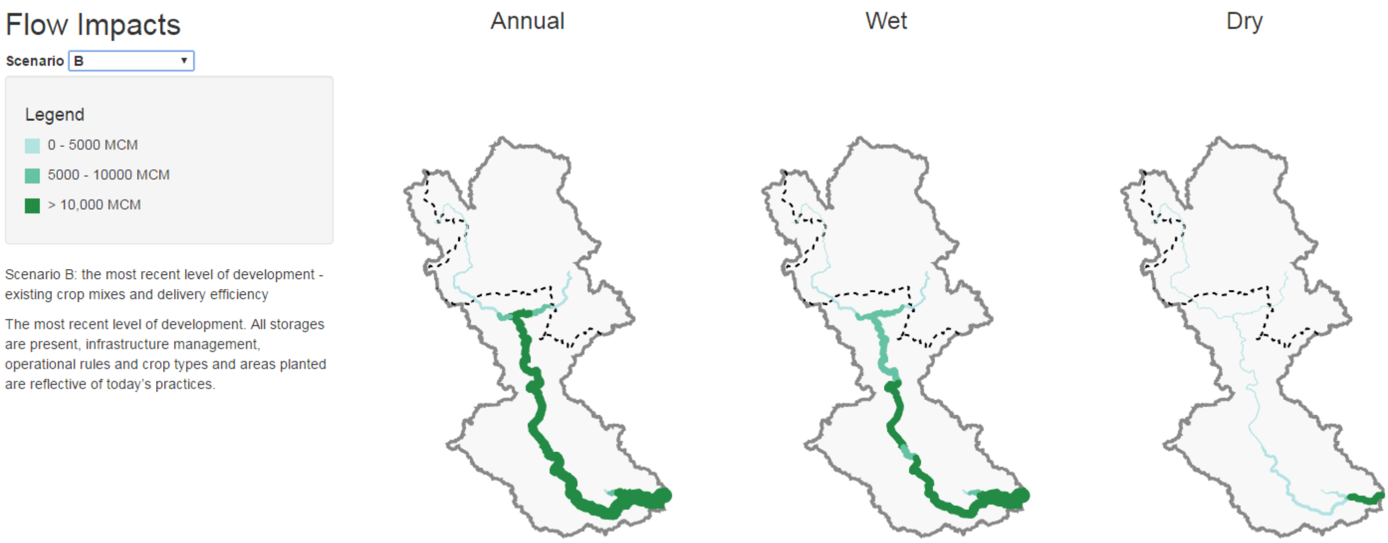

Figure 5 Annual and seasonal flows in the Brahmani Basin in the Baseline scenario which reflects current water use

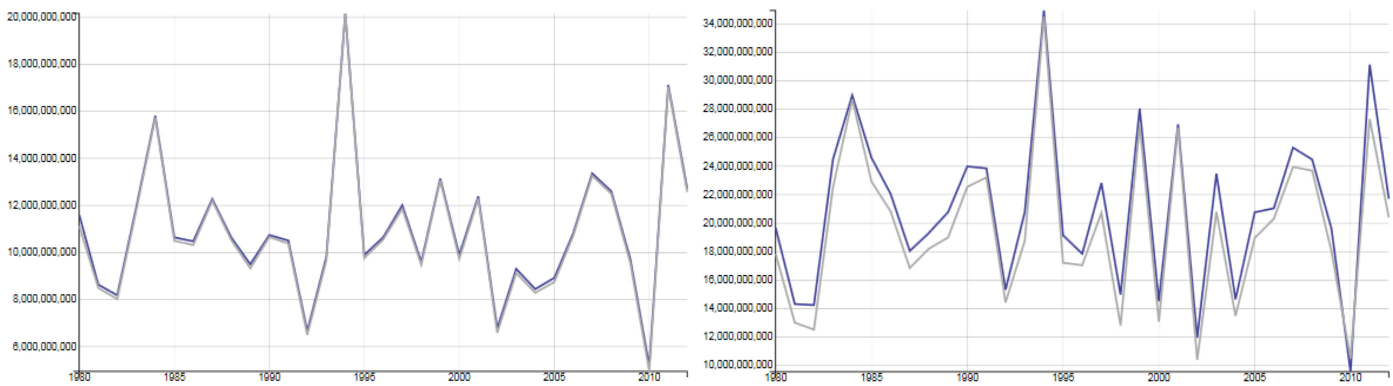

Figure 6 Annual flows (m^3/s) at the Panposh gauge (left) just downstream of the confluence of the Sankh and South Koel Rivers, and the Jenapur gauge (right) at the end of the system in the Baseline (light grey) and the Without Development scenario (dark blue)

How is water use distributed across users within the Brahmani Basin and states?

The bulk of the Basin water use is in Odisha, with hydropower being the highest water user. Note that hydropower is a non-consumptive water user, and the water used for hydropower is re-distributed to other users (Figure 7). There is minimal water use in Jharkhand across water sectors.

What is the current modelled agricultural output from irrigation in the Brahmani Basin?

The dominant crop in the Basin is Kharif rice. The Basin produces approximately 367 kt/y of irrigated rice, with 99% of that in Odisha (Figure 8). Approximately 90% of land used for irrigation in the Basin is in Odisha. The Basin has low irrigated yields for rice crops, with the highest yield being 3 t/ha/y for irrigated rice.

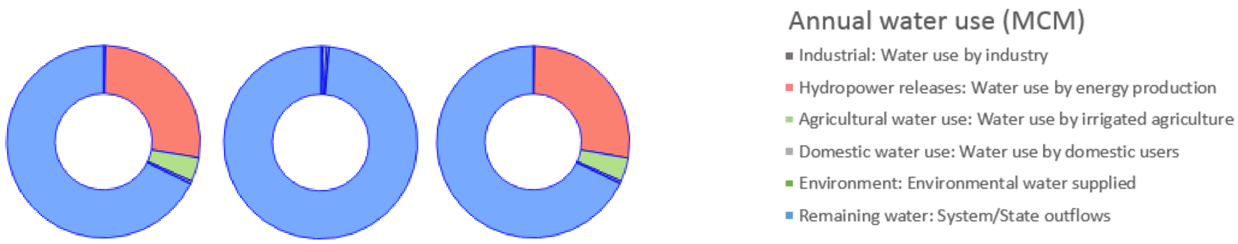

Figure 7 Distribution of water use across water sectors in the Baseline scenario, showing the whole of Basin (left), Jharkhand (middle) and Odisha (right)

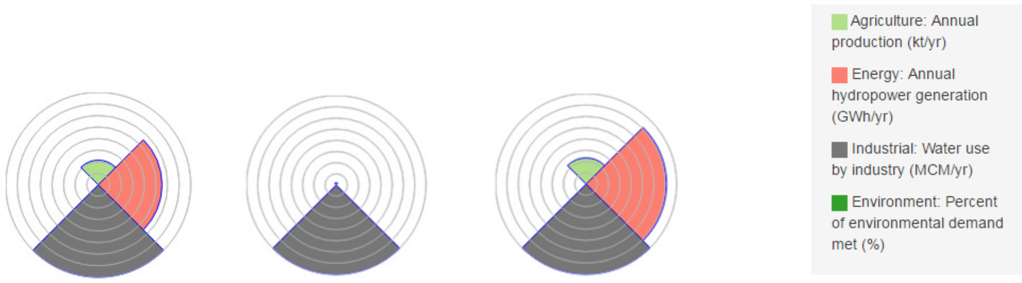

Figure 8 Crop and energy production and industrial water use in the Baseline scenario, showing the whole of Basin (left), Jharkhand (middle) and Odisha (right)

What are the options for improving water efficiencies in the Brahmani Basin, through investments in delivery infrastructure?

Water delivery efficiency can be improved by lining of canals to prevent water losses through seepage. In the model, we assumed that under current conditions 35% of water released does not reach the crop, but is lost through seepage. By lining canals, we estimated these losses could be reduced to 20% (i.e. 80% efficiency).

With this investment, the model shows no discernible changes to flows in the upper Basin. Average annual flows have a modest increase at the end of system (ranging from 200 to 400 MCM).

What are the options for improving crop production in the Brahmani Basin?

We explored three options for improving production in the Basin. The first targets cropping practices, through maximising crop areas and changing crop patterns in command areas. The second is through the construction of new storages. The third explores a combination of these.

Cropping areas and patterns (S1 set)

By changing cropping areas and patterns in the Basin, there is a potential to triple rice production from 373 kt/y to 978 kt/y. Approximately 90% of land used for irrigation in the Basin is in Odisha, therefore the bulk of benefits are in Odisha. There is an increase in water use for agriculture in Odisha and the overall availability of water in the river is reduced (Table 2).

By contrast, the benefits to Jharkhand are only modest, with production increasing to 99 kt/y from 19 kt/y.

Table 2 Water use and total rice production considering scenarios of cropping (S1 set)

Scale	Model outputs	Baseline	Cropping area	Cropping area + pattern
Basin	Water use - agriculture	1170 MCM/y	2397 MCM/y	3305 MCM/y
	Total rice	373 kt/y	824 kt/y	978 kt/y
Jharkhand	Water use - agriculture	62 MCM/y	240 MCM/y	311 MCM/y
	Total rice	19 kt/y	84 kt/y	99 kt/y
Odisha	Water use - agriculture	1109 MCM/y	2157 MCM/y	2995 MCM/y
	Total rice	354 kt/y	740 kt/y	879 kt/y

New storages and command areas (S2 set)

We considered two new irrigation schemes in Jharkhand to secure water supplies. These are represented as Koel Karo Reservoir Scheme (combining two major storages on the South Koel and North Karo Rivers) and Sankh Reservoir Scheme (major storage on the Sankh River).

The new storages increase the water storage capacity in Jharkhand from 17% up to 40% of the total Basin water storage resources.

In Jharkhand this results in an increase in rice production from 19 kt/y to 445 kt/y (Table 3). As new storages are hydropower schemes, there is also energy production. There is a reduced reliability of water supply to industry, reduced from 42 MCM/y to 38 MCM/y, due to the increased irrigation demands (Figure 9).

Table 3 Water use and total rice and energy production considering scenarios of new storages (S2 set)

Scale	Model outputs	Baseline	New storages	New storages + flood rules
Basin	Water use - agriculture	1170 MCM/y	2385 MCM/y	2176 MCM/y
	Total rice	373 kt/y	799 kt/y	799 kt/y
	Energy production	1814 GWh/y	2628 GWh/y	2517 GWh/y
Jharkhand	Water use - agriculture	62 MCM/y	1283 MCM/y	1272 MCM/y
	Total rice	19 kt/y	445 kt/y	445 kt/y
	Energy production	0 GWh/y	917 GWh/y	892 GWh/y
Odisha	Water use - agriculture	1108 MCM/y	1102 MCM/y	905 MCM/y
	Total rice	354 kt/y	354 kt/y	354 kt/y
	Energy production	1814 GWh/y	1711 GWh/y	1625 GWh/y

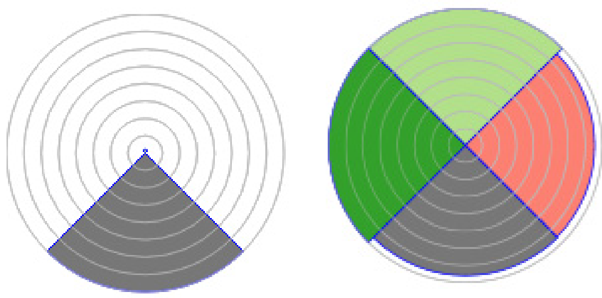

Figure 9 Baseline (left) and new storages scenario (right) outcomes for Jharkhand, showing relative increases in agriculture production (light green) accompanied by reduced reliability of supply for industry (grey). Energy produced from hydropower (pink) and environmental flows (dark green) are water users in this scenario

Combination: cropping and new storages (S3 set)

In this scenario, the new storages and changed cropping scenarios are combined. Water use is increased, being almost four times greater than the baseline (Table 4; Figure 10). Rice and energy production are also increased.

With the greater use of water in the Basin, dry season flows are decreased, with an increased number of days where there is no flowing water at the end of the system. The reliability of water supply to domestic and industrial users is also reduced.

Table 4 Water use and total rice and energy production considering scenarios of cropping and new storages (S3 set)

Scale	Model outputs	Baseline	New storages + cropping area + cropping patterns	New storages + cropping area + cropping patterns + flood rules
Basin	Water use - agriculture	1170 MCM/y	4445 MCM/y	4426 MCM/y
	Total rice	373 kt/y	1398 kt/y	1397 kt/y
	Energy production	1814 GWh/y	2595 GWh/y	2481 GWh/y
Jharkhand	Water use - agriculture	62 MCM/y	1519 MCM/y	1518 MCM/y
	Total rice	19 kt/y	525 kt/y	525 kt/y
	Energy production	0 GWh/y	900 GWh/y	876 GWh/y
Odisha	Water use - agriculture	1109 MCM/y	2926 MCM/y	2908 MCM/y
	Total rice	354 kt/y	873 kt/y	872 kt/y
	Energy production	1814 GWh/y	1694 GWh/y	1604 GWh/y

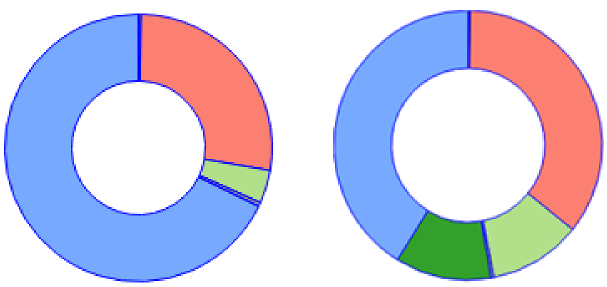

Figure 10 Baseline (left) and combined (right) scenario outcomes, showing relative increases in water use by water sectors (agriculture production: light green; hydropower: pink; environment (dark green). Blue represents unallocated water

What is the influence of implementing an environmental flows policy?

We used the Brahmani model to explore the influence of an environmental flows policy on river flows. Environmental flow demands were implemented, with flow rules introduced for storages with gates. Demands were described as 30% of inflows to the storage being released in the monsoonal period and 20% in the dry season. Flows were subsequently reused for meeting other demands resulting in no changes in the modelled flows further down the river system.

In the cropping intensification and new storage scenarios, water availability is reduced in the Basin, with the greatest impacts to non-monsoon flows, evidenced by increased days of having no flow in the river.

Synthesis

- The flow regime in the Basin is influenced by water use and infrastructure in Odisha. Under the baseline there is little change in flows in Jharkhand.
- By changing irrigation crop practices, it is possible to increase agricultural production in Odisha. This requires releasing stored water within the Basin to extend cropping seasons. This can be achieved through defining operational rules for water storages.
- Water constraints are experienced in Jharkhand. To address this, we have explored building new storages. Whilst there is potential to increase crop production in Jharkhand, the gains are still constrained by available water supply. Assessment of tradeoffs and the evaluation of land, social and environmental impacts is needed to test feasibility.
- Environmental flows from storages are being re-used downstream of storages and have no discernible effect on the flow regime.

Next steps

This study implemented a basin modelling approach to explore alternative water development scenarios for increasing agriculture through irrigated crop production and investments in current and new water infrastructure.

We have demonstrated how to explore this using an evidence base with local data for modelling. Further scenario analysis of related social and economic impacts can further support basin planning activities in the Brahmani Basin.

This framework can be expanded and applied to other basins to explore basin opportunities. This can be achieved through further focussed studies and through targeted capacity building activities.

Acknowledgements

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We hope that the results of this study are used to improve the livelihoods of the people of the Brahmani Basin.

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