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INDIA-EU WATER
PARTNERSHIP

Final Draft
River Basin Management (RBM) Toolbox

Prepared within the frame of the Tapi River Basin Committee
and under the India-EU Water Partnership’s

Equity
Efficiency
Sustainability
WRD

In cooperation with

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Implemented by

giz
Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

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Abbreviations

^{0}C	Degree Celsius
ACCCRN	Asian Cities Climate Change Resilience Network
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BIS	Bureau of Indian Standards
BMZ	German Federal Ministry of Economic Cooperation and Development
BOD	Biological Oxygen Demand
CBO	Community Based Organization
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
CSO	Civil Society Organisation
CWC	Central Water Commission
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DPAP	Drought Prone Area Programme
DPSIR	Driver-Pressures-State-Impact-Response
EC	End Century
EC	Electrical Conductivity
EC	European Commission
EEA	European Economic Area
E-Flows	Environmental Flows
EGR	Extractable Groundwater Resource
EU	European Union
EUD	Delegation of the European Union to India
FC	Faecal Coliform
FDC	Flow Duration Curve
G/D/S/Q	Gauge/Discharge/Sediment/Quality
GIS	Geographical Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMU	Groundwater Management Unit
GoI	Government of India
GPCB	Gujarat Pollution Control Board
GW	Ground Water
GWRA	Ground Water Resources Assessment
HO	Hydrological Observation
ICPR	International Commission for the Protection of the Rhine
IEWP	India-EU Water Partnership
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
JWG	Joint Working Group

Km	Kilometre
KWMI	Key Water Management Issue
lpcd	litre per capita per day
LULC	Land Use and Land Cover
MBBR	Moving Bed Biofilm Reactor
MC	Mid Century
MCM	Million Cubic Metre
MLD	Million Litre Per Day
mm	millimetre
MoAFW	Ministry of Agriculture & Farmers Welfare
MoJS	Ministry of Jal Shakti
MoRD	Ministry of Rural Development
MPCB	Maharashtra Pollution Control Board
MPPCB	Madhya Pradesh Pollution Control Board
MWRRA	Maharashtra Water Resources Regulatory Authority
NAQUIM	National Aquifer Mapping Programme
NEERI	National Environmental Engineering Research Institute
NGT	National Green Tribunal
NHS	National Hydrograph Station
NPK	Nitrogen, Phosphorous & Potassium
NRSC	National Remote Sensing Centre
NWA	National Water Academy
NWQMP	National Water Quality Monitoring Programme
PET	Potential Evapotranspiration
PMKSY	Pradhan Mantri Krishi Sinchai Yojna
PMU	Project Management Unit
PoM	Programme of Measures
RBC	River Basin Committee
RBM Plan	River Basin Management Plan
RIBASIM	RIver BAsin SIMulation model
rKm	River Kilometre
SBM	Swachh Bharat Mission (Clean India Mission)
SBR	Sequencing Batch Reactors
SDG	UN Sustainable Development Goals
SFD	Shit Flow Diagram
SGR	Support to Ganga Rejuvenation
SMC	Surat Municipal Corporation
SOE	Stage of Groundwater Extraction
SWAT	Soil and Water Assessment Tool
SWMU	Surface Water Management Unit
TC	Total Coliform
TDS	Total Dissolved Solids

TIDC	Tapi Irrigation Development Corporation
ToC	Team of Consultants
TOC	Total Organic Carbon
TPS	SAGA Thin Plate Spline
TSS	Total Suspended Solids
WFD	Water Framework Directive
WG	Working Group
WLF	Water Level Fluctuation
WMO	World Meteorological Organisation
WQ	Water Quality
WQI	Water Quality Index
WRD	Water Resources Department
WRIS	Water Resources Information System
WUA	Water Users Association
WWTP	Wastewater Treatment Plant

1 Introduction of the RBM Toolbox 2023

1.1 River Basin Planning & Management

*See **Annex 1** – Training Module on River Basin Management in a broader perspective: lessons learned from India and Europe.*

Water is fundamental for life on Earth. Clean and sufficient water in ponds, lakes, reservoirs, aquifers and rivers is critical to ensuring quality of the living environment and an important condition for social advancement and economic progress. Adequate quantities of water of reasonable quality from the natural system (aquifers, streams, rivers, lakes and ponds)) are necessary for agricultural production, cost-effective production and supply of water for human consumption and process water for manufacturing. Water of adequate quality in rural and urban areas is essential for ensuring t quality of life, as it supports human and animal health and promotes recreation. Last but not the least, a good water quality is essential for ecosystem health.

Water is a social, economic and environmental good. Water security is essential for human development, economic progress, livelihoods and ecosystem services. Hence, water resources are in demand by multiple users including competitive and in-stream uses. In river basins that are 'water-scarce' (characterized by water demands exceeding water availability with respect to space and time) competition for water and conflicts over water use exist. Inter-sectoral water allocation to meet all future water needs from various use sectors without compromising the hydrological integrity of the river basin is essential for ensuring long-term, sustainable use of water resources and preventing further deterioration of water ecosystem in such river basins. This is integrated water resources management. These goals can be achieved by development of river basin management plans that describe the strategies and measures for achieving these goals, and their implementation using scientific, empirical data and evidence. Such plans will consist of structural and non-structural measures (that are technological and institutional), supported by appropriate legal and policy framework, and monitoring and control mechanisms. In addition, implementation of IWRM through river basin management planning and its implementation supports realisation of global frameworks and commitments such as the UN Sustainable Development Goals (SDG's)[1] and the climate-resilient water resources management.

1.2 Background RBM Toolbox 2023

The EU Water Framework Directive[2] sets out rules to halt deterioration of surface and groundwater bodies and achieve good status for Europe's rivers, lakes and groundwater.
Citizens, nature and industry all need healthy rivers, lakes and aquifers. The EU Water Framework Directive (WFD) focuses on ensuring good health of the hydrological (natural water resource) system in terms of water availability and quality, i.e., reducing pollution and ensuring that there is enough water to support ecosystems at the same time as human needs.

Since 2000, the WFD has been the main regulatory framework for water resource protection in Europe. It applies to inland, transitional and coastal surface waters as well as groundwater. It ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including

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[1] THE 17 GOALS | Sustainable Development (un.org)
[2] EUR-Lex - 32000L0060 - EN - EUR-Lex (europa.eu)

regulation of individual pollutants and setting corresponding regulatory standards. It is based on a river basin district approach to make sure that all basin countries cooperate to manage the rivers and other bodies of water that they share. Many European river basins are international, crossing administrative and territorial boundaries. Therefore a common understanding and approach is crucial to the successful and effective implementation of the Directive.

The EU Water Framework Directive served as a good model for introducing River Basin Management planning in the Tapi and Ramganga basins of India. The WFD approach has been adopted to Indian practice and context. The River Basin Management Plans (RBM plans) are the key tool for implementing the WFD. They are drawn up after public consultation and are valid for a defined period.

The *River Basin Management (RBM) Toolbox 2023* describes the process of carrying out and developing a RBM plan according to the RBM Plan Cycle based on the WFD. In the following chapters, we refer to the RBM planning and management cycle and describe each step of the process.

1.3 Objectives of the RBM Handbook, Toolbox and E-Flows Guide

The *RBM Handbook* (IEWP Action Phase 1/SGR I) is a practitioner’s guide to undertake basin planning and the subsequent implementation of the plan so developed for the Indian context. It is based on the “River Basin Management Cycle” of the EU Water Framework directive modified and adopted for the Indian condition. It is designed as a document to guide practitioners through the river basin management planning process and resulting management actions looking at key factors contributing to success, identifying challenges in the Indian water management context and provide potential courses of action to move through the planning process steps and achieved the desired outcomes and impact. The RBM Handbook is focussing on the governance and coordination structures, stakeholder engagement and general RBM planning.

The *RBM Toolbox 2023*, is a step-by step practical guide and hence focusses on the *process* descriptions, of *how* to develop the different steps of the RBM cycle. It will outline the technical aspects of RBM planning, including analysis of monitoring data, data management, identifying key water management issues, conducting a basin risk assessment and subsequently developing a program of measures. It includes technical options and how to decide which option to choose based on given criteria.

The assessment of Environmental Flows (E-Flows) is a highly interdisciplinary process that requires direct and indirect contributions from basin stakeholders of various disciplinary backgrounds, including water and natural resource planners and managers, ecologists, biodiversity specialists, hydrologists, water resource engineers, geo-morphologists and other technical specialists, and other local knowledge holders. In the previous phase of the India-EU Water Partnership (IEWP) Action, E-Flows assessments were carried out by an interdisciplinary team of Indian and EU experts to evaluate the performance of various methodologies in three river pilots representing different hydro-climatological regions in India. The principle of E-Flows Assessment as part of river basin management is addressed in the ‘*Guidance document for Environmental Flows Assessment in India, 2020*’.

Documents	Brief outline
RBM Handbook 2020	The RBM Handbook (IEWP Action Phase 1/SGR I) reflects and outlines RBM in theory, institutional set-ups, coordination mechanisms and overall processes that are needed to develop integrated RBM Plans.
RBM Toolbox 2023	The RBM Toolbox follows the RBM Cycle steps and outlines related technical methodologies, data needs to undertake the risk assessments and develop the graphs/figures, tables and GIS maps of risks for RBM Plans.
E-Flows guidance document 2020/23	An IEWP Guidance Document (Nale et al. 2020) was developed to support the advancement of the E-Flows assessment methodologies in India towards EU and international good practices. It provides an overview of the current status of the India approach for E-Flows, as well as the requirements in terms of data, knowledge and expertise to improve E-Flows assessments locally.

These 3 guidance's are complementary documents that can be used as guiding documents for future RBM plan developments as well as coming river basin management cycles in India. The guidance's can be updated and revised based on future insights as soon as RBM planning evolves in India and becomes a new standard in implementing IWRM at basin level.

1.4 The River Basin Planning and Management Cycle

For the development of any RBM Plan reference can be made to the River Basin Management Cycle (Figure 1) based on the implementation requirements of the WFD.

The RBM Cycle sets the framework to guide the planning and management process of entire river basins beyond administrative borders addressing their full hydrological drainage area. The result of RBM Cycles is River Basin Management Plans (RBMP) that have been developed jointly by responsible water authorities and relevant stakeholders.

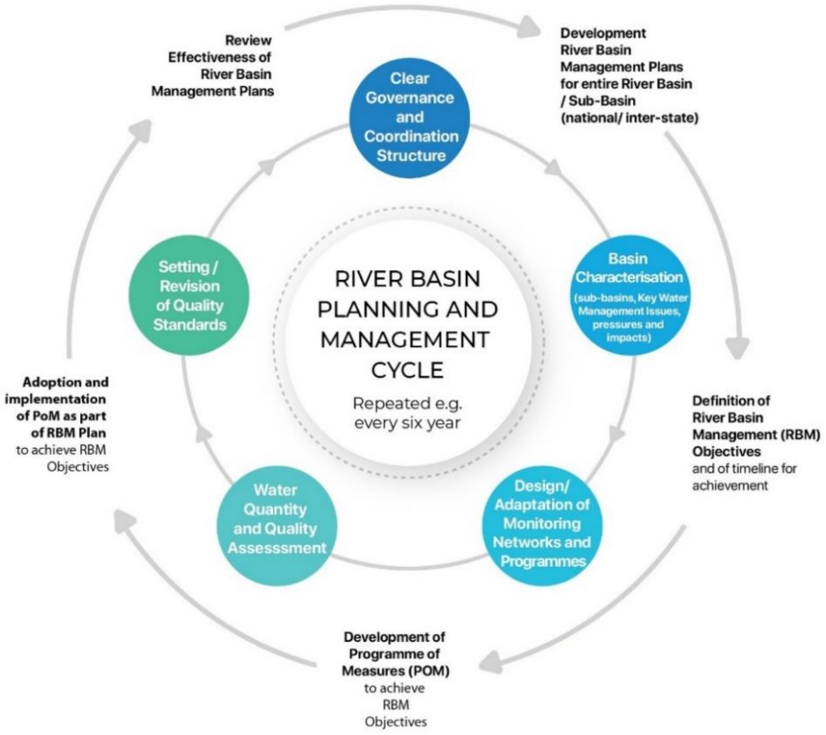


Figure 1 The River Basin Management Cycle

Each RBMP must apply to a dedicated river basin. The river basin planning process involves:

1. Setting of environmental objectives for all groundwater and surface waters within the river basin;
2. Identify Key Water Management Issues (KWMI's) for the basin;

3. Undertake a Pressure/Impact Analyses indicating a qualitative and quantitative status and risk assessment; and
4. Proposing a Programme of Measures (PoM). The PoM is the core of any RBM Plan as it sets forth concrete actions that improve the status of the basin's water bodies towards aims and objectives that have been jointly agreed.

1.5 Methodology for preparing the River Basin Management Plan

The DPSIR approach (*drivers, pressures, state, impact,* and *response* model of intervention), is the theoretical methodology used to develop the RBM plan. The DPSIR framework is mainly used to describe the interactions between society and the environment.

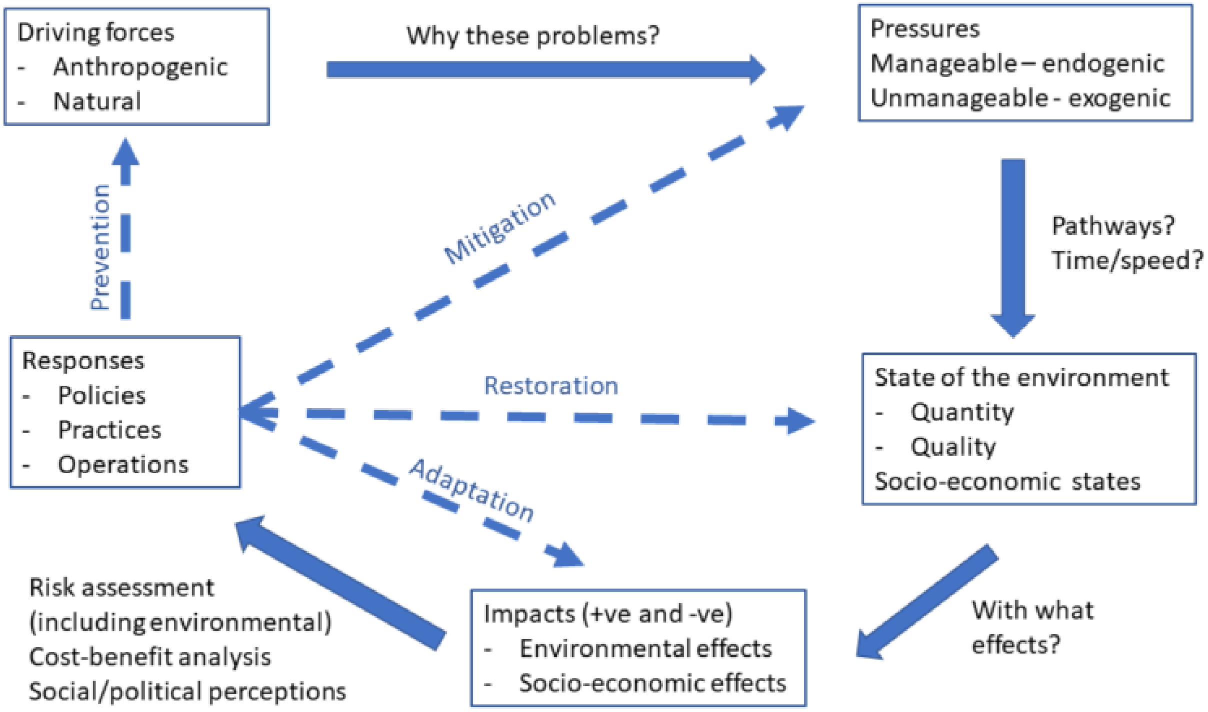


Figure 1 The DPSIR framework

DRIVER	***Driving forces*** *refers to the social, demographic, and economic developments which influence the human activities that have a direct impact on the environment.* An anthropogenic activity that may initiate negative effect on water quality and/or quantity: agriculture, industry, water supply, infrastructure development. *Note:* climate change can be a DRIVER even though not anthropogenic.
PRESSURE	***Pressure*** *represents the consequence of the driving force, which in turn affects the state of the environment.* The direct effect of the **DRIVER** can be classified into three types: (a) excessive use, (b) changes in land cover/use and (c) emissions (pollution).

STATE	***State** of the environment describes the physical, chemical and biological condition of the environment or observable temporal changes in the system.* The condition of the water quality and/or quantity resulting from both natural and anthropogenic factors/pressures.
IMPACT	***Impact** refers to how changes in the state of the system damages the environment.* The effect of a **PRESSURE** on water quality and/or quantity: lower population health, crops destroyed, ecosystem modified, aquatic life cannot thrive, etc.
RESPONSE	***Responses** refers to actions taken to correct the problems of the previous stages, by adjusting the drivers, reducing the pressure on the system, bringing the system back to its initial state, and mitigating the impacts.* Actions/measures taken to address an undesired, negative **IMPACT** which can affect any part of the chain between **DRIVERS** and **IMPACTS** (e.g., restricting abstraction, limiting point source discharges, developing best practice guidance for agriculture).

The DPSIR methodology should be used within the context of the national legal and institutional arrangements, local circumstances vis-à-vis data availability and reliability and existing expertise and experience, complimented by a process of cooperation of all relevant competent water authorities and stakeholders.

The following steps and main activities should be conducted, partly in parallel, based on the WFD requirements for developing the RBM plan (reference is made to the most important WFD Articles and Annexes):

1) Mutual understanding on the purpose, definitions and steps of the RBM Cycle based on WFD approach (WFD, Article 1 and 2);
2) Setting up of the institutional framework to develop and implement the RBM Plan by the dedicated competent water authorities at National, State and Regional level and at basin level by a River Basin Committee (RBC) with all responsible water authorities and relevant stakeholders (WFD, Article 3);
3) Prepare a basic outline of the RBM plan (WFD, Article 13 and Annex VII);
4) Identification of Key Water Management Issues (KWMIs) and definition of vision and management objectives for each KWMI (WFD, Article 10 and Annex II);
5) Delineation of Surface Water and Groundwater bodies (WFD, Annex II);
6) Environmental Objectives, Environmental Quality Standards and Establishment of Provisional Reference Conditions for both surface- and groundwater bodies (WFD, Article 4, Annex II);
7) Drivers & Pressures: Basin Characterisation (WFD, Article 5);
8) State: Groundwater and Surface water monitoring analysis (WFD, Annex V);
9) Impact: Pressure/Impact Assessment (WFD, Article 5 and Annex II, V);
10) Developing Groundwater and Surface water monitoring programs and analysis following the EU guidance (WFD, Article 8);
11) Socio-Economic Analysis (WFD, Article 9 and Annex III);
12) Response: Development of the a RBM Plan + Programme of Measures (WFD, Article 11, 13 and Annex VI, VII);
13) Financing and funding.

All above steps / activities should be worked out in detail and documented in Technical Reports attached as Annexes of the RBM plan.

Table 1 Overview of potential Technical Reports prepared for a RBM plan.

Annex No.	Technical Reports
1.	Data collection & Data analysis of existing conditions
2.	Basin Characterisation and Pressure/Impact Assessment
3.	Environmental Objectives, Environmental Quality Standards and Establishment of Provisional Reference Conditions
4.	Groundwater chemical and Surface water ecological and chemical monitoring program
5.	Socio-Economic Analysis
6.	Reports of Technical Workshops and Field Missions for developing the RBM plan and the PoM
7.	Capacity Building Support

For example, for the Tapi RBM plan 2023, the following technical reports are developed:

Annex 1	Technical Reports and Background Information to the Risk Assessments of KWMI 1–5, including the Technical Report on the RIBASIM model for the Tapi Basin.
Annex 2	Existing National and State Level Legislation, Policies and Plans Relevant for the Identified KWMI’s in the Tapi River Basin, updated Annex of Phase I.
Annex 3	Programs by Government of India and Tapi Basin States towards sustainable water resources management, updated Annex of Phase I.
Annex 4	Hydrological Modelling in the Tapi River Basin using the Soil Water Assessment Tool (SWAT), based on Annex of Phase I.
***Annex* 5**	Tapi Catchment RIBASIM Model has been separately handed over.
Annex 6	Identified Problem Statements for all 5 KWMI’s and factsheets per Problem Statement.
Annex 7	Tapi RBM Plan 2023 Map Atlas.

1.6 Implementation timeline

The RBM process is based on multiyear planning and implementation cycles that are to be repeated with a certain frequency to enable a revision process, adjusting to the new conditions and addressing new challenges in the basin. The RBM Plan cycle for the Tapi Basin for example is planned to be repeated every six years with a Pressure/Impact Analyses and Risk Assessment in between, to monitor the improvements resulting from implementation of the measures identified and the progress in achieving the Overall River Basin aims and objectives (see Chapter 1.4).

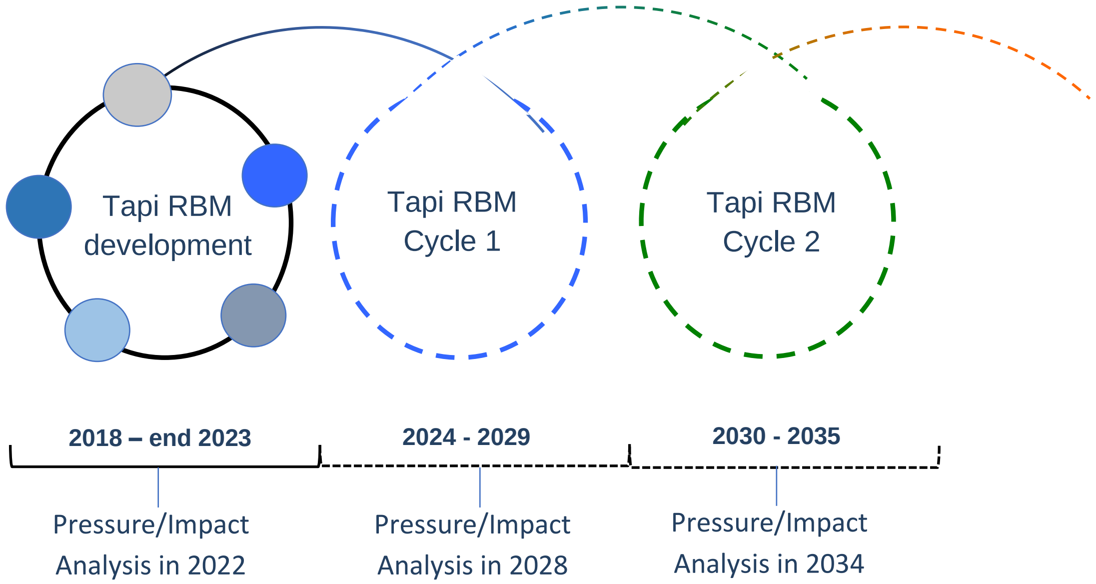


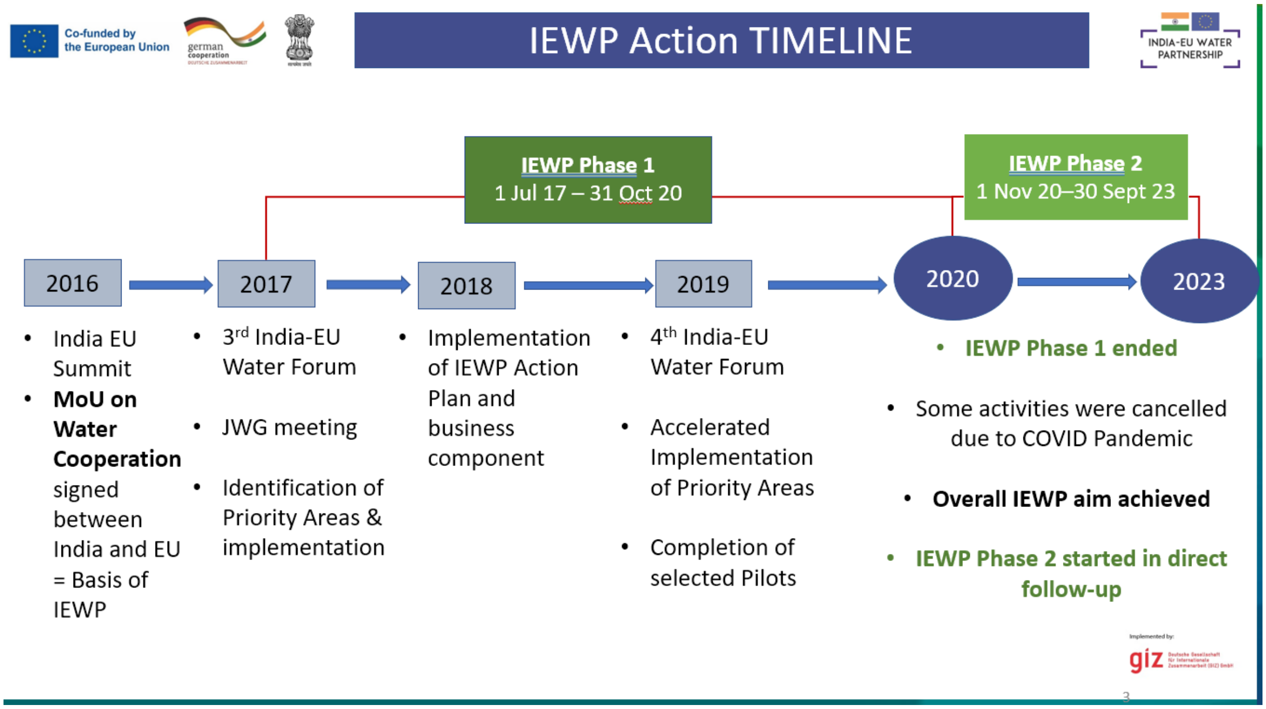
Figure 2 Example timeline and review frequencies for the Tapi RBM Plan.

In the above context, the Tapi RBM Plan has been developed within the first RBM cycle, which will last until the end of 2029. It will be followed by consecutive cycles in order to achieve the Overall River Basin management goals and objectives.

1.7 Experiences used to develop the RBM Toolbox

Under the IEWP Action phase 1 and phase 2 (see timeline), RBM plans are developed for the Tapi (Tapi RBM plan 2020 and 2023) and Ramganga basins (Ramganga RBM plan 2023). The development of the RBO Toolbox 2023 is mainly based on the experiences of an international team of experts and the GIZ project Team working on the Tapi RBM plan 2023. Off course, also the lessons learned during the development of the Tapi RBM plan 2020 during phase I have also been used. Besides, the team of international experts had also worked on many other countries within the EU, India and elsewhere developing RBM plans. The knowledge and insights gained by them from those projects were applied while developing the Toolbox.

In November 2023, as part of the finalization of Phase 2 of the India-EU Water Partnership (IEWP), an interactive 5-day RBM training week will be organized at the National Water Academy (NWA) in Pune. The RBM Toolbox, the Training Modules, presentations and training materials (see Annex 1, 2 & 3) will be used during the training.



IEWP Action TIMELINE

IEWP Phase 1
1 Jul 17 – 31 Oct 20

IEWP Phase 2
1 Nov 20–30 Sept 23

2016
- India EU Summit
- **MoU on Water Cooperation** signed between India and EU = Basis of IEWP

2017
- 3rd India-EU Water Forum
- JWG meeting
- Identification of Priority Areas & implementation

2018
- Implementation of IEWP Action Plan and business component

2019
- 4th India-EU Water Forum
- Accelerated Implementation of Priority Areas
- Completion of selected Pilots

2020

2023
- **IEWP Phase 1 ended**
- Some activities were cancelled due to COVID Pandemic
- **Overall IEWP aim achieved**
- **IEWP Phase 2 started in direct follow-up**

Figure 3 IEWP Action timeline 2016 – 2023.

1.8 Target audience

- Stakeholders from Indian institutions involved in River Basin Management Planning
- Senior as well as junior practitioners

1.9 Structure of the Toolbox

The Toolbox is structured in a way that allows the reader to understand the steps involved in carrying out a River Basin characterization, defining Basin Management Objectives and and identifying Key Water Management Issues (KWMIs), as well as understanding the necessary data needs and ways to analyse and process them. Building on this groundwork, the Toolbox provides step-by step guidance, a selection of helpful tools and approaches to overcome arsing challenges in carrying out Basin Risk Assessment, structured by KWMI. The following section describes tools to model surface water, groundwater and E-Flows in a river basin, including a detailed description of RIBASIM. Afterwards, the necessary steps to develop and implement Program of Measures are explained and tools for database management and GIS outlined. Rounding off the toolbox, the Annexes provide the tested and refined training modules.

2 River Basin characterization

Basin characterization: baseline, <u>Drivers</u> and <u>Pressures</u>

2.1 Introduction

*See **Annex 1** – Training Module on River Basin Management in a broader perspective: lessons learned from India and Europe.*

The basin characterization is all about defining a river basin in such a way that the current condition of the river basin with regard to the resource availability (flows and stocks), the resource development status and the various competitive and in-stream uses of water in the basin can be ascertained. This would mean describing the hydrological regime (rainfall and its pattern of occurrence, soils, climate, land uses and runoff), geological and geohydrological settings (depth to groundwater table, groundwater stock) and topographical conditions in order to describe the resource condition, as these factors have a strong bearing on the resource availability (runoff, discharge rates and groundwater recharge). It would mean describing the various water resource infrastructure in the basin (large & small reservoirs, diversion systems, water distribution networks) vis-à-vis their location and size in order to explain the water storage and distribution capacities available and how the appropriated water is distributed across the basin to meet various needs.

The basin characterization should also describe the socio-economic system of the basin (population and its distribution, past population growth rates (rural and urban) livestock population, crops & cropped areas, irrigated areas under different crops and type and size of industries) and how that is likely to change over time as they together with the climatic conditions would determine the nature and size of various competitive uses of water in the basin (for agriculture, domestic and livestock uses, industrial uses) in different seasons and how those uses are likely to change in future. It should also indicate the various competitive uses of water in quantitative terms.

The basin characterization should also describe the ecological status of the basin, comprising the eco-regions, the various species of flora and fauna found in different regions, the requirements of the ecosystem with regard to flows, quantity and quality of water in rivers and lakes and the current ecological status of the water bodies, i.e., whether they are heavily modified or moderately modified or in pristine condition and the various pressures that are at work (such as pollution from industries and urban areas, and non-point pollution from agriculture). It should also mention whether there are protected areas falling in the basin and the key species of animals in these protected areas.

2.2 Basin characterisation outline

Determination of hydrological units

Determining logical geographical/hydrological units for surface water as part of river basin planning involves a systematic approach that considers the characteristics of the river basin, its sub-catchments, and the desired level of spatial resolution. Here are the main steps in determining surface water units as logical geographical/hydrological units:

- **Basin Delineation:** Start by delineating the boundaries of the river basin using available topographic data and hydrological information. This can be done using Geographic Information System (GIS) tools by identifying the ridge lines or water divides that separate the basin from its surroundings.
- **Sub-basin Delineation**: Divide the main basin into sub-basins based on hydrological and geographical characteristics. Factors to consider can include the flow patterns, land cover, topography, and administrative boundaries. Common approaches for sub-basin delineation include the Strahler ordering system, watershed divide analysis, or automated tools like ArcGIS hydrological analysis tools.
- **Spatial Analysis**: Conduct spatial analysis to identify logical geographical units within the sub-basins. This involves considering various factors such as terrain characteristics, land use patterns, geology, and ecological features. GIS tools can be used to combine and analyze multiple layers of spatial data to identify coherent geographical units.
- **Stakeholder Engagement**: Seek input from relevant stakeholders, such as local communities, experts, and water management agencies, to understand their perspectives on the natural or administrative boundaries that influence the logical units. Local knowledge and expertise can provide valuable insights into the spatial organization of surface water units.
- **Scale Considerations:** Consider the desired scale of analysis and planning. This will depend on the available data, resources, and objectives of the river basin planning exercise. The level of resolution may vary from large regional-scale units to smaller sub-catchments or even individual stream segments, depending on the goals and capacity for data collection and analysis.
- **Adaptive Approach**: Keep in mind that the determination of surface water units is not a one-size-fits-all process and may require an adaptive approach. It may involve iterations and adjustments based on data availability, stakeholder consultations, scientific analyses, and the evolving understanding of the river basin's hydrology and geographical characteristics.
- **Documentation:** Ensure clear documentation of the delineation process, including the rationale for selecting the identified geographical units. Documenting the methodology, datasets, and criteria used will facilitate transparency, reproducibility, and future modifications if required.

Natural baseline characterization

- **Precipitation**: this section should discuss the precipitation in the basin and how it varies across space and time. The spatial variation in the mean annual precipitation of various gauging stations or grids can be presented. The catchments that contribute most to the basin runoff by virtue of high rainfall shall be identified. Also the temporal variation in the average annual rainfall of the entire basin can be presented. Along with this, the data on rainy days should be analyzed and presented, particularly the mean annual rainy days (in different sub-basins) and how the rainy days vary temporally with the variation in quantum of rainfall and if there are definite relationships that exist between rainfall and rainy days.
- **Surface water resources**: this section should describe the annual runoff in the basin (dependable yield and mean annual yield) as available from modelling studies of the basin and the sub-basins (or sub-catchments), the inter-annual variability in the runoff (expressed in terms of coefficient of variation), the observed stream flows in different seasons at the key observation sites, the maximum

discharge observed at key observation sites. It should also discuss the inter-annual variation in surface runoff in the basin as a result of variation in annual and seasonal rainfall. It should also discuss the long-term changes in land use and land cover, if any observed, as such changes will have significant impact on the runoff generation potential of the basin, even without any changes in the rainfall conditions. It should also explain if there are significant variation in the runoff rates across space and the factors contributing to such variations (such as rainfall, land cover, soil, etc.)

- **Groundwater resources**: this section should first discuss the geological profile of the basin, the different types of formations that are encountered. Then it should discuss the groundwater condition in the basin, in terms of annual replenishment, groundwater stocks, annual groundwater abstraction rates and ground water level fluctuations over time based on data available from a number of observation wells. Data on groundwater stocks will be crucial if deep alluvial and semi consolidated sedimentary formations are found in the basin. If different types of geological formations are encountered in the basin, then analysis of water level trends should be performed for representative observation wells from distinct geological formations (like hard rocks, alluvium and semi-consolidated sedimentary formations) for drawing the right inferences with regard to changes in groundwater conditions. In that context, it is important to provide data on the specific yield and hydraulic conductivity of the aquifers also. Maps on the regional groundwater levels shall be presented for different time periods, if depth to water level data are available for reasonably long time periods) to understand the regional groundwater flow trends and to understand the groundwater-surface water interactions.
- **Soils and Land Use**: Soils and land use have significant bearing on the runoff generation potential of the basin. They also influence the way contaminants get transported through the soil media to groundwater. Hence high resolution maps of different types of soils (according to FAO classification) and land use and land cover shall be provided.
- **Eco-regions, biodiversity and protected areas**: this section should present spatial data on forests, grasslands, eco-regions, rivers and lakes and protected areas. It should collate all available information about the important species of flora and fauna (both terrestrial and aquatic) found in the basin, their population and how the same has been changing over time. Particular focus should be on the aquatic species, especially the fish, otter, turtle and crustaceans, and to the species that are facing extinction.

Hydrological baseline characterization

- **Flood events**: the available data on the maximum river discharge observed at various gauging stations in the river and its tributaries shall be presented in the graphical form. The morphological map of the basin shall also be presented to understand the river stretches that are most prone to floods. Results of flood frequency analysis, if available, should be presented. Along with this, the data on the historical flood events, with data of the maximum observed flood magnitude and the inundation caused by those floods shall be presented and discussed.
- **Drought events, their role and frequency**: in this section, data on annual rainfall of various gauging stations should be analyzed and presented in the form of standard precipitation index. The standard precipitation index is a measure of the departure of the rainfall from the mean value expressed in terms of number of standard deviations of the rainfall. This is to factor out the effect of the inherent variations in the way rainfall occurs in different regions. Certain regions witness extreme year to year variability in rainfall, whereas certain other regions witness much less variability, though both the regions might have almost the same amount of mean annual rainfall. This basically means that high

degree of departure of rainfall from the mean value towards the lower side doesn't suggest a high intensity drought, if the rainfall in the area witness high inter-annual variability.

Existing water infrastructure projects

- **Irrigation & multi-purpose projects, command areas and water diversions, hydropower dams**: the features of the existing infrastructure projects for irrigation and domestic water supply, industry and hydropower shall be discussed. The features should include: the live storage and gross storage of the reservoirs, the carrying capacity of the canal systems; and the diversion capacity of the weirs/barrages, and the FRLs of the major reservoirs (including those for hydropower). It should also discuss the area to be irrigated (in case of irrigation schemes), the population to be covered (for rural & urban water supply) and the power generation capacity of the hydropower dams.
- **Groundwater abstraction and recharge structures**: this section should discuss the types of groundwater abstraction and recharge structures. The abstraction structures normally include open wells, bore wells, and shallow & deep tube wells. Open wells are common in both hard rock and alluvial areas. Bore wells are drilled only in hard rock areas. Shallow and deep tube wells are used only in the alluvial and semi-consolidated formations. It is important to mention that average yield of wells in each of the geological settings that are encountered in the basin. The well yield generally varies widely in the hard rock formations due to variation in the formation characteristics (extent of weathering and fractures). Since groundwater draft through electrified wells depends on the availability of electricity, it is important to mention that average hours of power supply for agriculture in the region under consideration.
- The groundwater recharge structures will include natural geological features that enable groundwater recharge from precipitation and irrigation (outcrop areas) and wetlands. It is important to map them and show them on the basin map to understand the recharge pattern. Since many river basins have witnessed implementation of artificial recharge schemes by the government and Civil Society Organizations (CSOs), it is important to map them, with their locations on the drainage lines along with the geological profile of the basin. Since paddy wetlands are also a good source of recharge, it is important to map them along with the artificial recharge structures and other water bodies.
- Sewage treatment plants: this section should describe the location and size of the sewage treatment plants in the basin, the type of treatment provided by each one of them and the actual capacity utilization by the plant. Also, the natural sink for the treated wastewater for each one of these STPs should also be mentioned and if there is reuse of treated sewage.
- Industrial effluent treatment plants: this section should discuss the location, size, treatment capacity and types of treatment provided by various effluent treatment plants. The extent of recycling and reuse of the treated industrial effluent should also be mentioned as these will have significant implications for the effective water supply to meet various demands.

Expected Socio-Economic Developments in the basin

- **Population growth**: population growth is one of the biggest drivers of increase in water demand, as it increases the demand for food and agricultural commodities and water for direct human consumption, unless there is change in the way water is used by people due to technological and institutional changes. Population growth will also increase the water demand for manufacturing, unless there is change in the manufacturing process. Hence, population is one of the important parameters defining the character of a basin. This section should discuss how the population in the basin is expected to growth in future, based on the consideration of past growth trends and the changes in other factors (such as fertility rates, child mortality rates and life expectancy) influencing population. More than population growth rates, where the growth happens is important. Growth in urban population will have a much greater impact on water demands than growth in rural population, merely because of the fact that the urban water demands are higher than the rural water demands.

- **Water supply and wastewater generation and treatment**: change in water supply conditions will have implications for the character of a river basin. Increase in water supply would require higher appropriation of water through reservoirs or diversion systems. More water supplies for water supply in rural and urban areas would result in more wastewater generation. If the increase in water supply is in the urban areas, this would lead to concentrated wastewater generation as the wastewater is generally collected through sewers, whereas if it happens in rural areas, there are greater chances for the wastewater to be reused for crops (kitchen gardens, homesteads, etc.). Hence, the extent of changes in water supply, the new developments that are taking place to augment the water supply, and where the additional water is going to be supplied and where the wastewater would end up are important.
- **Urban development**: Urban development will have significant implications for water, as high growth in urban areas would mean higher per capita water demand for domestic and municipal uses (watering gardens, trees, and recreational activities). Further, urban centres would be concentrated points of wastewater generation. At the same time, expansion of cities will have implications for land use, with more build up area. This will impact natural groundwater recharge also, if such developments occur in the outcrop areas of aquifers. Therefore, spatial information about urban development is also critical.
- **Agricultural development**: agricultural development will have significant implications for water resources, as it changes the land use of the region impacting on runoff and recharge from precipitation. It will also mean more demand for water for crop production especially in semi- arid and arid regions with monsoon climate. This increase in water demand will have to be met either through development of surface irrigation schemes or private well irrigation, depending on what technically feasible and economically viable. In the absence of surface irrigation, farmers are likely to develop groundwater resources, even if they are limited in the region where agricultural development happens.
- **Major planned infrastructure projects in the River Basin**: development of infrastructure such as road networks and bridges will have significant impact on water consumption. Better transportation facilities will encourage farmers in remote areas to go for commercial farmers high value cash crops and also adopt modern irrigation technologies (to obtain higher yield and better produce). This can have long-term consequences for aggregate water use and water use efficiency. Therefore, which region is likely to face what kind of new infrastructure development are important.

2.3 Climate change impacts in the River Basin

First of all, the long-term changes in the climate of the basin should be analysed in detail and presented on a spatial format. The analysis shall include long-term changes in rainfall (vis-à-vis annual rainfall, number of rainy days, number of rainy events in which the rainfall exceeds a certain magnitude), temperature (mean annual temperature, average temperature of certain months and seasons, lowest and highest min and max. temperature of a year, etc.) and relative humidity. Following this, the results of predictions available from regional climate models of changes in the basin rainfall for different scenarios can be presented. Further, the results of the available studies examining the impact of the above-mentioned predicted changes in the climatic condition on the basin runoff, soil moisture conditions, recharge and peak discharge shall be presented and discussed.

2.4 Data collection and how to deal with data gaps

One major issue in analysing river basin management issues in the developing countries is inadequate data on the hydrology, though in India this issue is being tackled fast by the government at the national level through various projects. As mentioned early, the major issue is with the data on stream-flows, an important parameter for arriving at the runoff generated by various catchments.

For instance, in the case of India, all the 20 major river basins have river gauging stations, but the density of the network is not adequate. For instance, in the case of Tapi river basin, which has a drainage area of 69,000 sq. km, there are only six operational gauging stations where the river discharge is measured. This issue can be tackled through simulation models. There is a good network of rain-gauging stations in India and data of daily rainfall is available for a considerable number of years. The data on land use/land cover and soil profile can also be obtained from various sources. These datasets can be used to estimate the daily runoff using SCS curve number method and rainfall-runoff models can be generated for the un-gauged catchments. If weather data are available, SWAT model can also be set up for those catchments.

Another source of information is the reservoir mass balance. For the large reservoirs, the mass balance (inflow, storage change, outflow and release) data are maintained by the state water resources department. The inflow into such reservoirs, as available from the mass balance data, can be treated as runoff from the upper catchment of the reservoir and can also be used for developing rainfall-runoff model for similar catchments (with the same amount of rainfall and catchment characteristics—land cover, soils and topography).

3 Basin Management Objectives & Key Water Management Issues

3.1 Definition of basin wide management objectives

*See **Annex 1** – Training Module on River Basin Management in a broader perspective: lessons learned from India and Europe.*

Setting management goals objectives for mid- and/or long-term in a river basin is a crucial step within the RBM planning process. Agreed goals consistently guide all involved responsible water authorities and relevant stakeholders towards clearly-defined goals. The overall river Basin goals are the consolidated goals which have been agreed upon to be achieved in the River Basin aligned to the RBM Cycle timeline. The Overall River Basin Aims are the basis of all assessments in this RBM Plan as well as the actions in the PoM aim towards their achievement.

To ensure sustainable water resources management in the River Basin enabling the protection of the aquatic environment as well as a sustainable socio-economic development and water supply security through appropriate measures. In general, it is aimed for:

- to ensure good quality of surface waters and groundwater through the reduction of pollution and all other relevant pressures.
- to ensure good/sufficient water quantity in surface waters and groundwater through efficient water use and all other needed measures.

The Overall River Basin Aims have been backed-up by more detailed objectives to be achieved for each Key Water Management Issue, as part of the Pressure/Impact Analysis and Risk Assessment. For each objective criteria and/or thresholds have to be developed to assess the likelihood if surface waters and groundwater or parts of these might fail to meet the objectives and, hence, the Overall River Basin Aims. In case of failure, measures will be identified to support the future achievement of the aims and objectives.

3.2 Key Water Management Issues

The key water management issues (KWMIs) give an overview of the key issues and challenges affecting the water environment that are considered to challenge our ability to achieve the RBM goals and objectives. The identification of KWMIs is also part of WFD Article 14 and should be presented in public consultation summary documents at river basin level, national or international level as an intermediate step in the preparation of a RBM plan.

Public consultation on the KWMIs helps in prioritizing the main issues that need to be tackled through appropriate measures in the next RBM plan. In addition to presenting evidence on the main pressures and their sources, the summaries of KWMIs also inform the stakeholders on the main measures that could be implemented as well as outline further possible solutions to address these issues. Thus, public consultation on the KWMIs is an opportunity to comment on measures identified for addressing the key issues and to propose additional measures that could make an important contribution.

Within the EU, similar to the first and second planning cycles, Member States have published summaries of KWMIs for a 6-month public consultation in preparation of their third RBM Plan.

Based on an assessment of all recent EU RBM plans, the European Environmental Agency (EEA) documented the top 10 of European KWMIs, which are related to pollution issues, hydro-morphological pressures, abstractions and water scarcity, problems related to aquaculture and invasive alien species. These KWMIs arise not only from ongoing human activities (such as agriculture or energy production) but also partly from historic human activities (e.g. obsolete barriers on rivers, abandoned mines) and new developments (e.g. new hydropower plants).

The KWMIs have been selected based on the analysis of significant pressures affecting water bodies in the 2nd RBMPs (see EEA 2018 assessment of status and pressures of European waters). Pressures were selected that affect a sufficiently large share of water bodies. In addition, KWMIs have been selected, which were long time important enough to develop a rather solid basis of knowledge and information to describe the scope of the issue. Additional KWMIs may be identified in the future as data collection and research improves on activities and pressures that put water bodies at risk of reaching the RBM objectives.

Table 2 Overview of potential key water management issues in a river basin (Source: EEA 2021)

KWMI	Impact
Pollution: point source (urban waste water, industry)	• Oxygen deficit from organic pollution with impacts on biota • Impacts from nutrients, hazardous substances and emerging pollutants
Pollution: diffuse source with nutrients and chemicals (agriculture, atmospheric deposition)	• Eutrophication and algal blooms affecting biota • Groundwater nitrates affecting drinking water quality • Pesticide threats to biota and human health • Sediment run-off with impacts on habitats • Impacts on biota from atmospheric deposition of mercury
Pollution: non-connected dwellings	• Many disease-causing organisms affecting human health • Local oxygen depletion • Nutrient input leading to eutrophication and oxygen depletion
Pollution: mining	• Changes in surface and groundwater hydrology • Metal pollution • Sediment load • Acid run-off
Hydro-morphological pressures: barriers (hydropower, flood protection and irrigation)	• Habitat loss • Flow regulation • River fragmentation • Changed sediment transport and erosion • Water quality • Cumulative effects
Hydro-morphological pressures: loss of lateral connectivity (flood protection and drainage on floodplains)	• Loss of key habitats and species decline in rivers and floodplains • Changed hydro-morphology dynamics and sediment supply • Impacts on nutrient cycling

Hydro-morphological pressures: Hydropower	• Interruption of river continuity and impacts on migrating fish • Altered sediment transport • Changed flow regime with morphological and ecological effects • Altered physicochemical conditions • Cumulative effects
Hydro-morphological pressures: navigation	• Hydro-morphological changes in river beds and banks • Changed water levels and flows • Loss of connectivity with floodplain • Interruption of river continuity • Impacts on key habitats of biota • Pollution (waste, accidents) • Spread of invasive alien species
Abstractions and water scarcity (agriculture, cooling, water supply)	• Low flow and dry rivers with impacts on biota • Decreased ability to dilute contaminants • Lowered groundwater levels • Salinisation of aquifers
Aquaculture	• Release of oxygen-consuming substances, nutrients and chemicals (pharmaceuticals) • Escape of cultured organisms • Disruption of continuity (barriers), hydrological changes and sediment transport disruption
Invasive alien species (IAS) (aquaculture, pet/aquarium species, shipping, fisheries/ angling)	• Altered biota communities • Impacts on food webs • Constraint on recovery of native biodiversity

3.3 Prioritization of KWMIs in the Tapi Basin

River basins exhibit natural features as well as alterations resulting from human activities, which can influence the attainment of the desired basin objectives. The process of characterization involves recognizing Key Water Management Issues, understanding their associated impacts, and verifying them. Through extensive consultations conducted at both national and state levels, the Tapi Basin States have collectively determined and accepted five Key Water Management Issues.

Specifically, the following 5 KWMIs have been selected for the Tapi River Basin:

- *KWMI 1: Pollution from Urban Settlements and Industries*
- *KWMI 2: Area Source Pollution from Agriculture and other sources*
- *KWMI 3: Alterations of River Hydrology/Water Quantity*
- *KWMI 4: Alterations of Groundwater Quality and Quantity*
- *KWMI 5: Alterations of River Morphology through Sand Mining*

3.4 Defining Vision and Management Objectives for KWMIs

In order define aims and managerial steps for each KWMI as well as to enable a targeted assessment in the RBM Plan, visions and management objectives have been agreed for each of them. The basic principles of these can be described as follows:

The KWMI visions reflect shared values regarding the jointly identified KWMIs that are shared by at national level (CWC, CGWB, CPCB) and state level (State WRM departments, State branches of CWC, CGWB, CPCB), cooperating at basin level in the River Basin Committee (RBC).

The visions for the identified KWMIs describe the principle objectives for the River Basin from a long-term perspective (20+ years). The KWMI management objectives are based on the visions and describe concrete implementation steps towards the agreed Overall River Basin Aims. The management objectives support the overall river basin management objective. They enabled a targeted data collection and Pressure/Impact Analysis. The management objectives follow the RBM Cycle timeline regarding achievement and are of qualitative and/or of quantitative and measurable nature. They are aimed to be achieved through measures to reduce/ eliminate pressures.

4 Database management and GIS

4.1 The importance of database management

Database management is the process of organizing and storing data in a way that makes it easy to access and use. For river basin management, there is a need to store geospatial data (such as the drainage network or earth observation imagery), time series data such as population trends, crop production statistics or stream flow data series, and standard alphanumeric data on all facets of the basin management.

While there are database management systems available which can store such a wide variety of data (vector maps, raster layers, time series statistics, and normal attributes) they are all server based, meaning advanced technological solutions and/or internet connectivity are required to access them. The best known open-source database management systems are PostgreSQL and MySQL and can store such a variety of data formats, but require a client-server environment or a cloud based solution. This is often beyond the capacity of a river basin organization and therefore data is stored in a number of different file based databases such as “Geodatabase”, Excel data sheets, and Access Databases. This requires specific management with master copies stored and managed by the GIS manager.
The benefits of proper database management include:

- Improved data accuracy: Database management systems can help improve data accuracy by ensuring that data is entered and stored correctly. This can help to prevent errors and improve the quality of decision-making.
- Increased data security: Database management systems can help to increase data security by providing access controls and encryption. This can help to protect data from unauthorized access and tampering.
- Enhanced data accessibility: Database management systems can help to enhance data accessibility by providing users with easy ways to search, sort, and filter data. This can help users to find the information they need quickly and easily.
- Improved data performance: Database management systems can help improve data performance by optimizing queries and data access. This can help reduce the time taken to access data and improve the overall performance of the system.
- Overall, database management is an essential tool for businesses and organizations of all sizes. By implementing a database management system, organizations can improve efficiency, productivity, and decision-making.

4.2 How to set up a basin-wide database

The setup of the TAPI basin database is a complex process that has required careful planning and execution. The following steps provide the workflow of establishing the TAPI basin database:

1. Determine the data requirements. Once you have identified the data sources, you need to determine the data requirements for the database. This includes the types of data that will be stored, the level of detail that is required, and the frequency with which the data will be updated.

2. Identify the data sources. The second step is to identify all of the data sources that will be used to populate the database. This could include government agencies, academic institutions, research institutes, and other organizations.
3. Design the database. The next step is to design the database. This includes creating a database schema, which is a blueprint for the database. The schema should define the tables, columns, and relationships between the data in the database.
4. Populate the database. Once the database has been designed, it needs to be populated with data. This can be done manually or by using a data loader.
5. Deploy the database. Once the database has been tested, it can be deployed to production. This means making the database available to users.
6. Maintain the database. Once the database is in production, it needs to be maintained. This includes keeping the data up-to-date, fixing any errors, and adding new features as needed.
7. The structure of the TAPI basin database is provided in a separate document.

4.3 The importance of clear and understandable basin maps

Basin maps are essential for managing water resources in the watershed. The maps provide information about water flows, extent and storage of water bodies, groundwater levels, water quality and more. This information helps in planning water allocation, managing water quality, and determining sustainable usage levels. Basin maps also show areas of environmental significance, such as wetlands, forests, or wildlife habitats, and these maps help in conservation planning and environmental impact assessment. The maps are also used for Land Use Planning by showing the distribution of different land uses within the basin, such as urban areas, agricultural lands, or protected areas. This way, the basin maps can help in land use planning and conflict resolution.

While creating these basin thematic maps, it is important to use clear and concise symbols and labels. The maps should also be scaled appropriately so that the features of interest can be easily identified. The maps should be accurate and up-to-date with the latest available information. The maps should use a consistent style throughout the atlas. This will make it easier for users to understand the maps and to find the information they need.

5 Monitoring data: analysing & processing

- ***Defining the state of the water system.***

*See **Annex 2** – Training Module on (i) Surface Water (quantity & quality); (ii) Ground Water (quantity & quality) and (iii) River morphology and Sediment Transport.*

The purpose of this chapter is to provide hands-on information on how to process relevant monitoring data so that CWC, CGWB and CPCB both at national and state level are able to replicate the risk assessment for the related KWMIs in other river basins. We will concentrate on the practical use of excel databases & QGIS, though you are free to use other tools for data management and GIS.

5.1 Introduction

Monitoring helps define the state of the water system. The condition of the water resource system can be in terms of: 1) the annual quantum flows (stream-flow) at different points across the basin, the flow patterns (seasonal flows and the peaks), the contribution of different catchments of the basin to the total quantum of flows, and the contribution of rainfall and snowmelt to the annual and seasonal flows; 2) the changes in the quality of water (physical chemical, bacteriological) in the river over time (annual and seasonal); 3) the condition of the groundwater in the basin in terms of depth to water levels at different points in the basin, the regional groundwater flow pattern, the long-term trends and annual and seasonal fluctuations in water levels in different parts of the basin; the changes in groundwater quality with seasons and over the long-term (such as changes in iron, nitrite, nitrate, salinity and fluoride levels). Close monitoring of the water systems clear indications of the changes that are happening.

Reduction in annual flows over time can be indicative of either reducing rainfall (that contribute to runoff) or changing land use in the catchment or changing temperature conditions (that result to faster depletion of soil moisture) or increase in groundwater draft in the catchment (causing reduction in the lean season flows) or upstream developments or a combination of all these activities and processes. Hence, monitoring should include several parameters, such as flows, weather, groundwater abstraction, u/s water diversions, land use, etc. to arrive at correct inferences about the basin conditions, especially the types of stresses that the basin is subject to.

Seasonal fluctuations in water levels are indicative of the various hydrological stresses that the aquifer is subject to and the inflows into the aquifer. Increase in sediment load in the runoff can be indicative of the increasing soil erosion from the catchment due to degradation (in the form of deforestation) or sudden landslides. Long-term secular decline in water levels of a region are indicative of the lowering stock of groundwater due to the abstraction exceeding the natural replenishment on a continuous basis. Hence regular monitoring of the water resource system on various indicators related to water quality and quantity is important for assessing the performance of the basin. For monitoring two aspects are important: 1) density of the monitoring network; and, 2) the frequency of monitoring. The density of monitoring network should be decided by the degree of variation in the hydrological, geological and morphological characteristics of the basin and the level of precision required for taking the management decisions.

For sound river management knowledge of the status quo of the river system, past temporal and long-term changes of the river and expected long-term changes are important. Analyses of changes can only be carried out if sufficient information is available, i.e. data of the hydrology, bathymetry and planform, as well as the forecasted developments (analytical or by models). The following aspects are of importance: data acquisition (locations, frequency, and methodology), maintenance (monitoring), and use of data for river management and river models.

1. *General*

General needs for data and approaches of data acquisition are described. For specific goals extra or other measurement data may be needed. Data requirements for various morphological models may differ, so manuals have to be consulted. To apply a hydraulic or morphological models sufficient training is required.

2. *Data for general river management*

General river management uses data for day-to-day management (irrigation, drainage, reservoir management, navigation, agriculture), disaster management (flooding, failure of structures), planning of river works and evaluation of river system changes.
To that end data series of rainfall, discharges, water levels, elevation maps, riverbed soundings and deducted relations are important.

- Rainfall-Runoff relations are used for flood forecasting, irrigation, drainage and reservoir operations.
- Stage-Discharge (rating curve) relations at various stations, bifurcations, inlets, outlets have to be established and regularly checked as local bed erosion and downstream changes in the riverbed, overall river geometry and hydraulic roughness influence the water levels at a given discharge. Yearly discharge and water level measurements can show these changes. Near bifurcations changes in the rating curves will also change the discharge distributions.

3. *Data for river models*

Hydraulic and morphological river models use specific data that are derived from the general data, that are used in schematized form. GIS operations may facilitate these transformations to a large extent. For models the river properties have to be schematized into hydraulic and morphologic parameters. Manuals of the specific river model software describe the operations in detail.
General hydraulic information and parameters for hydraulic models are:

- Time series of water levels and discharges.
- From the measurements defined discharge-water level relationships (rating curves).
- Relations between river discharge and average velocity in the main channel.
- Definition of the spatial variability and size of the river using a number of representative cross sections. Use of measured cross-sections (soundings) every 0.5, 1, 5 or 10 km, depending on the detail required. Longitudinal bed levels can be derived from the cross-sectional soundings or directly measured.
- Definition of the planform of the main channel with riverbanks and bed levels. Definition of the planform of flood plains with summer dikes, lakes, side channels, oxbow lakes, weirs, buildings, vegetation. Defining hydraulic structures like bridges, underpasses, dams, side channels, oxbow lakes, irrigation canals.
- For the planform use can be made of digital elevation models (DEM) and digital Terrain Models (DTM). DTM´s are often confused with DEM´s. The main difference between the two models lies

in the fact that the DEM generally takes into account all persistent objects on the ground (vegetation, buildings, and other artefacts), while the DTM shows the development of the geodesic surface, so the geometry of the riverbed could be found in DTM data.

- Hydraulic roughness of the riverbed. A first estimation is obtained from bedform dimensions. The hydraulic roughness of the floodplain can be obtained from floodplain vegetation maps using known roughness values for different vegetation types. The hydraulic roughness values in the model are finally calibrated by hydraulic computations using discharges, known water levels and discharge distributions at bifurcations.
- The downstream boundary is the water level at the downstream boundary of the chosen model length, which can be read from discharge rating curves or tide water levels.
- The location of the downstream boundary is at a certain distance from the area of interest at the downstream end of the river, so that backwater effects do not influence the results (order of 10 km, depending on the type of river).
- The upstream boundary consists of the discharge regime.
- After the first runs of the model built, more detail can be obtained introducing more cross sections (focus on "problem locations") and checks with more water level and discharge data, e.g. at problem locations and around bifurcations.

5.2 Monitoring Networks and Data Collection

5.2.1 Surface water quantity & quality

The purpose of this manual is to provide hands-on training on how to process the data so that CWC can replicate the surface water risk assessment in other river basins.

Surface water quantity:

One of the biggest challenges facing the water managers of Indian river basins is the lack of adequate amount of data on the surface hydrology of the river basins they deal with. For surface hydrology, the most important question is the runoff generating capacity of the basin, i.e., what percentage of precipitation actually gets converted into runoff.

That said, there is a very good density of rain gauging and snow measuring stations across the country to quantify the total amount of precipitation occurring over different catchments. They are geographically well spread over the river basins of the country.

For a comprehensive understanding of the hydrology, it is important that there are gauging stations established to monitor the water levels, daily discharge, sediment load and chemical quality of water periodically and frequently. The number of gauging-stations should be ideally decided on the basis of the types of catchments, the size of the catchments, the length of the river, morphological features, etc. Greater the diversity of the catchment in terms of rainfall conditions, the land cover and soil types and morphological features, higher the number of gauging stations as the variation in runoff rates (runoff per unit catchment area, shape of the run-off hydrograph) and flow regimes (flow channel shape) will be high in such instances.

Another important consideration for fixing the gauging stations is the probability of occurrence of floods. In the case of rivers that are prone to floods, there should be enough number of stations for monitoring the river stage (water levels), depending on the catchment area and length of the river channels. Nevertheless, the number of gauging stations (for water levels, discharge, sediment yield and water quality) should finally be decided in such a way that a good understanding of the water and sediment yield contributions from different parts of the basin can be developed and flood forecasting can be done with early warning. With regard to flood forecasting, there are standard internationally accepted criteria and norms developed by the World Meteorological Department (WMO) which need to be followed (WMO, 2014).

Surface water quality:

In the Tapi basin, 4 monitoring stations are managed by the CWC, 38 are managed by the CPCB and there are 6 additional stations. In principle, sampling of the water quality takes place on monthly basis.

Step 1: The following online portals/websites can be used to find water quality data:
https://indiawris.gov.in/wris/#/SWQuality

In case of downloading external files or uploading internal data, it's best to store them in a 'raw data' folder and make a 'working' copy before any editing. This insures you have a fall back in the inevitable event of making mistakes during your analysis process. Next step is to read all metadata associated with your datasets. Metadata is a file documenting variables, creation date, data issues, etc.

Step 2: Export of information to excel.

A table with the following columns can be prepared:

- Index
- State
- District
- Station name
- Station unique ID
- Station coordinates (latitude, longitude)
- Date of sampling
- Weather situation
- Date of analysis (optional)
- Kind of sample (graph, real time online, ..)
- Different results including …unit…

Step 3: Data processing and cleaning
The purpose of the data cleaning process is to detect:

- Outlier values
- Spatial errors
- Spelling mistakes
- Unlike trending

Different (statistical) tools to clean the data. Examples of software that can be used:

- Excel tools like minimum/maximum values, mean values, pivot tables

Step 4: Analyses and validation of data

The data processing should be done by a person/team that is really able to become familiar with the data as that makes the cleaning and analyses more worthwhile. Then, expert judgement is possible. Visualising the data using graphs, tables.

The following supportive questions can be of help:
- What kind of questions am I trying to answer with my data?
- How will I communicate the data to whom? Is graphical presentation needed?
- Who will use my data and see my end products?

Document the choices made and the process followed and name and save in a logical way.

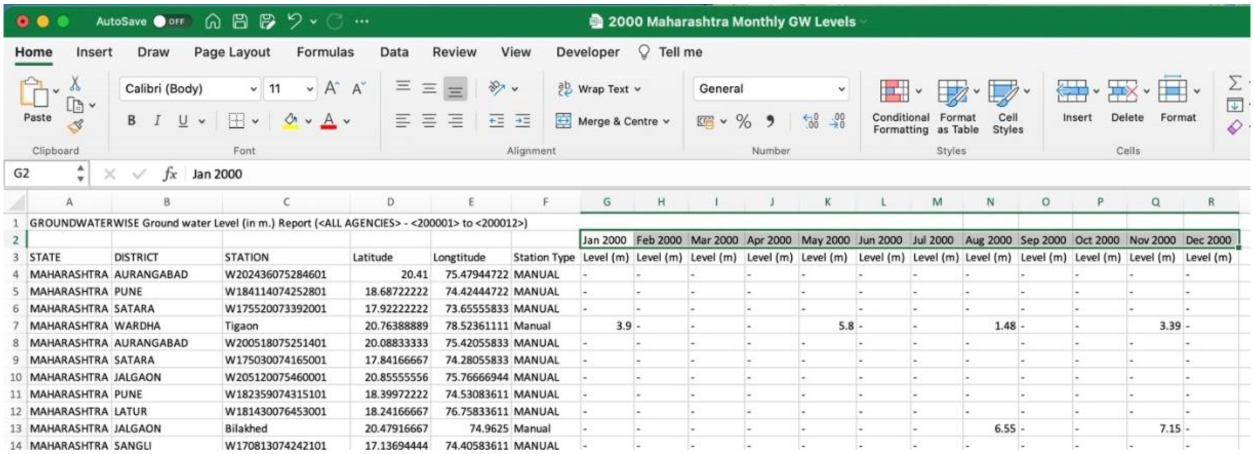
5.2.2 Groundwater quality & quantity

The purpose of this manual is to provide hands-on training on how to process the data so that CGWB can replicate the groundwater risk assessment in other river basins. We will concentrate on the practical use of excel databases & QGIS, though you are free to use other tools for data management and GIS.

Key data management skills

<u>Key Skills - Rules for Database Tables (Excel)</u>
There are some very simple rules for the structure of database tables which are universal. This means that they apply to all databases, even those built in MS Excel. If you follow the database rules below, your data table can easily be used in any database application (Excel, Access, SQL databases etc). It can also be used in Geodatabases for Geographical Information Systems (GIS).

<u>Database Rule 1: Only One Title Row</u>
There must be only one (1) title row in any database table. Do not use two or more title rows.
For example, the India Water Resources Information System (WRIS) water level data for Maharashtra 2020 has the month and year on one row, and then Level (m) below it. There is no need for a second title row. Before you can use this data in a database, you need to merge the information from the two rows.



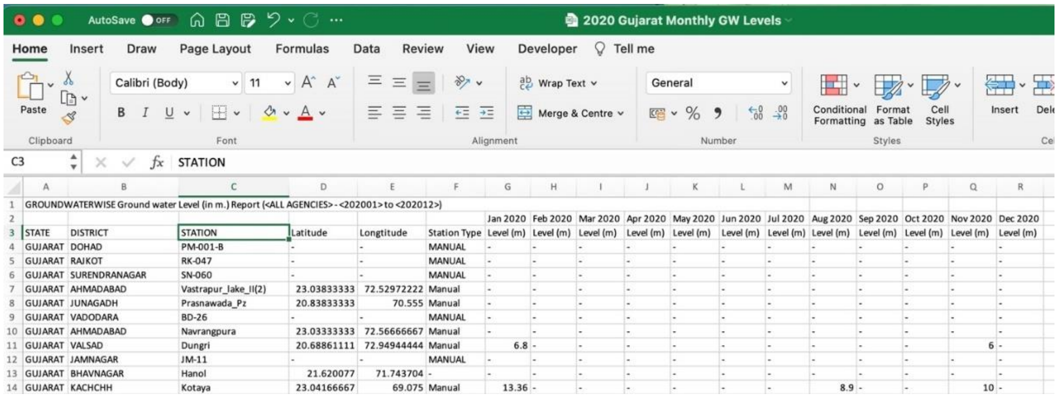
GROUNDWATERWISE Ground water Level (in m.) Report (<ALL AGENCIES> - <200001> to <200012>)

						Jan 2000	Feb 2000	Mar 2000	Apr 2000	May 2000	Jun 2000	Jul 2000	Aug 2000	Sep 2000	Oct 2000	Nov 2000	Dec 2000
STATE	DISTRICT	STATION	Latitude	Longtitude	Station Type	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)
MAHARASHTRA	AURANGABAD	W202436075284601	20.41	75.47944722	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	PUNE	W184114074252801	18.68722222	74.42444722	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	SATARA	W175520073392001	17.92222222	73.65555833	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	WARDHA	Tigaon	20.76388889	78.52361111	Manual	3.9	-	-	-	5.8	-	-	1.48	-	-	3.39	-
MAHARASHTRA	AURANGABAD	W200518075251401	20.08833333	75.42055833	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	SATARA	W175030074165001	17.84166667	74.28055833	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	JALGAON	W205120075460001	20.85555556	75.76666944	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	PUNE	W182359074315101	18.39972222	74.53083611	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	LATUR	W181430076453001	18.24166667	76.75833611	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
MAHARASHTRA	JALGAON	Bilakhed	20.47916667	74.9625	Manual	-	-	-	-	-	-	-	6.55	-	-	7.15	-
MAHARASHTRA	SANGLI	W170813074242101	17.13694444	74.40583611	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-

Figure 4 : Example data table with multiple header rows

Database Rule 2: Separate the Different Languages
When we have a dual language database table, things become a bit more complicated. Do not mix English with e.g., Hindi in the title rows or the database itself. Information in different languages should be kept in separate columns because they are separate bits of information.

Database Rule 3: Always include a unique identifier.
Every water well needs to have a unique identifier, so that we can link data from different years and perhaps different sources to this well. In the example from Maharashtra 2020 we can see that most, but not all the wells have a unique number. In the case of Gujarat and Madhya Pradesh each well has a station name, which is unique with the District of the State but there can be stations with the same name in other districts. This means that the station name cannot be used as a unique identifier, and a separate identifier needs to be created. In this case we used a concatenation of State-District-Station.



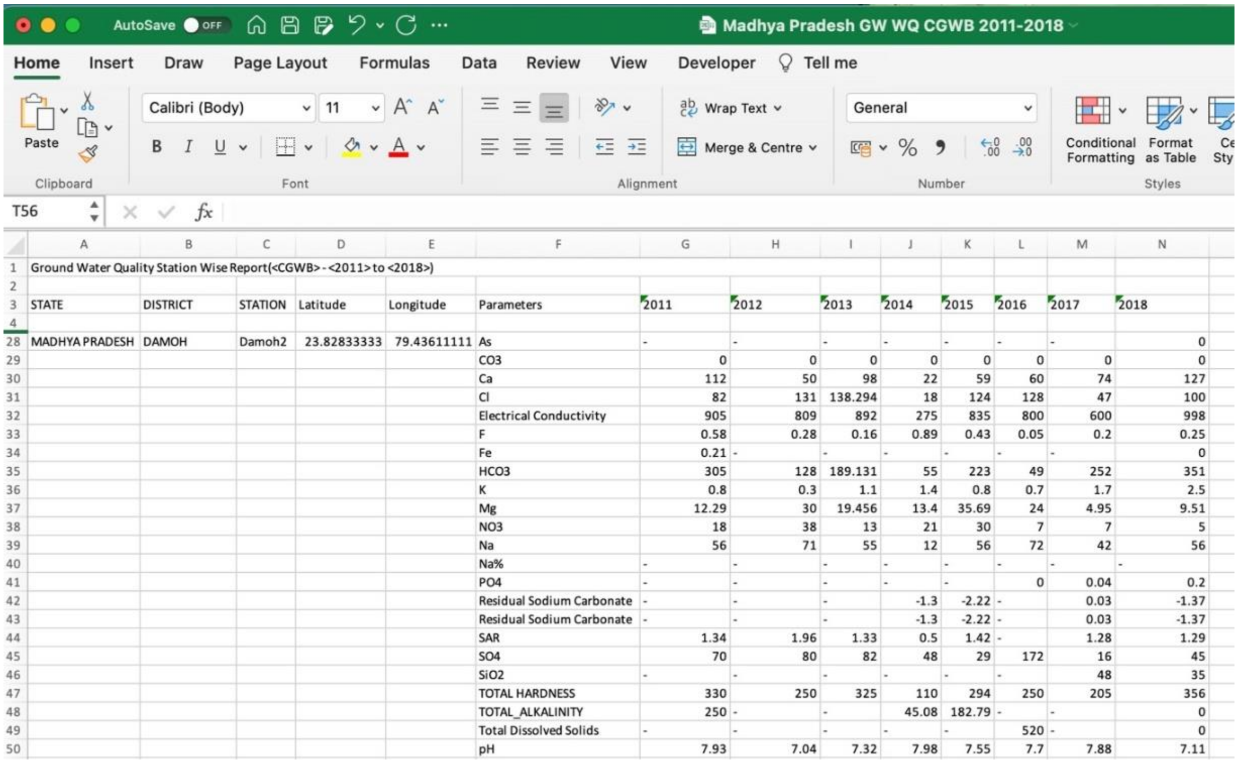
GROUNDWATERWISE Ground water Level (in m.) Report (<ALL AGENCIES> - <202001> to <202012>)

						Jan 2020	Feb 2020	Mar 2020	Apr 2020	May 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020	Nov 2020	Dec 2020
STATE	DISTRICT	STATION	Latitude	Longtitude	Station Type	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)	Level (m)
GUJARAT	DOHAD	PM-001-B	-	-	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	RAJKOT	RK-047	-	-	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	SURENDRANAGAR	SN-060	-	-	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	AHMADABAD	Vastrapur_lake_II(2)	23.03833333	72.52972222	Manual	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	JUNAGADH	Prasnawada_Pz	20.83833333	70.555	Manual	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	VADODARA	BD-26	-	-	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	AHMADABAD	Navrangpura	23.03333333	72.56666667	Manual	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	VALSAD	Dungri	20.68861111	72.94944444	Manual	6.8	-	-	-	-	-	-	-	-	-	6	-
GUJARAT	JAMNAGAR	JM-11	-	-	MANUAL	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	BHAVNAGAR	Hanol	21.620077	71.743704	-	-	-	-	-	-	-	-	-	-	-	-	-
GUJARAT	KACHCHH	Kotaya	23.04166667	69.075	Manual	13.36	-	-	-	-	-	-	8.9	-	-	10	-

Figure 5: Example data table without a unique identifier

Database Rule 4: Always show the Units
The unit for any parameter should always be shown in brackets ( ) immediately after the parameter name. This will avoid one of the most common mistakes in water resources management, which is a confusion of the units. This is especially important in India where there can be a mixture of imperial and international units.

In the example of Gujarat above, it is clear that the water levels are measured in metres and not feet. However, in the latitude and longitude columns we have coordinates in decimal degrees, but the coordinate system is not specified. For example, instead of Latitude, it is better to specify Latitude (WGS84).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Ground Water Quality Station Wise Report(<CGWB> - <2011> to <2018>)													
2														
3	STATE	DISTRICT	STATION	Latitude	Longitude	Parameters	2011	2012	2013	2014	2015	2016	2017	2018
4														
28	MADHYA PRADESH	DAMOH	Damoh2	23.82833333	79.43611111	As	-	-	-	-	-	-	-	0
29						CO3	0	0	0	0	0	0	0	0
30						Ca	112	50	98	22	59	60	74	127
31						Cl	82	131	138.294	18	124	128	47	100
32						Electrical Conductivity	905	809	892	275	835	800	600	998
33						F	0.58	0.28	0.16	0.89	0.43	0.05	0.2	0.25
34						Fe	0.21	-	-	-	-	-	-	0
35						HCO3	305	128	189.131	55	223	49	252	351
36						K	0.8	0.3	1.1	1.4	0.8	0.7	1.7	2.5
37						Mg	12.29	30	19.456	13.4	35.69	24	4.95	9.51
38						NO3	18	38	13	21	30	7	7	5
39						Na	56	71	55	12	56	72	42	56
40						Na%	-	-	-	-	-	-	-	-
41						PO4	-	-	-	-	-	0	0.04	0.2
42						Residual Sodium Carbonate	-	-	-	-1.3	-2.22	-	0.03	-1.37
43						Residual Sodium Carbonate	-	-	-	-1.3	-2.22	-	0.03	-1.37
44						SAR	1.34	1.96	1.33	0.5	1.42	-	1.28	1.29
45						SO4	70	80	82	48	29	172	16	45
46						SiO2	-	-	-	-	-	-	48	35
47						TOTAL HARDNESS	330	250	325	110	294	250	205	356
48						TOTAL_ALKALINITY	250	-	-	45.08	182.79	-	-	0
49						Total Dissolved Solids	-	-	-	-	-	520	-	0
50						pH	7.93	7.04	7.32	7.98	7.55	7.7	7.88	7.11

Figure 6: Example data table without clear units

Another example is the water quality analysis of groundwater samples from Madhya Pradesh. The units should be shown in brackets immediately after the Parameters. For example, is Arsenic measured in mg/L or µg/L?

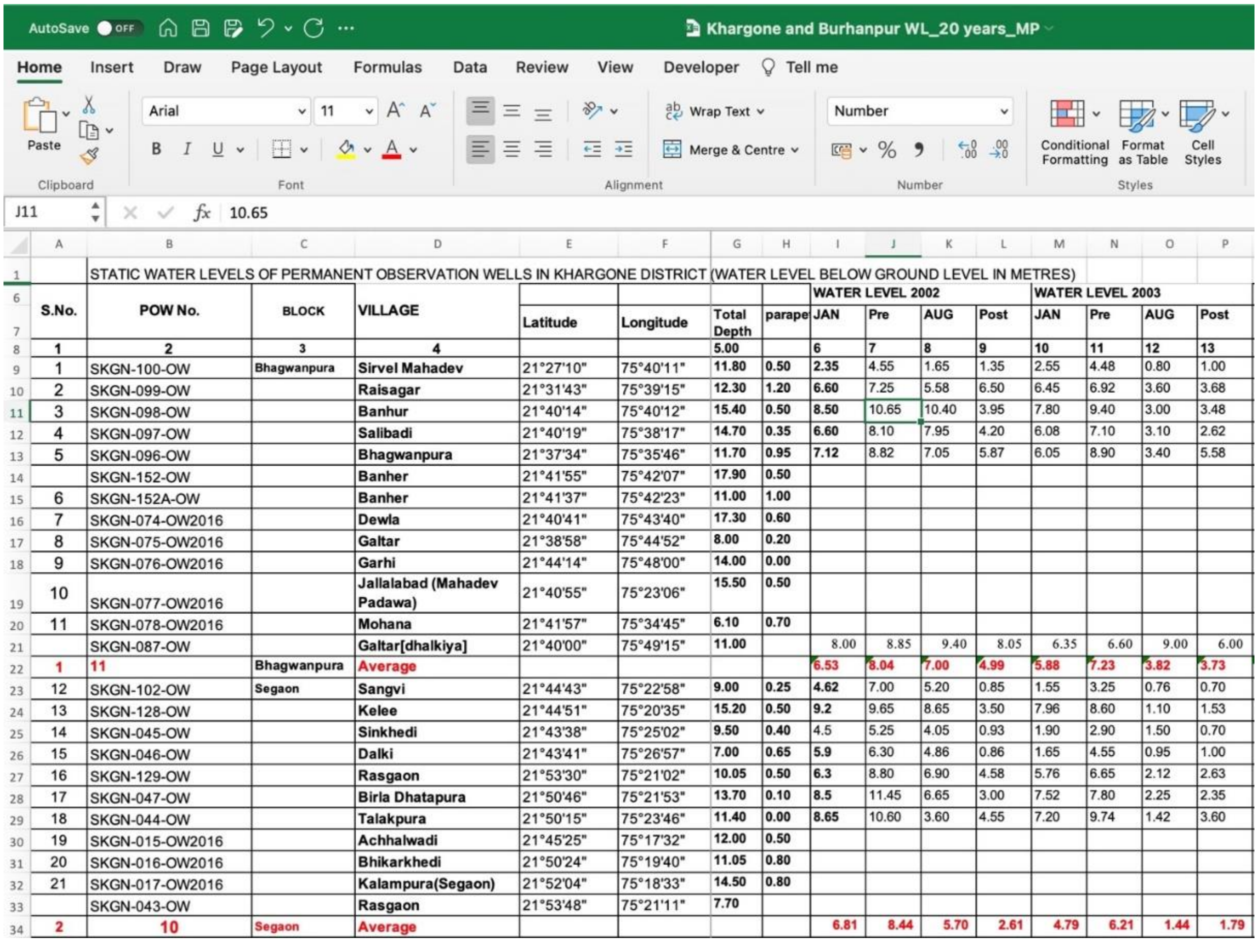
<u>Database Rule 5: Do not mix text data with number data.</u>

If you mix text with numbers, the computer will automatically assume that it is a text. This means that the information cannot be used for any type of calculation. You need to decide beforehand if a parameter in a column is a text or a number.

In the example above, when there is a missing data entry the “-“ has been used. This is not a number so it will create confusion in the database. In this case it would be better just to leave the cell blank, or to use a clearly defined “No data” value such as 99999.

<u>Database Rule 6: Do not sub-divide the Table</u>

In the example below the data table has been split into sections to summarize the average groundwater levels for each block in red. This is fine if we just want to print the database for inclusion as a table in the Annex of a report. However, for a database table which we want to be able to use in many different applications never add summary lines or extra titles within the table.
Add one more column near the beginning of the table. Include the data in the green row as a value which is repeated for every row to which this information applies.



STATIC WATER LEVELS OF PERMANENT OBSERVATION WELLS IN KHARGONE DISTRICT (WATER LEVEL BELOW GROUND LEVEL IN METRES)

S.No.	POW No.	BLOCK	VILLAGE					WATER LEVEL 2002				WATER LEVEL 2003			
				Latitude	Longitude	Total Depth	parape	JAN	Pre	AUG	Post	JAN	Pre	AUG	Post
1	2	3	4			5.00		6	7	8	9	10	11	12	13
1	SKGN-100-OW	Bhagwanpura	Sirvel Mahadev	21°27'10"	75°40'11"	11.80	0.50	2.35	4.55	1.65	1.35	2.55	4.48	0.80	1.00
2	SKGN-099-OW		Raisagar	21°31'43"	75°39'15"	12.30	1.20	6.60	7.25	5.58	6.50	6.45	6.92	3.60	3.68
3	SKGN-098-OW		Banhur	21°40'14"	75°40'12"	15.40	0.50	8.50	10.65	10.40	3.95	7.80	9.40	3.00	3.48
4	SKGN-097-OW		Salibadi	21°40'19"	75°38'17"	14.70	0.35	6.60	8.10	7.95	4.20	6.08	7.10	3.10	2.62
5	SKGN-096-OW		Bhagwanpura	21°37'34"	75°35'46"	11.70	0.95	7.12	8.82	7.05	5.87	6.05	8.90	3.40	5.58
	SKGN-152-OW		Banher	21°41'55"	75°42'07"	17.90	0.50								
6	SKGN-152A-OW		Banher	21°41'37"	75°42'23"	11.00	1.00								
7	SKGN-074-OW2016		Dewla	21°40'41"	75°43'40"	17.30	0.60								
8	SKGN-075-OW2016		Galtar	21°38'58"	75°44'52"	8.00	0.20								
9	SKGN-076-OW2016		Garhi	21°44'14"	75°48'00"	14.00	0.00								
10	SKGN-077-OW2016		Jallalabad (Mahadev Padawa)	21°40'55"	75°23'06"	15.50	0.50								
11	SKGN-078-OW2016		Mohana	21°41'57"	75°34'45"	6.10	0.70								
	SKGN-087-OW		Galtar[dhalkiya]	21°40'00"	75°49'15"	11.00		8.00	8.85	9.40	8.05	6.35	6.60	9.00	6.00
1	11	Bhagwanpura	Average					6.53	8.04	7.00	4.99	5.88	7.23	3.82	3.73
12	SKGN-102-OW	Segaon	Sangvi	21°44'43"	75°22'58"	9.00	0.25	4.62	7.00	5.20	0.85	1.55	3.25	0.76	0.70
13	SKGN-128-OW		Kelee	21°44'51"	75°20'35"	15.20	0.50	9.2	9.65	8.65	3.50	7.96	8.60	1.10	1.53
14	SKGN-045-OW		Sinkhedi	21°43'38"	75°25'02"	9.50	0.40	4.5	5.25	4.05	0.93	1.90	2.90	1.50	0.70
15	SKGN-046-OW		Dalki	21°43'41"	75°26'57"	7.00	0.65	5.9	6.30	4.86	0.86	1.65	4.55	0.95	1.00
16	SKGN-129-OW		Rasgaon	21°53'30"	75°21'02"	10.05	0.50	6.3	8.80	6.90	4.58	5.76	6.65	2.12	2.63
17	SKGN-047-OW		Birla Dhatapura	21°50'46"	75°21'53"	13.70	0.10	8.5	11.45	6.65	3.00	7.52	7.80	2.25	2.35
18	SKGN-044-OW		Talakpura	21°50'15"	75°23'46"	11.40	0.00	8.65	10.60	3.60	4.55	7.20	9.74	1.42	3.60
19	SKGN-015-OW2016		Achhalwadi	21°45'25"	75°17'32"	12.00	0.50								
20	SKGN-016-OW2016		Bhikarkhedi	21°50'24"	75°19'40"	11.05	0.80								
21	SKGN-017-OW2016		Kalampura(Segaon)	21°52'04"	75°18'33"	14.50	0.80								
	SKGN-043-OW		Rasgaon	21°53'48"	75°21'11"	7.70									
2	10	Segaon	Average					6.81	8.44	5.70	2.61	4.79	6.21	1.44	1.79

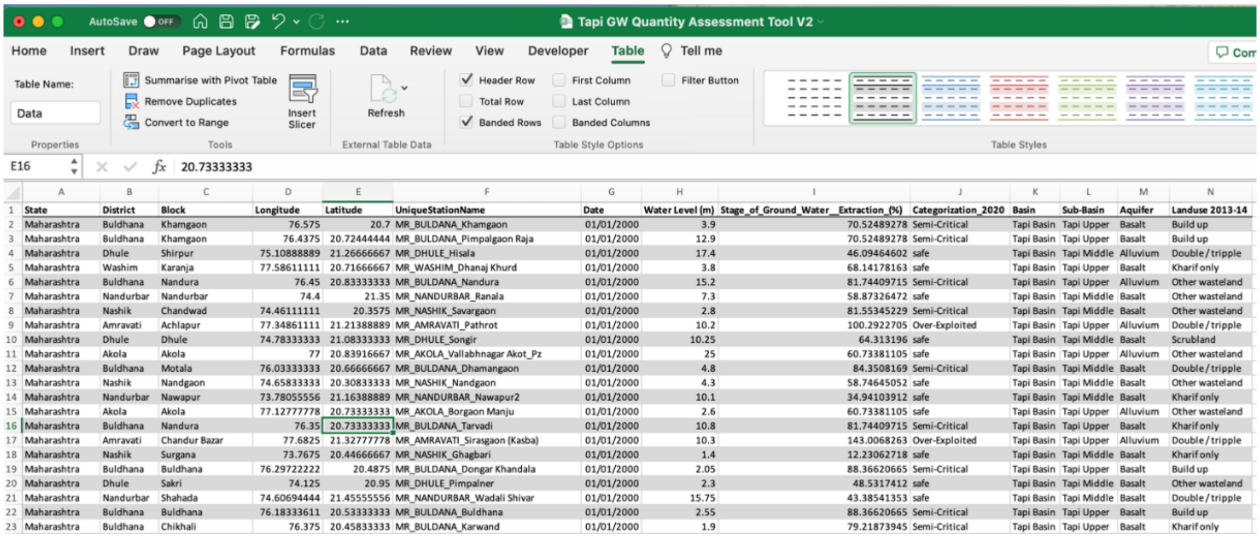
Figure 7: Example data table with sub-divisions

Database Rule 7: Use Format as Table

It is best to enter all the data in a table without any formatting, and then to format the entire table using **Format as Table**.

1. Start with a new Excel Sheet
2. Copy – paste special – values your data into a blank Excel sheet.
3. Some data such as dates may need to be formatted.
4. Select the data using CTRL-A
5. Home – Format as Table
6. Make sure that the My Table has headers option has been selected.
7. Go to Table Design & unselect the Filter Button.
8. In Formulas – Name manager chose "Edit" and give the table a sensible name.

In the final table we can see if everything is correctly formatted. All text values will align to the left and all number values (including dates) will align to the right.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	State	District	Block	Longitude	Latitude	UniqueStationName	Date	Water Level (m)	Stage_of_Ground_Water__Extraction_(%)	Categorization_2020	Basin	Sub-Basin	Aquifer	Landuse 2013-14
2	Maharashtra	Buldhana	Khamgaon	76.575	20.7	MR_BULDANA_Khamgaon	01/01/2000	3.9	70.52489278	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Build up
3	Maharashtra	Buldhana	Khamgaon	76.4375	20.72444444	MR_BULDANA_Pimpalgaon Raja	01/01/2000	12.9	70.52489278	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Build up
4	Maharashtra	Dhule	Shirpur	75.10888889	21.26666667	MR_DHULE_Hisala	01/01/2000	17.4	46.09464602	safe	Tapi Basin	Tapi Middle	Alluvium	Double / tripple
5	Maharashtra	Washim	Karanja	77.58611111	20.71666667	MR_WASHIM_Dhanaj Khurd	01/01/2000	3.8	68.14178163	safe	Tapi Basin	Tapi Upper	Basalt	Kharif only
6	Maharashtra	Buldhana	Nandura	76.45	20.83333333	MR_BULDANA_Nandura	01/01/2000	15.2	81.74409715	Semi-Critical	Tapi Basin	Tapi Upper	Alluvium	Other wasteland
7	Maharashtra	Nandurbar	Nandurbar	74.4	21.35	MR_NANDURBAR_Ranala	01/01/2000	7.3	58.87326472	safe	Tapi Basin	Tapi Middle	Basalt	Other wasteland
8	Maharashtra	Nashik	Chandwad	74.46111111	20.3575	MR_NASHIK_Savargaon	01/01/2000	2.8	81.55345229	Semi-Critical	Tapi Basin	Tapi Middle	Basalt	Other wasteland
9	Maharashtra	Amravati	Achlapur	77.34861111	21.21388889	MR_AMRAVATI_Pathrot	01/01/2000	10.2	100.2922705	Over-Exploited	Tapi Basin	Tapi Upper	Alluvium	Double / tripple
10	Maharashtra	Dhule	Dhule	74.78333333	21.08333333	MR_DHULE_Songir	01/01/2000	10.25	64.313196	safe	Tapi Basin	Tapi Middle	Basalt	Scrubland
11	Maharashtra	Akola	Akola	77	20.83916667	MR_AKOLA_Vallabhnagar Akot_Pz	01/01/2000	25	60.73381105	safe	Tapi Basin	Tapi Upper	Alluvium	Other wasteland
12	Maharashtra	Buldhana	Motala	76.03333333	20.66666667	MR_BULDANA_Dhamangaon	01/01/2000	4.8	84.3508169	Semi-Critical	Tapi Basin	Tapi Middle	Basalt	Double / tripple
13	Maharashtra	Nashik	Nandgaon	74.65833333	20.30833333	MR_NASHIK_Nandgaon	01/01/2000	4.3	58.74645052	safe	Tapi Basin	Tapi Middle	Basalt	Other wasteland
14	Maharashtra	Nandurbar	Nawapur	73.78055556	21.16388889	MR_NANDURBAR_Nawapur2	01/01/2000	10.1	34.94103912	safe	Tapi Basin	Tapi Middle	Basalt	Kharif only
15	Maharashtra	Akola	Akola	77.12777778	20.73333333	MR_AKOLA_Borgaon Manju	01/01/2000	2.6	60.73381105	safe	Tapi Basin	Tapi Upper	Alluvium	Other wasteland
16	Maharashtra	Buldhana	Nandura	76.35	20.73333333	MR_BULDANA_Tarvadi	01/01/2000	10.8	81.74409715	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Kharif only
17	Maharashtra	Amravati	Chandur Bazar	77.6825	21.32777778	MR_AMRAVATI_Sirasgaon (Kasba)	01/01/2000	10.3	143.0068263	Over-Exploited	Tapi Basin	Tapi Upper	Alluvium	Double / tripple
18	Maharashtra	Nashik	Surgana	73.7675	20.44666667	MR_NASHIK_Ghagbari	01/01/2000	1.4	12.23062718	safe	Tapi Basin	Tapi Middle	Basalt	Kharif only
19	Maharashtra	Buldhana	Buldhana	76.29722222	20.4875	MR_BULDANA_Dongar Khandala	01/01/2000	2.05	88.36620665	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Build up
20	Maharashtra	Dhule	Sakri	74.125	20.95	MR_DHULE_Pimpalner	01/01/2000	2.3	48.5317412	safe	Tapi Basin	Tapi Middle	Basalt	Other wasteland
21	Maharashtra	Nandurbar	Shahada	74.60694444	21.45555556	MR_NANDURBAR_Wadali Shivar	01/01/2000	15.75	43.38541353	safe	Tapi Basin	Tapi Middle	Basalt	Double / tripple
22	Maharashtra	Buldhana	Buldhana	76.18333611	20.53333333	MR_BULDANA_Buldhana	01/01/2000	2.55	88.36620665	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Build up
23	Maharashtra	Buldhana	Chikhali	76.375	20.45833333	MR_BULDANA_Karwand	01/01/2000	1.9	79.21873945	Semi-Critical	Tapi Basin	Tapi Upper	Basalt	Kharif only

Figure 8: Example data table in Excel formatted as Table

Online MS Excel Training

For some useful tips & tricks on how to use Excel as a tool for Water Resources Management, please have a look at this playlist on YouTube:

https://www.youtube.com/playlist?list=PLp1lK6n-xb5M2mdIgqXf2hr2pNMMy-eWf

One of the videos shows you how to calculate the Season and the Water Year (Hydrological Year) in Excel from any date, using the **Month(), Year(), Lookup(),** and **IF** functions. The CHIRPS daily precipitation data from the last 40 years was downloaded for the Tapi River Basin. The seasonal and annual precipitation is displayed using Excel tables, PivotTables, and Pivot Charts to show you that the monsoon rainfall has been increasing steadily over the past 40 years in the Tapi.

YouTube Video: Excel: How to calculate the Seasons & the Water Year: https://youtu.be/KdPht_4F-M0

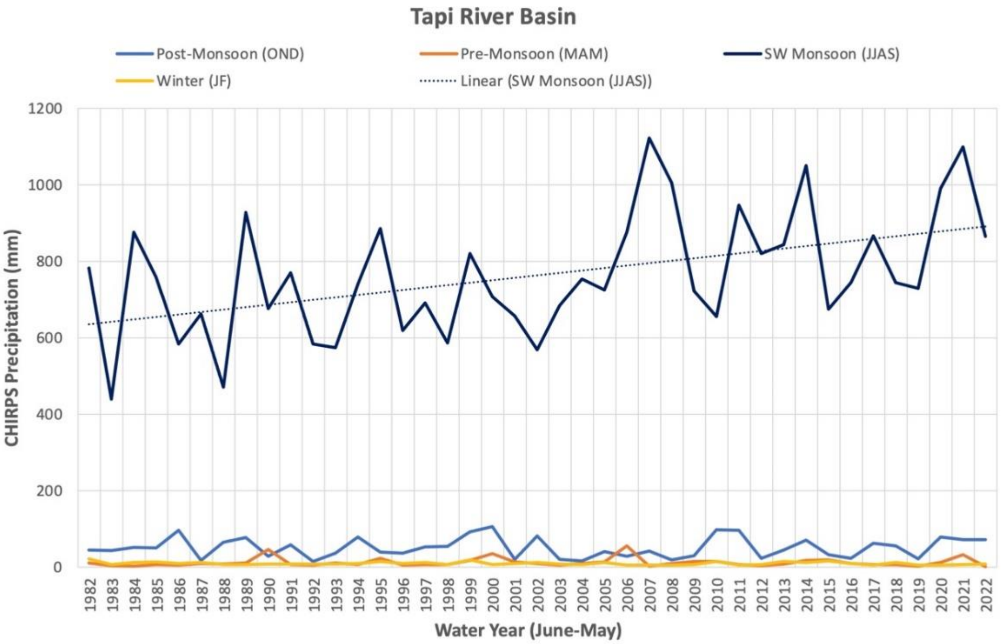
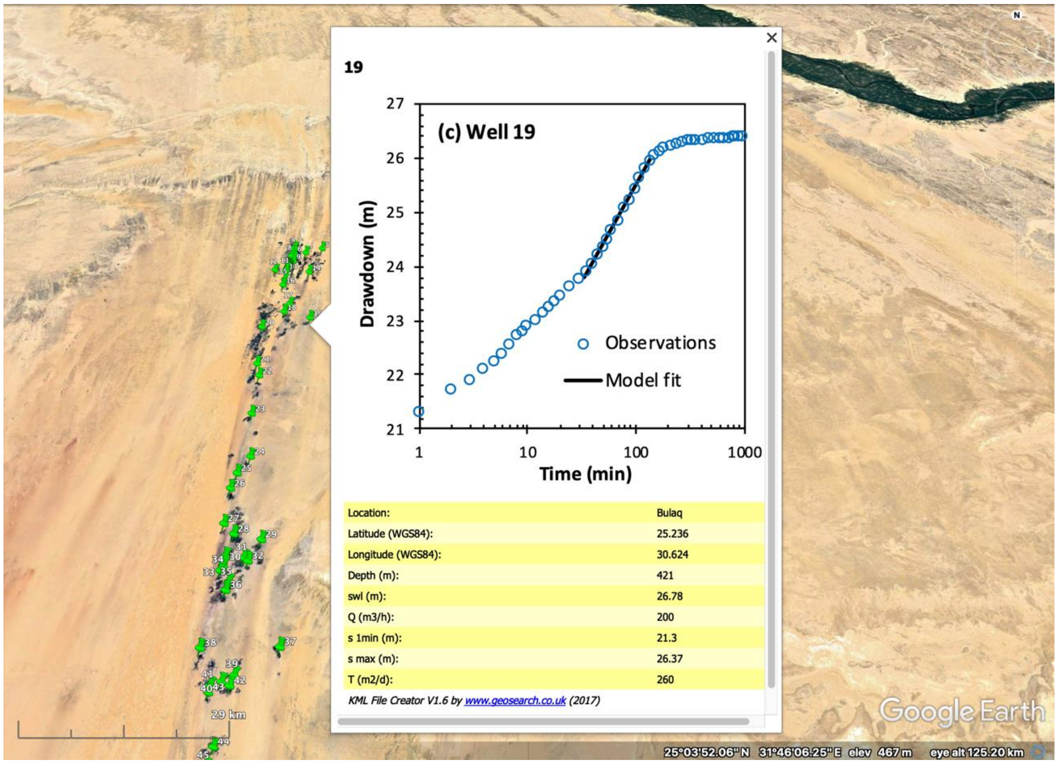


Figure 9: Seasonal changes in precipitation over the Tapi River Basin

Key Skills – Google Earth

Google Earth is one of the most simple and powerful tools available for quickly getting an overview of a River Basin. It is much faster and lighter on computer resources than most GIS programs, and easy to use.

One of the first things you can do is to export a few locations of interest to Google Earth. All you need for this is an Excel tool called the **KML File Creator** where you list the coordinates of the locations (in WGS84 datum as decimal degrees), and up to 15 parameters which describe this location. The KML File Creator will calculate a KML file of this information, which will open in Google Earth showing a pin and a pop-up data table at each location. You can even link the location to a picture.



Location:	Bulaq
Latitude (WGS84):	25.236
Longitude (WGS84):	30.624
Depth (m):	421
swl (m):	26.78
Q (m3/h):	200
s 1min (m):	21.3
s max (m):	26.37
T (m2/d):	260

KML File Creator V1.6 by www.geosearch.co.uk (2017)

Figure 10: Google Earth File Creator Tool

For full instructions on how to do this please have a look at this YouTube Video: https://youtu.be/4SKMB3v90tE

Link to KML File Creator V2.0: https://bit.ly/37MuD5i

Key Skills – Choice of colours for the legends of maps

The colours which you use for a map or illustration are important, and you should never choose them randomly. It is advisable to only use palettes from your GIS program, for example in QGIS the best one is cpt-city with currently 590 ramps available. You can access them via: **Symbology – Color Ramp – Create New Color Ramp - Catalog: cpt-city**

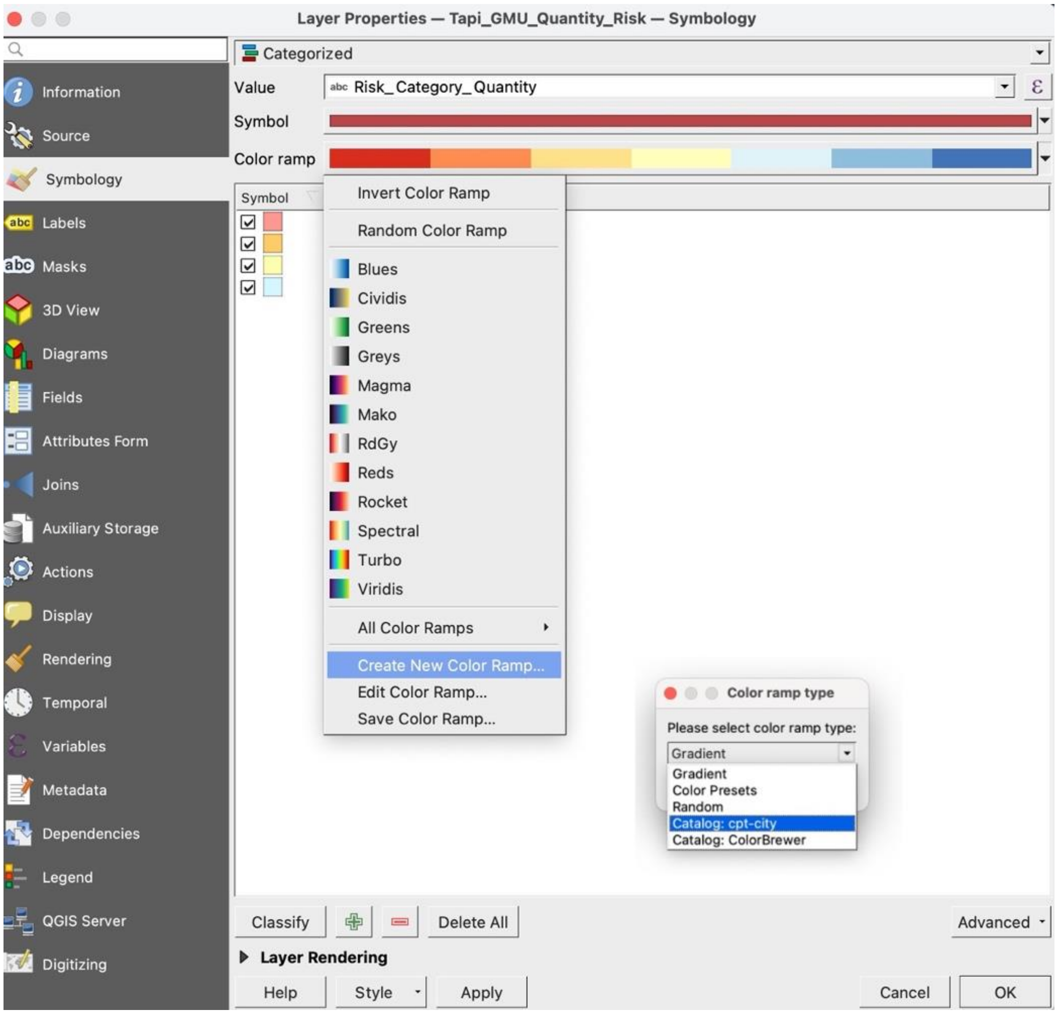


Figure 11: QGIS Colour ramps

You can also have a look at ColorBrewer 2.0: https://colorbrewer2.org/

Develop a conceptual model of the Basin Hydrogeology

The first thing you need to do before any type of analysis is to collect all available data and process it in such a way that you can use it to develop a conceptual model of the River Basin. These include:

- All available GIS layers especially:
    - Geology
    - Structural geology (faults, lineations etc.)
    - Soils
    - Digital Elevation Model (DEM)
    - Hydrology (precipitation, rivers, streams, reservoirs, lakes etc.)
    - Land Use Land Cover (LULC)
- CGWB annual groundwater resources assessment at Taluka & geology level.
- Groundwater levels from India WRIS & States
- Groundwater quality analysis from India WRIS & States
- State and National level reports, plans and strategies

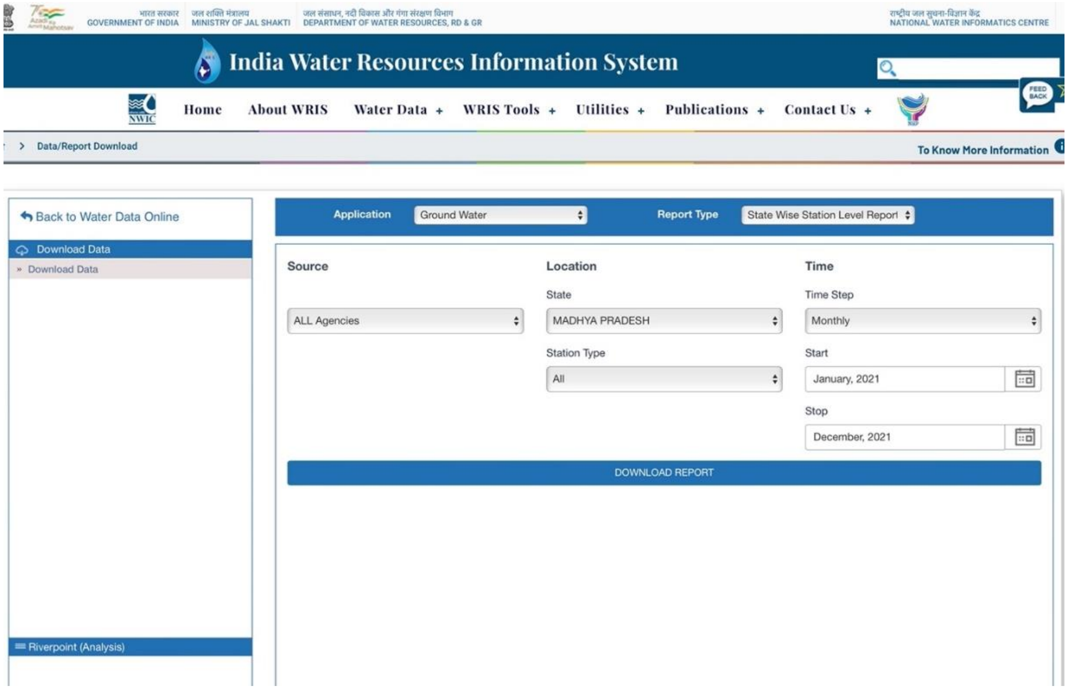
Most of the above data is self-explanatory. Where additional understanding and processing is required, this is explained in the following sections.

Download Water Level Data from India WRIS

The first step is to obtain the groundwater level data from the India WRIS at this web address:

https://indiawris.gov.in/wris/#/DataDownload

You can download all stations (wells) water level data for each State, but only one year at a time. Select all parameters as per the screenshot below.



Application: Ground Water
Report Type: State Wise Station Level Report
Source: ALL Agencies
Location
State: MADHYA PRADESH
Station Type: All
Time
Time Step: Monthly
Start: January, 2021
Stop: December, 2021

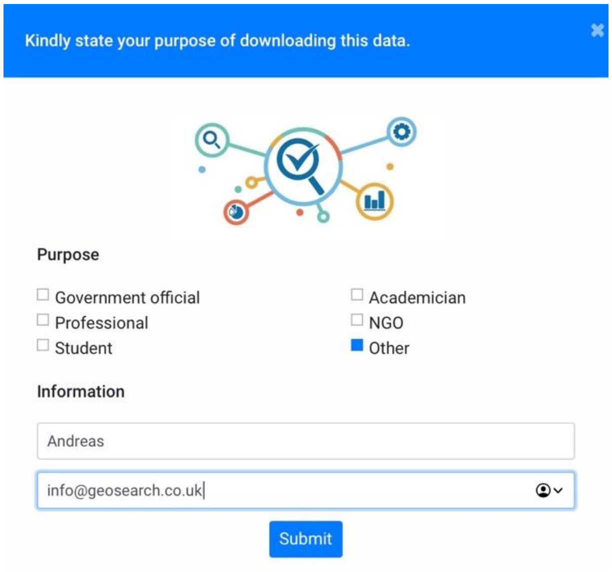
Figure 12: India WRIS Groundwater data portal

Note that we only need a monthly time-step as there are only 4 readings taken per year.
The settings are as follows:

- Application: Ground Water
- Report Type: State Wise Station level Report
- Source: All Agencies
- State: Name of the state
- Station Type: All
- Time Step: Monthly
- Start: January, YEAR
- Stop: December, YEAR

Click on **DOWNLOAD REPORT**

You will need to identify yourself. If necessary, click again on **DOWNLOAD REPORT.**



Kindly state your purpose of downloading this data.

Purpose

☐ Government official
☐ Professional
☐ Student
☐ Academician
☐ NGO
☑ Other

Information

Andreas

info@geosearch.co.uk

Figure 13: WRIS identification

The data will be downloaded in MS Excel format with a filename such as
groundwater_State Wise Station Level Report_1685439136329.xls

Rename the downloaded file & store it in your data folder. **Use consistent file names.** For example:
2000 Madhya Pradesh Monthly GW Levels.xls

Select the next year and download that year. You should get all years from 2000 to present. If you have time also get years before 2000.

You should end up with a Folder with one *.xls file for each year. For example
2000 Madhya Pradesh Monthly GW Levels.xls
2001 Madhya Pradesh Monthly GW Levels.xls

2002 Madhya Pradesh Monthly GW Levels.xls

Set up groundwater level databases in MS Excel

We have discussed the rules for databases earlier, and you will need to apply these rigorously to make a data table which can be used either in Excel or elsewhere. There are two options: (i) copy paste the data into the correct format, or (ii) use Excel to do it automatically. Here we will show you how to use the second and much faster option.

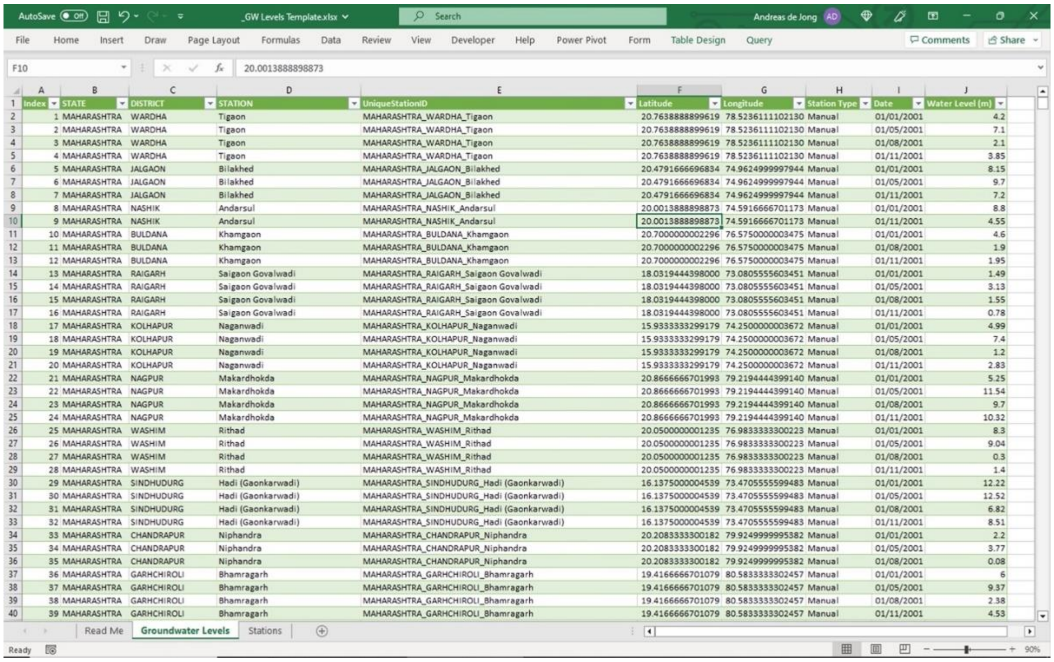
Step 01: Download the Excel Template

Download a copy of _India WRIS GW Levels Template.xlsx from: https://bit.ly/3C2OrjX

Step 02: Update the data link & load all the data into a data table

1. When you open the file, Enable External data connections.
2. Make the file a trusted document.
3. Data - Get Data - Data Source Settings…
4. Select Change Source…
5. Select Browse…
6. Select the folder where you have all the annual groundwater level measurements *.xls files.
7. Select Data - Refresh All
8. Go to Stations & Right Click & refresh the Pivot Table

All the data from the different annual files should now be ingested into the data table. Should you get an error, make sure that all the files in the folder are in the correct format & that there are no hidden files.



Index	STATE	DISTRICT	STATION	UniqueStationID	Latitude	Longitude	Station Type	Date	Water Level (m)
1	MAHARASHTRA	WARDHA	Tigaon	MAHARASHTRA_WARDHA_Tigaon	20.7638888899619	78.5236111102130	Manual	01/01/2001	4.2
2	MAHARASHTRA	WARDHA	Tigaon	MAHARASHTRA_WARDHA_Tigaon	20.7638888899619	78.5236111102130	Manual	01/05/2001	7.1
3	MAHARASHTRA	WARDHA	Tigaon	MAHARASHTRA_WARDHA_Tigaon	20.7638888899619	78.5236111102130	Manual	01/08/2001	2.1
4	MAHARASHTRA	WARDHA	Tigaon	MAHARASHTRA_WARDHA_Tigaon	20.7638888899619	78.5236111102130	Manual	01/11/2001	3.85
5	MAHARASHTRA	JALGAON	Bilakhed	MAHARASHTRA_JALGAON_Bilakhed	20.4791666696834	74.9624999997944	Manual	01/01/2001	8.15
6	MAHARASHTRA	JALGAON	Bilakhed	MAHARASHTRA_JALGAON_Bilakhed	20.4791666696834	74.9624999997944	Manual	01/05/2001	9.7
7	MAHARASHTRA	JALGAON	Bilakhed	MAHARASHTRA_JALGAON_Bilakhed	20.4791666696834	74.9624999997944	Manual	01/11/2001	7.2
8	MAHARASHTRA	NASHIK	Andarsul	MAHARASHTRA_NASHIK_Andarsul	20.0013888898873	74.5916666701173	Manual	01/01/2001	8.8
9	MAHARASHTRA	NASHIK	Andarsul	MAHARASHTRA_NASHIK_Andarsul	20.0013888898873	74.5916666701173	Manual	01/11/2001	4.55
10	MAHARASHTRA	BULDANA	Khamgaon	MAHARASHTRA_BULDANA_Khamgaon	20.7000000002296	76.5750000003475	Manual	01/01/2001	4.6
11	MAHARASHTRA	BULDANA	Khamgaon	MAHARASHTRA_BULDANA_Khamgaon	20.7000000002296	76.5750000003475	Manual	01/08/2001	1.9
12	MAHARASHTRA	BULDANA	Khamgaon	MAHARASHTRA_BULDANA_Khamgaon	20.7000000002296	76.5750000003475	Manual	01/11/2001	1.95
13	MAHARASHTRA	RAIGARH	Saigaon Govalwadi	MAHARASHTRA_RAIGARH_Saigaon Govalwadi	18.0319444398000	73.0805555603451	Manual	01/01/2001	1.49
14	MAHARASHTRA	RAIGARH	Saigaon Govalwadi	MAHARASHTRA_RAIGARH_Saigaon Govalwadi	18.0319444398000	73.0805555603451	Manual	01/05/2001	3.13
15	MAHARASHTRA	RAIGARH	Saigaon Govalwadi	MAHARASHTRA_RAIGARH_Saigaon Govalwadi	18.0319444398000	73.0805555603451	Manual	01/08/2001	1.55
16	MAHARASHTRA	RAIGARH	Saigaon Govalwadi	MAHARASHTRA_RAIGARH_Saigaon Govalwadi	18.0319444398000	73.0805555603451	Manual	01/11/2001	0.78
17	MAHARASHTRA	KOLHAPUR	Naganwadi	MAHARASHTRA_KOLHAPUR_Naganwadi	15.9333333299179	74.2500000003672	Manual	01/01/2001	4.99
18	MAHARASHTRA	KOLHAPUR	Naganwadi	MAHARASHTRA_KOLHAPUR_Naganwadi	15.9333333299179	74.2500000003672	Manual	01/05/2001	7.4
19	MAHARASHTRA	KOLHAPUR	Naganwadi	MAHARASHTRA_KOLHAPUR_Naganwadi	15.9333333299179	74.2500000003672	Manual	01/08/2001	1.2
20	MAHARASHTRA	KOLHAPUR	Naganwadi	MAHARASHTRA_KOLHAPUR_Naganwadi	15.9333333299179	74.2500000003672	Manual	01/11/2001	2.83
21	MAHARASHTRA	NAGPUR	Makardhokda	MAHARASHTRA_NAGPUR_Makardhokda	20.8666666701993	79.2194444399140	Manual	01/01/2001	5.25
22	MAHARASHTRA	NAGPUR	Makardhokda	MAHARASHTRA_NAGPUR_Makardhokda	20.8666666701993	79.2194444399140	Manual	01/05/2001	11.54
23	MAHARASHTRA	NAGPUR	Makardhokda	MAHARASHTRA_NAGPUR_Makardhokda	20.8666666701993	79.2194444399140	Manual	01/08/2001	9.7
24	MAHARASHTRA	NAGPUR	Makardhokda	MAHARASHTRA_NAGPUR_Makardhokda	20.8666666701993	79.2194444399140	Manual	01/11/2001	10.32
25	MAHARASHTRA	WASHIM	Rithad	MAHARASHTRA_WASHIM_Rithad	20.0500000001235	76.9833333300223	Manual	01/01/2001	8.3
26	MAHARASHTRA	WASHIM	Rithad	MAHARASHTRA_WASHIM_Rithad	20.0500000001235	76.9833333300223	Manual	01/05/2001	9.04
27	MAHARASHTRA	WASHIM	Rithad	MAHARASHTRA_WASHIM_Rithad	20.0500000001235	76.9833333300223	Manual	01/08/2001	0.3
28	MAHARASHTRA	WASHIM	Rithad	MAHARASHTRA_WASHIM_Rithad	20.0500000001235	76.9833333300223	Manual	01/11/2001	1.4
29	MAHARASHTRA	SINDHUDURG	Hadi (Gaonkarwadi)	MAHARASHTRA_SINDHUDURG_Hadi (Gaonkarwadi)	16.1375000004539	73.4705555599483	Manual	01/01/2001	12.22
30	MAHARASHTRA	SINDHUDURG	Hadi (Gaonkarwadi)	MAHARASHTRA_SINDHUDURG_Hadi (Gaonkarwadi)	16.1375000004539	73.4705555599483	Manual	01/05/2001	12.52
31	MAHARASHTRA	SINDHUDURG	Hadi (Gaonkarwadi)	MAHARASHTRA_SINDHUDURG_Hadi (Gaonkarwadi)	16.1375000004539	73.4705555599483	Manual	01/08/2001	6.82
32	MAHARASHTRA	SINDHUDURG	Hadi (Gaonkarwadi)	MAHARASHTRA_SINDHUDURG_Hadi (Gaonkarwadi)	16.1375000004539	73.4705555599483	Manual	01/11/2001	8.51
33	MAHARASHTRA	CHANDRAPUR	Niphandra	MAHARASHTRA_CHANDRAPUR_Niphandra	20.2083333300182	79.9249999995382	Manual	01/01/2001	2.2
34	MAHARASHTRA	CHANDRAPUR	Niphandra	MAHARASHTRA_CHANDRAPUR_Niphandra	20.2083333300182	79.9249999995382	Manual	01/05/2001	3.77
35	MAHARASHTRA	CHANDRAPUR	Niphandra	MAHARASHTRA_CHANDRAPUR_Niphandra	20.2083333300182	79.9249999995382	Manual	01/08/2001	0.08
36	MAHARASHTRA	GARHCHIROLI	Bhamragarh	MAHARASHTRA_GARHCHIROLI_Bhamragarh	19.4166666701079	80.5833333302457	Manual	01/01/2001	6
37	MAHARASHTRA	GARHCHIROLI	Bhamragarh	MAHARASHTRA_GARHCHIROLI_Bhamragarh	19.4166666701079	80.5833333302457	Manual	01/05/2001	9.37
38	MAHARASHTRA	GARHCHIROLI	Bhamragarh	MAHARASHTRA_GARHCHIROLI_Bhamragarh	19.4166666701079	80.5833333302457	Manual	01/08/2001	2.38
39	MAHARASHTRA	GARHCHIROLI	Bhamragarh	MAHARASHTRA_GARHCHIROLI_Bhamragarh	19.4166666701079	80.5833333302457	Manual	01/11/2001	4.53

Figure 14: Processed WRIS Groundwater level data

You should end up with an updated table with the following columns:

- Index
- State
- District
- Station
- UniqueStationID (STATE_DISTRICT_STATION)
- Latitude
- Longitude
- Station Type
- Date
- Water Level (m)

Download Groundwater Quality Data from India WRIS

The first step is to obtain the groundwater quality data from the India WRIS at this web address:

https://indiawris.gov.in/wris/#/DataDownload

You can download all stations (wells) water level data for each State, but only one year at a time. Select all parameters as per the screenshot below.

Data analysis using Pivot Tables & Pivot Charts

The key steps are as follows:

- Merge all the data tables from the different states.
- Import the data table into QGIS. For the methodology see this YouTube Video:
  QGIS 101: How to import Excel Data (No CSV files): https://youtu.be/OE4IcagdIos
- Select all the wells which fall inside the Tapi River basin
- Export the selected well data to Excel XLSX file.
- In Excel - Format as Table
- Rename the Table
- Insert Pivot Table/Pivot Charts
- Create Cutters
- Create a dashboard

Interpolation of groundwater levels & determination of groundwater flow directions

Contouring groundwater level data is difficult in most GIS software packages, including QGIS, as many interpolation techniques produce results which are very different from what we would get from a manual interpretation. For example, the IDW or TIN interpolation result in many “bull’s eyes”.

We need a technique which will fit a smooth surface through all the groundwater level elevations. For this the SAGA Thin Plate Spline (TPS) can produce some excellent results. The Thin Plate Spline method produces a smooth, 3D surface which passes through all the data points. Think of this surface like a flexible metal sheet which has been warped in many directions so that it best fits the observed points. In addition, groundwater flow direction arrows can be added perpendicular to the contour lines to aid in the interpretation.

The Tapi basin groundwater level dataset for May 2019 has been interpolated in QGIS using the Thin Plate Spline Interpolation tool. This is explained in a YouTube video & an accompanying manual.

YouTube Video: https://youtu.be/Ib8MQ68xemY
Manual: https://bit.ly/3ghPUeI

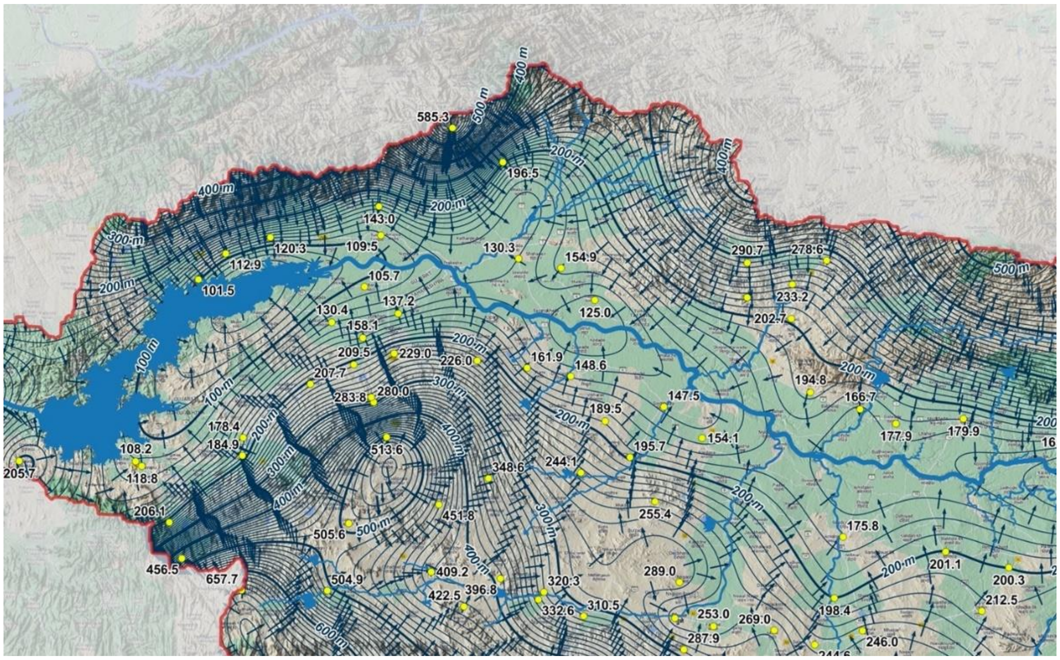


Figure 15: SAGA Thin Plate Spline Interpolation of water levels

Delineation of Groundwater Management Units (GMU)

Purpose of the Groundwater Management Unit (GMU)

The primary purpose of the GMU, as the name implies is to manage the groundwater. This means that GMUs are a management tool which should facilitate the decision-making process. A key consideration is therefore that each GMU should be an aquifer or group of aquifers which share similar properties in terms of well yields or water quality, so that they can be managed as a single unit. i.e., specific interventions or Programme of Measures (PoMs) can be identified for each GMU. *The international best practise is to divide the river basin into GMUs which are based on aquifers rather than administrative units.*

Delineation of Groundwater Management Units (GMUs)

In the Tapi Basin separate GMUs were identified for:

- a high yielding alluvial aquifer with a lot of agriculture & important groundwater-surface water interactions
- a basalt aquifer in a hilly area with little agriculture
- a basalt aquifer with a lot of agriculture
- a coastal aquifer with saline intrusion risks

The GMUs were developed in a workshop by hydrogeologists familiar with the Tapi Basin. The agreed GMU boundaries were then drawn digitally in a GIS, based on the following principles:

- The GMU boundaries are based on geological boundaries from the geological SHP files provided by the CGWB.

- Where a geological unit needs to be subdivided, where possible this division was based on Taluka boundaries to facilitate administration issues for groundwater management.

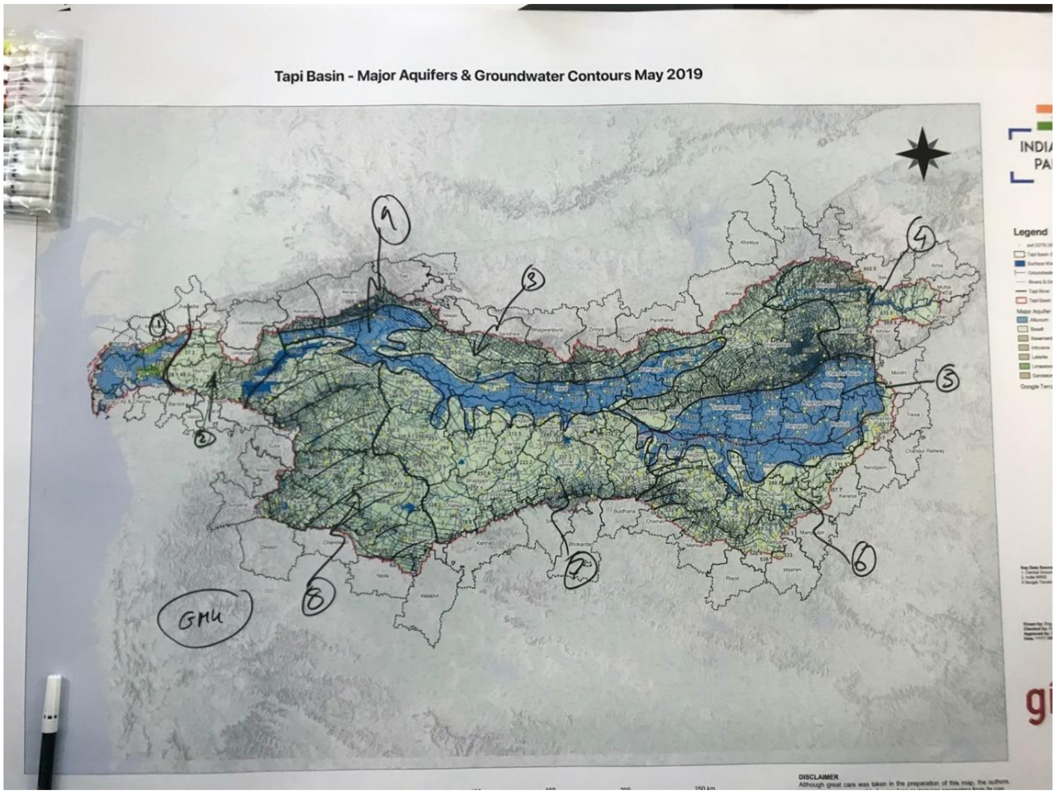


Figure 16: Manual delineation of GMUs

5.2.3 River morphology & Sediment Transport

For a sound analysis of river morphology and sediment transport in any river basin, besides the data on surface water quantity (see section 6.2.5) the following data is needed:

- Grain sizes: D10, D35, D50, D65, D90. Grain diameters determine sediment transport, bed roughness and other parameters. Grain sizes differ along the river. Upstream is mostly coarse material available, grain diameters gradually decrease downstream. However local features may affect the grain diameters. The morphological conditions along the river should be known, to represent hydraulic and morphological parameters well. In general grain diameters are sampled over the cross-section (e.g. 5 samples) every 500 m river's length. As the riverbed properties only slowly changes, the frequency of bed sampling is very low, 20 to 30 years. Grain diameter information is also important for sand mining operations. The required sediment properties for morphological modelling depend on the model concept used.
- Bed load and suspended load sediment transports. The available sediment loads are known for about 20 years at four stations. Probably these loads have been determined by turbidity measurements, which means that predominantly suspended sediment transport is measured. In general the sediment transport measuring methods used in the Tapi River are not known, the

same holds for the devices used, methodology, frequency. Sediment transports should also be measured at bifurcations and confluences.

- Presence of ripples and dunes on the riverbed. They largely influence the hydraulic roughness of the main channel. Regular soundings can illustrate these bed forms. Frequent (monthly) soundings during some years may show a regular pattern of bed forms related to the discharge regime and related to certain river reaches. Once a relation is established the soundings may be restricted to monsoon and non-monsoon periods.
- The upstream boundary of a morphological model is the sediment load influx going with the discharge. This boundary should be chosen at a certain distance upstream of the area of interest, as an error in the estimated sediment transport is translated in errors in the computed bed level, that will propagate downstream with a celerity of the so-called morphological timescale. For the Rhine River this timescale is about 2 km/year. In the case of the Tapi River that celerity probably will be higher due to the expected fine sands.
- The sediment influx at the upstream boundary sometimes can be derived implicitly from the morphological evolution at the upstream boundary.
- In the calibration process of morphological models the above sediment parameters can be changed.
- The calibration targets are the measured bed level changes and measured sediment transport rates.

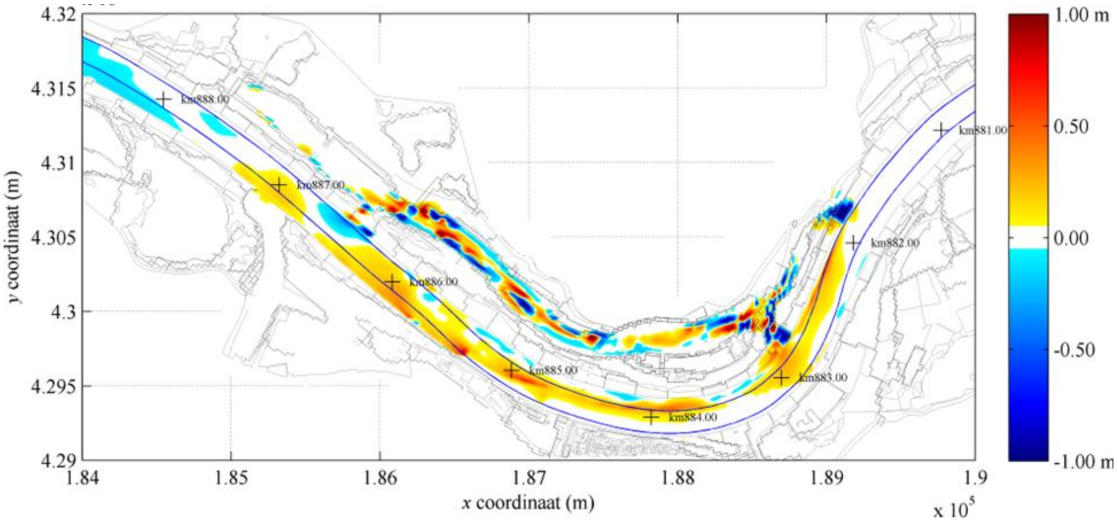


Figure 17 2D-morphological model result: erosion and sedimentation caused by new flood channel in Waal River bend at Nijmegen, The Netherlands.

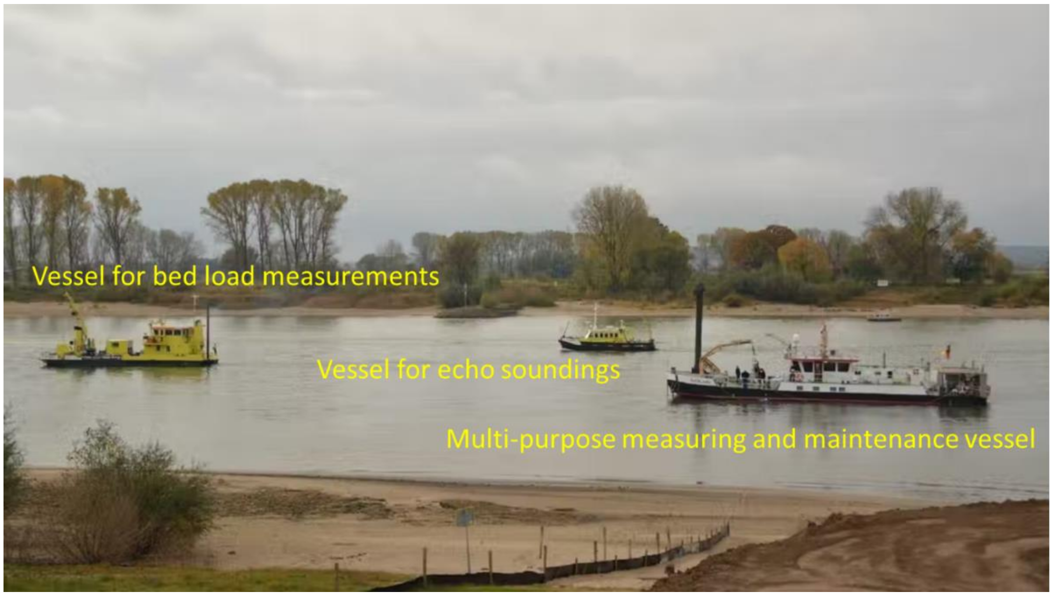


Figure 18 Boats equipped with equipment for measuring sediment transport, soundings and tools for regular maintenance work (Rhine River at Lobith, border between Germany and The Netherlands).

5.2.4 Formats for data collection

Based on the above sections on data collection of monitoring data to be used in the assessment the datasets and details per dataset are summarized in Table 3.

Table 3 Overview of essential monitoring data to be used in RBM risk assessment.

Datasets	**Location**	**Frequency**	**Purpose**
Rainfall-Runoff	Catchment of tributaries. Upstream reservoirs Downstream reservoirs	Daily	General
Stage-Discharge (Q/h) relations	Various stations (every 10 km), at bifurcations, inlets, outlets	Daily read. Yearly check.	General
Discharge-velocity (Q/u) relations	Various stations (every 10 km), at bifurcations, inlets, outlets	2-3 yearly	Models
Cross-sections	1-10km	Yearly	General, models
Longitudinal bed levels	5 to 10 longitudinal soundings (or combined measured)	Yearly	General, models
Planform	Main channel and floodplain	2-3 yearly	General, models
Hydraulic roughness of elements	Summer dikes, lakes, side channels, weirs, buildings, vegetation	2-3 yearly	Models
Hydraulic roughness of the river bed	5-10 km, through ripples and dunes	First years monthly, then yearly	Models

Rating curve at downstream boundary	Downstream boundary	Yearly	Models
Grain diameters	Every 500m, 5 samples	20-30 year	Models
Sediment transports	At bifurcations and confluences	Yearly, pre- and post-monsoon	General, models
Sediment transport-discharge (S/Q) relation at upstream boundary.	Upstream boundary	Yearly	Models

5.3 How to overcome challenges in monitoring (data gaps and accessibility)

5.3.1 Surface water quantity

Surface water: one of the biggest challenges in obtaining data pertaining to surface hydrology of river basins is to obtain precision data on river discharge and stream flows. The river discharge can keep fluctuating not only between seasons but also within the same day, especially during the monsoon months. For river basins that are very heterogeneous, the number of stations required for hydrological monitoring will be large if we have to obtain a comprehensive understanding of the basin. The traditional approach followed to measure the discharge was to use the velocity-area method wherein the gauges are used to measure the water levels at certain sections of the rivers and the same multiplied by the flow velocity arrived at on the basis of the ‘rating curve’ obtained for the same river cross section, which provides the velocities and discharges at different values of water levels. This method posed many challenges during flooding seasons. The data on stream flows, flow rates and water levels at different points in the rivers and their tributaries can be monitored on real time basis using telemetric station thereby avoiding the difficulty of physically accessing remote, often difficult to access, locations in the river basin.

5.3.2 Surface water quality

As the surface water quality monitoring network does not fully cover all SWBs in the Tapi river basin in a representative way and as the extent of indicators covered is also rather limited in relation to the potential anthropogenic pressures, it was decided to base the initial steps of the analysis on point pollution load estimates from urban and industry.

The available monitoring data could be better verified with more information on the reliability of the cycle of monitory stations through sampling / analyses.

Detailed pesticide concentration monitoring will be needed to assess (regularly) the level of pollution in water bodies (surface waters -rivers, ponds - and ground-water). Until this is in place, the average quantities of fertilizer and manure per crop can be calculated as averages across the states, which yet again makes it impossible to highlight the disparities between talukas.

Along these lines, initiatives to install real time online monitoring stations at crucial locations up- and downstream in the Tapi basin is a positive development.

5.3.3 Groundwater quantity & quality

The India WRIS database does not include the state groundwater monitoring well data, so additional databases were set up for the state groundwater level data.

Current water quality monitoring does not include important indicators such as pesticides, which should be addressed in the future.

Groundwater quality data downloaded from the India WRIS website from the last 20 years showed that at some locations, the NO3 levels were fluctuating in synchrony with each other, although this was not reflected in a similar fluctuation in the electrical conductivity (EC). This indicated that there could be either an analytical issue in the laboratory, or transcription error in the water quality database. It was agreed to screen all analysis and only use the data where the ion balance error between anion and cations was <5%. Ion balances will also be included in future versions of the groundwater quality database.

Along these lines, a project is currently underway to implement better monitoring system in 14,000 monitoring wells in India. Of these 5,000 are existing wells and 9,000 will be newly drilled.

5.3.4 River morphology & Sediment

Monitoring information can be gathered through surveys and by regular inspections. The surveys concern data of the hydrology, sediments, bathymetry and planform, to define changes in the river's appearance and to enable predictions of future developments (analytically or by models). Regular inspections can be best be organized by regional offices ("districts") that can also do the surveys. Districts can take care of regular surveys and inspection of the wet infrastructure regarding maintenance, stability and safety. To do so sufficient equipment is required, e.g. vessels/patrol boats, drones, measuring devices, maintenance crews) and personnel (staff, engineers, assistants).

5.4 Inter-state monitoring and sharing/coordination

For inter-state river basins, there are issues involved in the sharing of surface water between states, especially when water is scarce in the river basin (with demand exceeding the available supplies). For many river basins, conflicts already exist over the sharing of water and there are legal disputes. In many basins (Mahadayi, Krishna, Mahanadi, Ravi-Bras and Vansadhara), tribunals have already been set up for adjudicating the disputes over the sharing of water amongst states under the Inter-state Water Disputes Act 1956. For some basins (Godavari, Cauvery, Narmada and Indus), tribunals have already awarded the 'water share', and such awards have been honoured by the party states (or countries) in all except one case. In order to avoid conflicts over water sharing, data on water resource development (capacity of reservoirs, diversion systems built) and water use and reuse need to be shared between the basin-states on a real time basis to avoid violation of rights obtained through adjudication. For this, it is necessary to have an independent agency monitoring impoundment and diversion of water from the rivers and release of water from the reservoirs by the party states. Such monitoring should ideally cover even the small water harvesting structures if there are many such structures being built in the upper catchments. Further, gauging stations can be established in the rivers at or near the inter-state borders to make sure that the agreements of water sharing are honoured by the upper riparian state.

With planned maintenance it is important to know exactly what has to be managed, with good archiving of measurement data, drawings and calculations. It is also important to know and judge the state of the areal: the current quality level compared to the nationally prescribed level. Nationally, there will have to be uniformity of data and data storage. Means for this are GIS and the management plans. GIS contains an unambiguous description of the location, shape and dimensions of the TAPI RBC areal and its subdivision into management objects.

A mobile workplace is set up to carry out inspections, survey damage and incidents: patrol boats and maintenance vessels; a PC tablet equipped with positioning device connected to a central computer for data storage and processing. Management registers and files are created by linking to a (central-) GIS.

6 Basin Risk Assessment

- ***Defining the impact of the drivers and pressures on the water system.***

6.1 Defining the impact of the drivers and pressures on the water system

*See **Annex 2** – Training Module on (i) Surface Water (quantity & quality); (ii) Ground Water (quantity & quality) and (iii) River morphology and Sediment Transport.*

KWMI 1: Pollution from Urban Settlements and Industries

Point source pollution to surface waters relates mostly to discharges from urban waste water including storm overflows, industrial sites or to a much lesser extent to aquaculture. Groundwater is mainly affected by leaching of hazardous substances from irrigated agriculture, landfills and contaminated sites. Point source pollution results in water pollution by oxygen consuming substances, nutrients, and hazardous substances with high impacts on aquatic ecosystems and human health.

The main drivers behind the impact of urban and industrial point pollution are developments in:

- Population
- Economic growth
- Industrial activities

The information about population developments can be obtained from census data. The population development can be divided in:

1. The population in major cities (class I and II cities: population > 100.000 inhabitants).
2. Other urban population.
3. Rural population.

The information about economic and industrial developments can be obtained from:

- National bureau of statistics
- Chamber of commerce
- State and municipal corporation plans
- Geo based systems

The main pressures behind the impact of urban and industrial point pollution can be determined as follows:

- Determination of kind of pollutants to be taken into account: for example COD, BOD, coliform, conductivity (datasets can be chosen, depending on availability or purpose)
- Estimation or calculation of the pollutants loads as the product of estimated or calculated concentrations and water yields/volumes
- [ink to water yield information]
- Determine surface water units as logical geographical/hydrological units.
- These Surface water management units (SWMUs) will take into account the hydrological situation/units and will connect the spatial information to the pressures throughout the basin and establish the link with the impacts observed in the quality of the surface waters.
- Estimate of calculate the pollution load for each SWMU.

Remarks:

- Estimation is done with information from literature.
- Calculation is done by use of real figures.

KWMI 2: Area Source Pollution from Agriculture and other sources

Fertilizers and pesticides are critical inputs for efficient crop production, although their use is associated with a suite of direct and indirect costs in terms of impacts on human health and environmental damages. Overuse and misuse of fertilizers may have impacts on water environments notably eutrophication and possibly human health, while pesticides that do not reach the target (pests, fungal pathogens or weeds) are lost in the environment causing a wide range of effects on the environment and human health.

Agricultural production is in general dependant on the use of chemical fertilizers/manure and pesticides. How these inputs are used/managed or sometimes misused by farmers, the nature and intensity of transfer processes to the environmental compartments (air, soil water) that are very variable in space, will depend the pressure on the surface and subsurface water environments.
While some misuse of fertilizers and manure are reported in surveys of the Ministry of Agriculture & Farmers' Welfare (MoAFW) (in relation to nutrient requirements of cultivated crops), on an average, the use of nitrogen, phosphorus, and potassium (NPK) fertilizers and manure is in general limited in the different States. While eutrophication could occur in surface water bodies due to excessive nutrients in water, nutrient analyses of both surface and groundwater could show acceptable levels, even far below the EU standard for Nitrate concentrations (50 mg/l). What is all the more important is the fact that agriculture is not the only source of nitrate and phosphorus pollution.

While poor storage management of manure may also put pressure on the water system, the main agricultural pressure on water environments most likely occur from pesticide use. Indeed, while data on pesticides concentration in surface and ground water bodies are not available to date, pollution of water bodies in India caused by pesticides is reported in several academic publications (ref). Legacy of decades of use of highly dangerous pesticides and their impacts not only on humans but also aquatic environment (organophosphate, organochlorines p) is a matter that should be carefully studied, by starting first with an extensive screening (and then monitoring) of pesticides found in water bodies. While most of dangerous pesticides have been banned recently (Pesticide Management Bill, 2020), how the stocks will be used up/sold out and/or destroyed is also a concern. Ultimately, pesticides use or misuse and implementation of measures to reduce their transfer to streams/watercourses and groundwater will characterize the pressure on the overall water system.

Studies around the world have shown that the value of the crop being protected is an important determinant of between-crop variation in pesticide use. If crop value is the dominant driver of the use of pesticides directed at pests and plant pathogens, the most important predictor of pesticide use against weeds is the type of crops, with more frequent applications on perennial crops. In that respect, both economic and ecological drivers influence the extent of the potential crop losses, thereby shaping farmer pest control practices.

For example in the Tapi basin, crop value is the dominant driver of the use of pesticide and the agricultural areas represent around 67 % of the overall surface area of the Tapi river basin, an extensive overview on the agriculture and the crops cultivated is the first step to address KWMI 2. Because many various crops are cultivated in the basin, it is suggested to consider the crops which areas within the basin represent more than 10% of the cultivated areas.
For the Tapi basin, the main crops considered are the following:

- Gujarat: rice, pulses (arhar), sugar cane, cotton, representing 65% of the agricultural area of Gujarat within the Tapi River.
- Maharashtra: jowar (sorghum), bajra (pearl millet), pulses (green gram: moong), cotton representing 77% of the agricultural area of Madhya Pradesh within the Tapi river.
- Madhya Pradesh: maize, wheat, soyabean, cotton; representing 80% of the agricultural area of Madhya Pradesh within the Tapi River. When different types of millet or pulses are grown, we consider that the overall area is cultivated with the main crop of this group within the district, usually pearl millet and green gram.

KWMI 3: Alterations of River Hydrology/Water Quantity

The Tapi River Basin faces numerous drivers and pressures that have led to alterations in river hydrology and water quantity. These factors can be attributed to both natural processes and human activities, resulting in significant changes to the basin's water dynamics. Below are some key drivers and pressures impacting the Tapi River Basin:

Climate variability and change exert a significant influence on the Tapi River Basin. Alterations in temperature and precipitation patterns, including increased frequency and intensity of droughts or extreme rainfall events, impact the basin's water availability. These variations in climate patterns affect river flow, water levels, and recharge rates, leading to fluctuations in water quantity.

Rapid urban growth in cities within the Tapi River Basin, such as Surat and Nashik, has imposed substantial pressures on water resources. The expansion of urban areas results in increased water demand for domestic, industrial, and commercial purposes. Consequently, excessive withdrawals from the river and its tributaries for drinking water, irrigation, and other purposes contribute to reduced freshwater availability and altered hydrology.

Industrialization in the Tapi River Basin, particularly in Surat and Bharuch, has led to the establishment of various manufacturing units, including textile, chemical, and dye industries. These industries often consume substantial amounts of water and discharge effluents, which can pollute the river and impair its water quality. Consequently, river alterations occur due to both excessive extraction and pollution.

Intensive agricultural activities in the Tapi River Basin, including irrigation and cultivation practices, have a significant impact on water quantity. The demand for irrigation water, especially during dry periods, can lead to increased extraction from the river and depletion of groundwater resources. Additionally, inefficient irrigation practices, such as excessive water application or poorly maintained canals, further contribute to altered hydrology and reduced water availability.

Dam Construction and Water Management: The development of dams, reservoirs, and water management infrastructure within the Tapi River Basin has both positive and negative implications for river hydrology. While dam construction provides opportunities for water storage, flood control, and hydropower generation, it can also alter the flow patterns, sediment deposition, and river ecosystems downstream. These alterations affect the river's natural dynamics and water quantity downstream of the dam.

In addition, as our analysis for Tapi River Basin had illustrated, excessive withdrawal of groundwater can also affect stream-flows in areas where groundwater discharge contributes to stream flows in rivers. Such effects will be more pronounced during the lean season when the water levels in monsoon-fed rivers recede. Analysing such effects would require mapping of regional groundwater contours, marking of groundwater flow direction in relation to the drainage lines, analyzing groundwater flow gradients and ascertaining stream bed levels in relation to groundwater levels in the neighbouring areas.

KWMI 4: Alterations of Groundwater Quality and Quantity

Excessive extraction of groundwater for various purposes, including domestic, agricultural, and industrial needs, puts immense pressure on the aquifers in the Tapi River Basin. Unregulated pumping, particularly in areas with high demand, leads to a decline in groundwater levels and reduces water availability. Overexploitation disrupts the natural recharge processes, impacting the quantity of available groundwater.

Agriculture is a dominant sector in the Tapi River Basin, relying heavily on groundwater irrigation. Intensive agricultural activities, coupled with the use of inefficient irrigation techniques and excessive fertilizer/pesticide applications, lead to increased leaching and contamination of groundwater. Pollutants from agricultural runoff, including nitrates and pesticides, not only degrade water quality but also affect the health of the aquifers and the ecosystems they support.

Rapid urban growth and industrial development within the Tapi River Basin result in increased demand for water resources. Urban areas require substantial water supplies for domestic use, while industrialization leads to the discharge of pollutants and effluents that can seep into the groundwater. Additionally, inadequate sanitation infrastructure and improper waste disposal practices contribute to groundwater contamination, impacting both its quality and quantity.

Changing climate patterns, such as altered precipitation levels and rising temperatures, influence the availability and quality of groundwater in the Tapi River Basin. Reduced rainfall or increased evaporation rates affect recharge rates, resulting in decreased groundwater levels. Conversely, sudden heavy rainfall events may cause surface runoff and reduce recharge opportunities. Climate change also exacerbates the impact of other drivers, such as overexploitation and pollution.

The geological features and hydrological characteristics of the Tapi River Basin play a crucial role in groundwater dynamics. The basin comprises different types of aquifer systems with varying permeability, thickness, and storage capacity. Variations in lithology, fault zones, and geologic structures can influence groundwater flow paths, storage, and vulnerability to contamination.

KWMI 5: Alterations of River Morphology through Sand Mining

The demand for sand and gravel in India is huge, for building purposes and to make roads. As rivers transport sand and gravel from upstream areas to downstream areas at first hand it seems logic to excavate these materials from the river. However, while the discharge of water normally always is assured by the hydrological cycle, this does not hold for the sediments transported by a river. Once eroded, sediment will slowly be transported downstream, will settle in wider river reaches, ponds, flood plains, reservoirs and finally discharge into the sea.

In theory every river strives to an equilibrium state in which no major changes will happen in the overall slope, river width's and depth's. This equilibrium is determined by the water discharge regime and the sediment offered to the river. In this situation the sediment transport capacity equals the sediment flux. Dynamic temporal changes will regularly happen caused by extremes in the water and sediment discharges.

So, when sediment is taken out from the river, downstream of the mining site the missing sediment will be eroded from the river bed and/or banks to fulfil the sediment transport capacity. Sediment extraction will affect the downstream bed level (lower) and slope (smaller). The smaller slope will also lead to lower bed and water levels upstream of the extraction, see Figure 19 below.

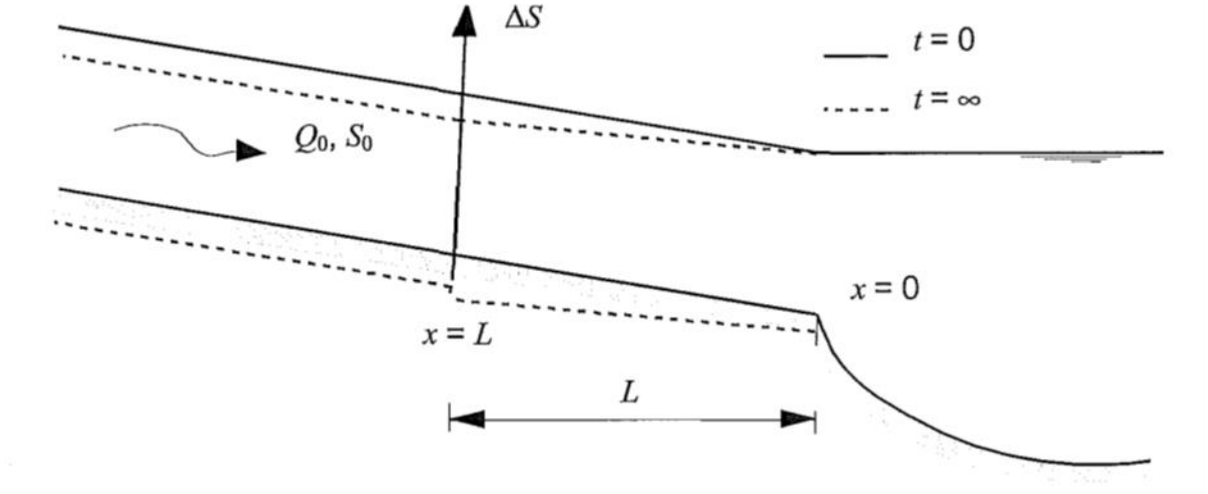


Figure 19 Impact of sediment withdrawal, S is sediment transport, Q is water discharge (copyright lit..TUD)

So, in general for sustainable river management sand mining from the river bed should be stopped altogether, to prevent lowering of the river bed, failure of river banks and river structures. If for navigation dredging is required the dredged spoil should not be taken out of the system but be replenished in deeper locations.

Sediment could be mined at spots where the sediment naturally will settle and will not be transported further downstream during high discharges, in such cases sediment flux offered downstream from other streams and flood plains must equalize the balance. This can be seen as natural replenishment. For sustainable sand mining a good insight is required of the sediment transport capacities of the river, the actual sediment transports and sediment supplies. To that end field data from sediment transports (through measurements) are needed and morphological models are used.

In the river system large ponds and flood plains catch a lot of sediment. Reservoirs are even capable of receiving all the transported sediment from upstream reaches. If that sediment is not replenished downstream severe bed erosion will occur as the river will take sediment from the bed and the banks to fulfil the transport capacity. All over the world a lot of bad experience is available where the sediment balance in rivers is disturbed by dams and reservoirs.

Artificial supply of bed-load material for the dynamic stabilization of river reaches affected by erosion is an accepted method in river engineering and is being applied increasingly, e.g. on German waterways downstream of impoundment weirs. The material is dumped from hopper barges and forms a thin mobile gravel carpet on the river bottom downstream of the weir. The amount of material and its grain-size composition are decided after consideration of the transport capacity of the reach to be stabilized and the grain size of the natural bed-load material. By using coarser material, additional stabilizing effects or a reduction of the amount of material to be added are expected. Conversely, the addition of finer material may be appropriate if the aim is to quickly stabilize river reaches further downstream.

6.2 Risk assessment approach, criteria and thresholds

6.2.1 Surface water quality

KWMI 1: Pollution from Urban Settlements and Industries

The approach has been done by taking into consideration the point sources by pollutant load estimates from urban and industrial sectors and integration this information with water yields for approaching expected concentrations in surface waters.

For the next level of the assessment it’s helpful to make an extinction between:
- Household pollution
- Industrial pollution

Assessment household pollution:
- Make a distinction between urban and rural areas;
- Estimate or calculate the sewage production of the population
- Estimate or calculate the sewage volumes based on the use of water supplies
- Estimate or calculate the raw pollution concentrations and loads for determined pollutants
- Determined pollutants depend on available information and can be: BOD, COD, N, P, coliform, TSS
- Estimate or calculate the treated or reduced pollution concentrations and loads. This can be done using information about the performance of STP’s or other technologies and the expected pollution reduction performances related to the pollutants that you want to take into consideration.

Assessment industrial pollution:

- Make an inventory of the kind of industries available in the basin including the kind of pollutants to be expected.
- Make an inventory of the locations of the industries including the treatment stations of industrial wastewater from geobased information sources.
- Make a distinction Inventory of the types of industries in 11 man sectors: fertilizers, meat, sugar, coffee, pulp and paper, petroleum, rubber, dairy, tannery, iron and steel and fish processing-that result in generation of wastewater with significant organic loads.
- Estimate or calculate the expected volumes of wastewater from estimation or calculation of wastewater production volumes per ton of products.
- Estimate or calculate the level of treatment of the industrial effluents: (i) take into account implementation rate of the zero emission policy; (ii) availability and performances of CETP's or other waste water treatment techniques.
- Based on these performances, estimate or calculate the concentration and load of chosen pollutants. The first pollutant to start with is COD, as a group parameter related to industrial waste water.
- Investigate if and how the spatial distribution of the industries and the amount of workers needs to be taken into account.
- Estimate or calculate the development of pollution loads in time (trend analyses) using industrial development figures.

Classification is based on available parameters and their compliance with the WQI thresholds. The average results of the evaluation of additional or updated monitoring stations are summarized in Table 4**Error! Reference source not found.**.

Table 4 Classification of monitoring stations according to CPCB Water Quality Index (State PCBs datasets)

Code Name (simplified)	Total Coliform Organisms (MNP / 100 ml)	pH	Dissolved Oxygen (mg / l)	Biochemical Oxygen Demand 5 days 20°C (mg/l)	WQ Class	Comments
2115 Tapti after mixing Pandhar Nalla	67,90		7,12	1,66	B	Lack of pH data
9 Tapi at Nepanagar	49,27		7,21	1,29	A	Lack of pH data
10 Tapi at Burhanpur	188,21		6,77	2,52	B	Lack of pH data
1250 Tapti at Hathnur	172,19		6,73	1,89	B	Lack of pH data
1913 Purna River at Dhupeshwar		8,01	5,61	8,22	Worse than C	Lack of coliform data
2155 Purna River at Nandura village		8,06	5,18	10,03	Worse than C	Lack of coliform data
2675 Morna River at Akola		7,83	4,31	17,03	Worse than C	Lack of coliform data
2695 Pedhi River at Dadhi-Pedhi village		8,09	4,65	10,97	Worse than C	Lack of coliform data
2700 Purna River at Asegaon		8,23	5,53	8,74	Worse than C	Lack of coliform data
2070 Tapi at Sahol Bridge		7,83	6,44	1,50	A	Lack of coliform data
Various stations D/S Ukai dam	366,69	7,71	6,12	1,75	B	once in a year
Ukai dam	31,00	8,10	7,08	0,91	A	once in a year

Source; own elaboration from State PCBs data

Special attention is needed to investigate the quality of the sediments in the SWMU (river stretches and reservoirs). Some information on the concentration of heavy metals in sediments is mentioned in the next table.

KWMI 2: Area Source Pollution from Agriculture and other sources

Because information on cropping pattern was available only at the district level, at a first stage, we considered that the crops are evenly distributed within the districts and only the share of the district within the Tapi River was used as a basis for calculations.

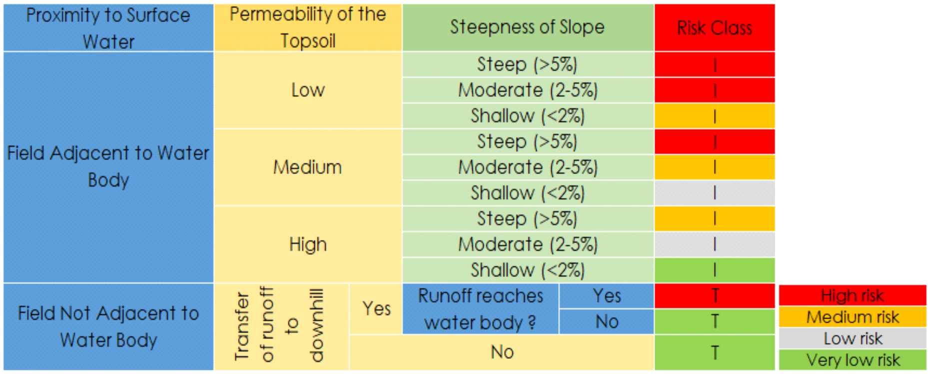
Pesticide use largely differ between crops (in relation with the value of the crop and not only with the pest and pathogen pressure). Nutrient load per district has been calculated on the basis of the average quantities of Nitrogen and Phosphorus fertilizers applied by crops, and the share of the crop within the district. The highest quantities of N fertilizers are applied on sugar cane, maize, and cotton. As for manure, it is mainly applied on cotton. Quantities of manure has also been calculated on basis of the average quantities applied by district. These quantities for both fertilizers and manure are below the standard uptake by crops (per unit of yield).

It has not been possible to calculate the load of pesticides per district (excepted for the Jalgaon district). Indeed, only average expenses of pesticides (at the state level) per crop are available todate. We applied the same calculation (average pesticide expenses x share of the crop within the district) for assessing the expenses of pesticides at the district level. For the Jalgaon district, the quantities of pesticides sold to farmers (at the taluka level) provides a better insight of the pesticide applied. It has not been possible to correlate the quantities sold with the cropping pattern (that is not available at the taluka level). Further, the real pressure of pesticide on the water system mainly depends on the active ingredient (with its own physical and chemical properties) and the frequency of application. From these properties, depend the pesticide ability to move to surface and subsurface water, its persistence before being degraded. Without detailed information on the active ingredients found in raw water and/or used by farmers, their frequency and dose of application, it has not been possible to investigate further this issue and notably to consider the use of synthetic indicators.

Without a comprehensive information on the active ingredients used by farmers and/or pesticides found in water analyses, it has been however possible to express the risk of transfer by considering landscape factors that play a role in this transfer. For this purpose, we set different dashboards for assessing first and then mapping the runoff risk by considering at a first stage that it is originated from infiltration restriction and saturation excess.

We used for that a dashboard for infiltration restriction that takes into account permeability of the topsoil and steepness of the slope. The objective is to define the level of risk and risk class (T: runoff for transfer and I: runoff for infiltration restriction) and then map this risk. The dashboard for saturation excess considers the proximity to surface water, the drainage status (agricultural drainage pipes or drainage trenches), the subsoil permeability, and the water holding capacity of soils (assessed from soils texture). From this dashboard is assessed the level of risk and the risk classes (T: runoff for transfer and S: runoff for saturation excess, SD: runoff for saturation excess + artificial drainage).

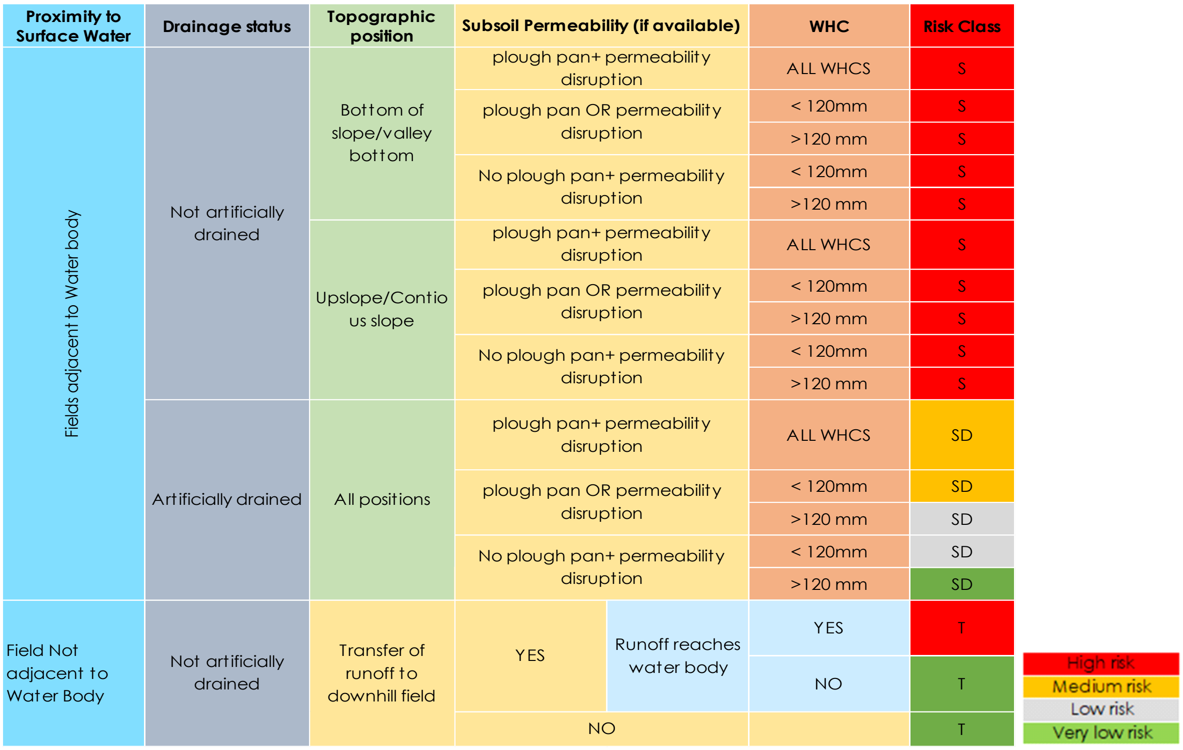
For designing the dashboard for infiltration restriction, we considered the proximity to surface water, the permeability of the top soil and the steepness of the slope to define risk classes (I: infiltration restriction and T: runoff by transfer)



Proximity to Surface Water	Permeability of the Topsoil		Steepness of Slope		Risk Class
Field Adjacent to Water Body	Low		Steep (>5%)		🟥 I
			Moderate (2-5%)		🟥 I
			Shallow (<2%)		🟧 I
	Medium		Steep (>5%)		🟥 I
			Moderate (2-5%)		🟧 I
			Shallow (<2%)		⬜ I
	High		Steep (>5%)		🟧 I
			Moderate (2-5%)		⬜ I
			Shallow (<2%)		🟩 I
Field Not Adjacent to Water Body	Transfer of runoff to downhill	Yes	Runoff reaches water body ?	Yes	🟥 T
				No	🟩 T
		No			🟩 T

🟥 High risk
🟧 Medium risk
⬜ Low risk
🟩 Very low risk

Figure 20 Dashboard for run-off risk



Proximity to Surface Water	Drainage status	Topographic position	Subsoil Permeability (if available)		WHC	Risk Class
Fields adjacent to Water body	Not artificially drained	Bottom of slope/valley bottom	plough pan+ permeability disruption		ALL WHCS	🟥 S
			plough pan OR permeability disruption		< 120mm	🟥 S
					>120 mm	🟥 S
			No plough pan+ permeability disruption		< 120mm	🟥 S
					>120 mm	🟥 S
		Upslope/Contious slope	plough pan+ permeability disruption		ALL WHCS	🟥 S
			plough pan OR permeability disruption		< 120mm	🟥 S
					>120 mm	🟥 S
			No plough pan+ permeability disruption		< 120mm	🟥 S
					>120 mm	🟥 S
	Artificially drained	All positions	plough pan+ permeability disruption		ALL WHCS	🟧 SD
			plough pan OR permeability disruption		< 120mm	🟧 SD
					>120 mm	⬜ SD
			No plough pan+ permeability disruption		< 120mm	⬜ SD
					>120 mm	🟩 SD
Field Not adjacent to Water Body	Not artificially drained	Transfer of runoff to downhill field	YES	Runoff reaches water body	YES	🟥 T
					NO	🟩 T
			NO			🟩 T

🟥 High risk
🟧 Medium risk
⬜ Low risk
🟩 Very low risk

Figure 21 – Dashboard for infiltration restriction

6.2.2 Surface water quantity

Introduction

An effort is made to refine the basin risk assessment framework used for assessing the water-related risk in Tapi river basin under IEWP Phase II for KWMI 3 - Alterations of River Hydrology/Water Quantity, in a way that enables the following: assessment of the overall water quantity related risk based on the standard criteria that consider ‘hazard’, ‘exposure’ and ‘vulnerability’; [3]and, assessment of the risk based on the hydro-climatic and socio-economic conditions in different hydrological sub-units within the basin (instead of different points in the river stretch, considered in the earlier phase).

Such an approach makes it possible to identify the most effective water management solutions, the scale at which they could be implemented and evaluate their cumulative impacts on water resources, water supplies, water quality and environmental flows, essential for upgrading and fine-tuning the basin plan. While doing this, it keeps almost all the parameters earlier considered for basin risk assessment, but puts them in a framework that enables proper assessment of the risk in the basin so as to evolve a sound river basin management plan for the Tapi. Further, the risk is assessed in relation to KWMI 3. The groundwater depletion risk, considered in the earlier work, is now extended to include droughts and water scarcity as they are interlinked. The risk is looked at from social, economic and environmental points of view. The risk is assessed as a cumulative effect of hazard, exposure and vulnerability.

Rationale

The Tapi River and its tributaries have undergone substantial alterations in the river flows due to reservoirs and diversion systems built across the basin. The changes in the flow regime of river/tributaries in the Tapi Basin have potential impacts on groundwater recharge, surface and groundwater quality, etc. Reducing stream flows due to water withdrawal can reduce the recharge to groundwater, if water levels in the rivers during the times of withdrawal are higher than that of the groundwater levels in the surrounding areas. At the same time, increased groundwater draft (which is a widespread phenomenon in parts of the basin) during the winter and summer seasons can reduce the outflow into the rivers/streams. But increased allocation of surface water for irrigation can result in rise in groundwater levels in the shallow aquifer of the command area due to irrigation return flows, which in turn can increase the outflow into streams. Uncontrolled increase in water demands is likely to cause further alterations in the flow regime and reduce the quantity of water available in different river stretches, making it difficult to maintain the ecosystem health.

During the first phase, the hydrological alterations undergone by the rivers were analysed using the results of hydrological simulation model (SWAT), and involved the use of simple criteria that looked at the extent of reduction in the natural flows at different stretches. But the basin-wide impacts of changing groundwater-surface water interactions occurring as a result of water diversion from rivers, groundwater pumping for irrigation and gravity irrigation could not be attempted in an integrated fashion. For instance, the impacts of groundwater draft on return flows to streams and surface irrigation on shallow groundwater were not clearly assessed. Similarly, the extent to which different competitive water demands in the basin are met through the river diversions and pumping from aquifers, and their impacts on groundwater regime, are not analysed. Neither are the changes in the supply-demand gaps during years of extremely low and extremely high rainfalls. Unmet water demands, which will only increase in future with rise in population and expansion of economic activities (agricultural expansion), can pose higher risks. In this regard, it is important to know how much water is used consumptively in the basin and how much remains unutilized during both the wet and lean years.

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[3] ‘Hazard’ is a generic term for events or trends that may not have adverse consequences for all elements of an affected system. Expsure refers to the geographical extent or infrastructure that are affected by the hazardous event. This sub-definition is centred on the interaction between hazard, vulnerability and exposure (building on the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation). It refers to potential for adverse consequences.

The overall observation (from the team and Tapi River Basin Committee (TRBC)) about KWMI 3 is that we need to look beyond the aggregate changes (or reduction) in stream-flows occurring due to water impoundments and diversions to understand the risks associated with hydrological alterations. Groundwater is a major source of water for meeting various needs in the basin, especially agriculture. The changes in the hydrological regime induced by groundwater draft in different parts of the basin need to be understood. Such changes can be in the form of reduction in lean season flows due to lowering of water levels resulting from increased pumping. Similarly, the impact of large-scale surface water availability (especially for irrigation in Ukai-Kakrapar command) on the groundwater regime needs to be understood. The rise in groundwater levels in certain pockets in the basins can also result in increased groundwater discharge into streams. Increased diversion of water from streams can impact on groundwater recharge.

The general feeling among the stakeholders about the risk associated with surface water hydrological alterations and water quantity and the programme of measures were as follows:

1) the criteria used for assessing the hydrological alterations in the basin is too simplistic, as it does not consider the variations in the hydrological regimes between different parts of the basin and integrate the concerns of varying water demands for agriculture (which is the major water user) due to spatial variations in climate. The point is that a single blanket criteria for the whole basin may not be appropriate.

2) the risk assessment did not consider the future increase in water demands (due to increase in food demand, industrialization, etc.) and;

3) It did not consider the change in the hydrological risk due to climate change impacts in the basin.

Variables for Assessing Risk of Alterations in Surface Water Hydrology and Water Quantity

Based on the interactions with the TRBC during the meetings held, our own internal discussions within the team and with the GIZ team, and the subsequent agreement on the need to revisit the risk assessment framework including the overall approach and criteria, in the wake of the issues mentioned above, several variables are identified as determinants of risk. The variables identified as critical for assessing the different dimensions of basin risk, viz., hazard, exposure and vulnerability were chosen on the basis of the knowledge available from extensive review of scientific literature using similar indices such as climate-induced WASH risk index (Kumar *et al*., 2021); WATSAN (water supply & sanitation) vulnerability index (Kumar, 2014), and the index for assessing rural households' vulnerability to problems associated with lack of water for domestic and productive needs (Kabir *et al*., 2016) and other studies dealing with the impact of climate variability on water management in India (Vedantam *et al*., 2021), many of which are already considered in the basin risk assessment tool developed under IEWP Phase I. The risk assessment, based on assessment of 'hazard, resulting from the alterations in surface hydrology, the 'exposure' of the water systems that the communities are dependent on to such alterations, and the 'vulnerability' of the communities to the disruptions in the services caused by the 'hazard' due to such exposure follows the DPSIR (driver, pressure, state, impact and response) approach. Here the drivers are: climate change, population growth, economic development, food security and agriculture growth, and international food trade, etc. Given the drivers, the need to increase the irrigated area for enhanced crop production, and improve the water supplies for domestic, municipal and industrial uses, which require water diversion from the river through reservoirs and diversion systems, corresponds to the 'Pressure'.

The ‘Hazard’ assessment corresponds to assessing the condition of the surface water in terms of quality and quantity resulting from both natural and anthropogenic factors/pressures (i.e., physical, chemical and biological characteristics), i.e., the ‘State’. The final ‘Risk’ resulting from the hazard**,** based on exposure and vulnerability corresponds to the Impact, which is the effect of a PRESSURE on water quality and/or quantity (e.g. lower population health, crops destroyed, ecosystem modified, aquatic life cannot thrive). The Program of Measures (PoM) is the Response to reduce the risk.

The methodology for computing the risk, which includes the various parameters influencing the three dimensions of the risk (i.e., hazard, exposure and vulnerability), the quantitative criteria for assigning values for each one of these parameters, the source of data for computing the values of the various influencing variables and the analytical procedure for computing the values are presented in Table 5, Table 6, and

Table 7.

The risk assessment has been done for all 10 sub basins in the Tapi Basin for the present situation (2023) and for a future scenario including the expected economic development and impact of climate change (based on RIBASIM scenario development, to be discussed).

Table 5 Parameters Influencing Hazards resulting from Hydrological Alterations

No.	Hazards (a)	Data required	Source from which it can be obtained	Remarks
1	**Extent of flow alteration**: ratio of the total annual water diversion/annual flow.	Flow data of the basin + virgin flow data for different stretches of the basin	Water year book – Tapi basin; data from CWC and state WRDs at xx locations in the basin; outputs from hydrological simulation study by INRM consultants and RIBASIM model of Deltares.	The extent of flow alteration is estimated by taking the ratio of the ‘difference between the current annual flows and the mean annual virgin flows’ and the mean annual virgin flows
2	**Aridity**: increases irrigation water demand, and agricultural drought occurrences.	Climate data of the basin	River basin report, CWC, Water year book – Tapi basin	Defined as the ratio of the potential evaporation and rainfall
3	**Rainfall variability**: increases the incidence of drought.	Historical data of rainfall in different parts of the basin	River basin report, CWC, Water year book – Tapi basin	It is estimated by taking the coefficient of variation in annual rainfall for a time series
4	**Annual renewable water resources (ARWR)**: the ARWR has a direct impact on the water scarcity for irrigation, domestic uses and environmental water scarcity in the basin. Higher the ARWR, lower will be the scarcity of water for irrigation and domestic uses and environmental water scarcity.	Renewable water resources in different years	CWC + CGWB Output from KWMI 4 Alterations of Groundwater Quality and Quantity analysis	ARWR is estimated by taking the sum of the mean annual runoff and the mean annual groundwater recharge
5	**Groundwater depletion**: increases water scarcity and the intensity of drought impacts.	Long term and seasonal groundwater levels	CGWB/India-WRIS Output from KWMI 4 Alterations of	The depletion is estimated by taking the difference in depth to water levels in

No.	Hazards (a)	Data required	Source from which it can be obtained	Remarks
			Groundwater Quality and Quantity analysis	the same season over a time period

Table 6 Parameters Influencing the Exposure to the Hazard

No.	Exposure (b)	Data required	Source from which it can be obtained	Remarks
1	**Impact on ecology**: change in ecological functions and associated economic activities that the river flow supports.	River ecology[4]	Report of ecological studies of Tapi river basin	It is indicated by the changes in the population of fish and other aquatic animals, and the size of the outputs from the economic activities that are dependent on the river (fishing, navigation and boating)
2	**Irrigation water scarcity**: gap between irrigation water requirement and water availability for irrigation	Irrigation potential of sources in the basin and potential evapotranspiration (PET) v/s rainfall data	Water year book – Tapi basin, India-WRIS + outputs from RIBASIM model and **Water accounting study**	Irrigation potential is estimated by taking the ratio of the total volume of water available from various sources for irrigation and the volume of water required to irrigate one ha of land; the total land area requiring irrigation is worked out by considering the total arable land where the potential evapotranspiration (PET) exceeds the effective rainfall and also considering the likely future expansion in irrigated area
3	**Drought Proofing Capacity of reservoirs**: provision of buffer storage of surface water in reservoirs per capita.	Renewable water resources in different years Reservoir storage details	River basin report, CWC, Water year book – Tapi basin + outputs from RIBASIM model and **Water accounting study**	Buffer storage of water is estimated by the total live storage of water in the surface reservoirs divided by the population
4	**Drought Proofing Capacity of groundwater**: Stock of good quality groundwater per capita--reduces the exposure of agricultural systems and drinking water supply systems to shocks from droughts.	Groundwater data from CGWB	India-WRIS, NCIWRDP report (1999) Output from KWMI 4 Alterations of Groundwater Quality and Quantity analysis	This is estimated by taking the ratio of the total static groundwater available within the unit (considered for analysis) by the population of the area
5	**Pressure on Groundwater for Economic Activities**: proportion of area irrigated by groundwater.	Data on irrigated area by source,	Economics & Statistics Division, Directorate of Agriculture + **Water allocation study outputs**	Ratio of the net groundwater irrigated area/net irrigated area

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[4] The data relating to river ecology will include the number of aquatic and riparian species (flora and fauna) that the river provides habitat for (source: based on Sponseller *et al*., 2013: Thompson & Lake, 2010; Ward & Stanford, 1983; Webster, 2007); and the biological processes (nutrient recycling; breeding of aquatic animals) that the continuous flow of water supports (Barbarossa et al., 2020).

No.	Exposure (b)	Data required	Source from which it can be obtained	Remarks
6	**Pressure on Groundwater for Socioeconomic Production**: proportion of water supply for drinking, domestic and industrial water supply, from groundwater (in terms of population).	Data on coverage of water supply schemes in terms of population size	From state rural water supply depts. & municipalities/corporations + outputs from RIBASIM model	Population (or volume ?) covered by net groundwater supply for drinking, domestic and industrial water supply / total population (or volume ?) covered by supply for drinking, domestic and industrial water supply.

Table 7 Parameters Influencing the Vulnerability to Disruptions caused by Hydrological Alterations

No.	Vulnerability (c)	Data required	Source from which it can be obtained	Remarks
1	Proportion of people who are directly dependent on the river water (for the ecological functions and the economic activities that they support) for livelihoods	Socio-economic profile data + reports of ecological studies available for the basin & expert opinion	CWC Tapi basin report, published research papers and expert opinion	This can be estimated by the total number of people who are dependent on fishing from the river, navigation and recreational services for their livelihood divided by the total population
2	Proportion of people whose source of livelihoods is dependent on surface and groundwater, directly (agricultural communities, cattle rearing communities and fisher-folk)	Socio-economic profile of people in the basin + overall response of the crops to temperature stress	River basin report, CWC, Water year book – Tapi basin	This is estimated by taking the ratio of the sum of the population of farmers (including, farm labourers), dairy farmers and fishing communities, and the total population in the geographical unit
3	Proportion of farm outputs dependent on groundwater (%)	Agricultural statistics	Census data	This is estimated by taking the ratio of the approx. value of agricultural outputs from groundwater irrigated area and the total agricultural outputs in value terms (including that from rain-fed areas)
4	Access of drinking water well users to alternate source for water supply	Data on drinking water supply sources in the rural areas	Census data	

Table 8 Defining Quantitative Criteria for Assigning Values for Different Influencing Variables

S. No	Risk Assessment Variables		Quantitative criteria for Assessing the Variables	
(a)	Hazards			
	Variable	Highly prone to hazard	Moderately prone	Least prone to hazard

S. No	Risk Assessment Variables		Quantitative criteria for Assessing the Variables	
1	Extent of flow alteration	If flow alteration > 90% of mean runoff of monsoon season and > 50% of the non-monsoon (lean season) flows in a semi-arid area, or > 50% of mean runoff of monsoon and > 25% of the mean runoff of lean season in sub- humid area	Flow alteration between 90% and 50% of the runoff of the monsoon season and between 50% & 25% of the runoff of the lean season in semi-arid area, or between 50% and 25% of the mean monsoon runoff and between 25%-10% of the lean season flow in sub-humid area	Flow alteration <50% of the monsoon runoff and < 25% of the lean season runoff in a semi-arid area or < 25% of the monsoon runoff and < 10% of the lean season runoff in sub-humid area
2	Aridity	Arid to Hyper-arid	Semi-arid	Humid-sub- humid
3	Rainfall variability (coefficient of variation, %)	CV more than 40%	CV in the range of 17-40%	CV less than 17%
4	Annual renewable water resources (m^3/capita)	<1000m^3/capita/year	Between 1000 and 1700 m^3/capita/year	1700 m^3/capita/year
5	Groundwater depletion (water level drop)	Long term decline in water levels + seasonal depletion	Short term decline only during meteorological droughts	Only seasonal depletion of groundwater
(b) Exposure				
		High exposure	**Moderate exposure**	**Low exposure**
1	Impact on Ecology: Extent of impact of flow alterations on the ecological and economic activities that the river supports	Both ecological and economic functions are severely affected	Ecological and economic functions are moderately affected	Economic and ecological functions are not affected
2	Irrigation water scarcity: irrigation potential of the existing sources/ total land area requiring irrigation #	Irrigation potential of existing sources in ha/total arable land in ha < 0.5	Irrigation potential of existing sources/total arable land = 0.5 to 1.0	Irrigation potential of existing sources/total arable land> 1
3	Drought Proofing Capacity of Reservoirs: Provision of buffer storage of water in reservoirs (m3/capita/year)	Provision of buffer storage in a reservoir less than 10 m^3/capita/year	Provision of buffer storage in a reservoir is 11 to 36 m^3/capita/year	Provision of buffer storage in a reservoir is > 36 m^3/capita/year
4	Drought Proofing Capacity of Groundwater: Groundwater stock reduces the exposure of agricultural systems and drinking water supply systems to shocks from droughts (m^3/capita)	Groundwater stock per capita/annum < 200 m^3	Groundwater stock per capita/annum, 200-500 m^3	Groundwater stock per capita > 500 m^3
5	Pressure on Groundwater for Economic Activities (%)	More than 50%	Between 50% and 25%	Less than 25%
6	Pressure on Groundwater for Socio-economic Production (%)	Proportion >75%	Proportion = 75% to 25%	Proportion < 25%
(c) Vulnerability				
		High vulnerability	**Moderate vulnerability**	**Low vulnerability**

S. No	Risk Assessment Variables		Quantitative criteria for Assessing the Variables	
1	Proportion of people dependent on the river (for the ecological functions and economic activities that they support) for livelihoods (%)	Proportion > 25%	Proportion, 25% to 10%	Proportion < 10%
2	Proportion of people whose source of livelihood is dependent on water, directly (agricultural communities, cattle rearing communities and fisher folk (%)	Proportion >50%	Proportion = 50 % to 20%	Proportion < 20%
3	Proportion of farm outputs dependent on groundwater irrigation (%)	More than 50%	Between 50% and 25%	Less than 25%
4	Drinking water well users' access to alternate sources of water supply (%)	Less than 25% of those dependent on groundwater have alternate source	50-25% of those dependent on groundwater have alternate sources	More than 50% of those dependent on groundwater have alternate sources

Method of Computation of the Composite Index

Here we propose to assign the following values for the different variables involved in assessment of hazards, exposure and vulnerability. For 'high' degree, the value will be 3.0; for moderate, the value will be '2.0' and for low, the value would be 1.0. Equal weightage is given to all the variables. The final value of each sub-index (like 'hazard', 'exposure' and 'vulnerability') will be obtained by dividing the sum of the values assigned to each parameter divided by the multiple of the total number of parameters involved (n) and the maximum score possible for any parameter (i.e. 3.0), for normalization. For 'hazard', the number of parameters is 5 (five); for exposure, it is 6 (six), and for vulnerability it is 4 (four). Hence for normalization, the total score for hazard will be divided by 15 (i.e., 5 X 3). For exposure, the total score will be divided by 18, and for vulnerability, the score will be divided by 12. The final risk will be H x E x V**.** If the value of hazard for a sub-basin is 0.6, exposure 0.40 and vulnerability 0.40, then the risk will be 0.09.

The unit of analysis considered for risk assessment is the sub-basin. In the case of Tapi river basin, for which the risk assessment was carried out using the methodology explained above, a total of ten sub-basins (with clearly-defined drainage boundaries) were identified.

To give an illustrative example, in the case of sub-basin 9, the total value of all the five variables considered for hazard is 9. Then the final value of the hazard sub-index will be 9/ (5 X 3) = 0.60. Similarly, if the total value of all the six variables under exposure is 9.0. Then the final value of the exposure sub-index will be 9/ (6 X 3) =0.50, As regards vulnerability, if the total value of the four variables put together is 6.0. Then the final value of the sub-index for vulnerability will be 6/ 4 X 3 =0.50. Now the final value of the risk index for the sub-basin will be 0.60X 0.50 X 0.50 = 0.15.

Based on this, we have identified four risk categories, depending on the value of the risk index. The various risk categories, the value ranges for each category and the colour codes are given below. The lowest risk value that any hydrological unit can obtain is 0.035.

S No.	**Risk Categories**	**Value Range**	**Colour Code**
1	No Risk	0.035 to 0.20	🟩
2	Low Risk	0.200-0.350	🟨
3	Moderate Risk	0..351-0.650	🟪
4	High Risk	0.651 to 1.0	🟥

6.2.3 Groundwater quality

Introduction

Assuming that the GMUs have been defined, the Pressure/Impact Analysis and Risk Assessment for groundwater quality is carried out following a 4-step approach:

- **Step 1:** Consideration of diffuse and point source pollution by land use data.
- **Step 2:** Consideration of groundwater monitoring data.
- **Step 3:** Expert judgement considering the conceptual understanding of the GMU and field observations.
- **Step 4:** Final synthesis with the final risk assignment, including all related significant pressures and the confidence level of the risk assessment result.

In Step 1 the main land use categories, which are present in the Tapi River Basin, were classified according to their potential of posing risk of not achieving the RBM targets for groundwater quality. They were clubbed into three priority land use classes according to their risk potential and they represent diffuse and point sources of pollution. The step-1 risk assessment is undertaken according to the following assessment matrix where the worst risk classification of a priority land use class is decisive for the overall risk classification in the following assessment steps.

Table 9: Groundwater quality risk assessment categories

Interim risk result – Step 1		**Risk criterion** [% of the total GMU area]			
Priority land use classes	**Land use categories included**	**Not at risk**	**Low risk**	**Medium risk**	**High risk**
1	Built up Area + Double Cropped Area + Perennial crops	≤ 10	> 10 – ≤ 25	> 25 – ≤ 50	> 50
2	Other Agricultural Area	≤ 25	> 25 – ≤ 50	> 50 – ≤ 75	> 75
3	Forest Area, Water Bodies Area, Wasteland				

The output of Step 1 is a preliminary categorization of each GMU into (i) not at risk, (ii) low risk, (iii) medium risk or (iv) high risk.

In Step 2 the effects of land use are validated by monitoring data, as far as data are available and given that the monitoring networks and monitored substances/indicators are representative of the different anthropogenic pressures and the conceptual understanding of the GMU. The validation focuses on nitrates (NO_3) and electrical conductivity (EC) as they are indicators of anthropogenic contamination of groundwater resources. The threshold values for the two parameters are laid down in standard BIS 10500:2012.

Table 10: Groundwater monitoring quality indicators

Parameter	Value	Criteria
Nitrate (NO_3)	45 mg/l	drinking water criterion
Electrical Conductivity (EC)	2250 µS/cm	agriculture criterion

The output of Step 2 is the locations of all water quality sampling points which exceed the limits shown in Table 10. These point locations are overlain on top of the GMU quality risk category map developed during Step 1.

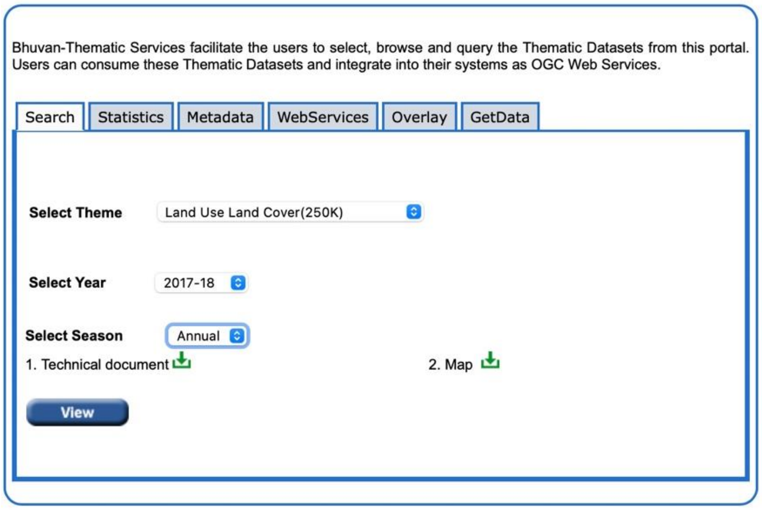
Steps 3 and 4 comprise the individual validation of the interim risk results from step 1 and 2 (e.g., evaluating the representativeness of the monitoring data) by the local groundwater expert(s) wherein the conceptual understanding of the GMU is taken into account by making use of the related GMU characterisation template and any further field observations. The final decision on the risk status of each GMU is given in four categories: Not at risk, Low risk, Medium Risk and High risk and includes an explanation, details on the significant point source and diffuse pressures, and the confidence in the final risk result.

Download the Land Cover-Landuse (LCLU) TIF & VAT files

The Land Use/Land Cover (LULC) data for India is produced by the National remote Sensing Centre Annual LULC mapping is carried out at 1:250,000 scale. See: https://www.nrsc.gov.in/EO_LULC_Objective

The LULC data is available at ISRO's Geo-portal (Bhuvan): https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php

Note that you need to be a registered user to download the data.


Bhuvan-Thematic Services facilitate the users to select, browse and query the Thematic Datasets from this portal. Users can consume these Thematic Datasets and integrate into their systems as OGC Web Services.

Select Theme: Land Use Land Cover(250K)

Select Year: 2017-18

Select Season: Annual

1. Technical document

2. Map

Figure 22: LULC data portal

The LULC data is a raster TIF file with a pixel size of 56x56 meters. The data is stored as a Byte - Eight bit unsigned integer. Each pixel has a value ranging from 0 to 17. It is accompanied by a VAT file which is where the legend for each pixel value is stored. This includes the red-green-blue colour value from 0 to 1, the opacity and three levels of information. For example, a pixel with value of 2 refers to Agricultural Land (Level 1), Cropland (Level 2) and Kharif (Level 3).

The LULC needs to be cropped to the outline of the river basin & then it is ready for processing. For the Tapi Basin, for the year 2017-2018 we have the following two files:

Tapi_lulc250k_1718.tif

Tapi_lulc250k_1718.tif.vat.dbf

Load the LULC file into QGIS

If you load the LULC raster into ArcGIS it should automatically appear with the correct legend. QGIS does not have the ability to load VAT files automatically. It requires the installation of a plugin.

Go to Plugins – Manage and Install Plugins and look for **RasterAttributeTable**.

raster attribute

☑ RasterAttributeTable

RasterAttributeTable

Display and manage Raster Attribute Tables.

Display and manage Raster Attribute Tables.

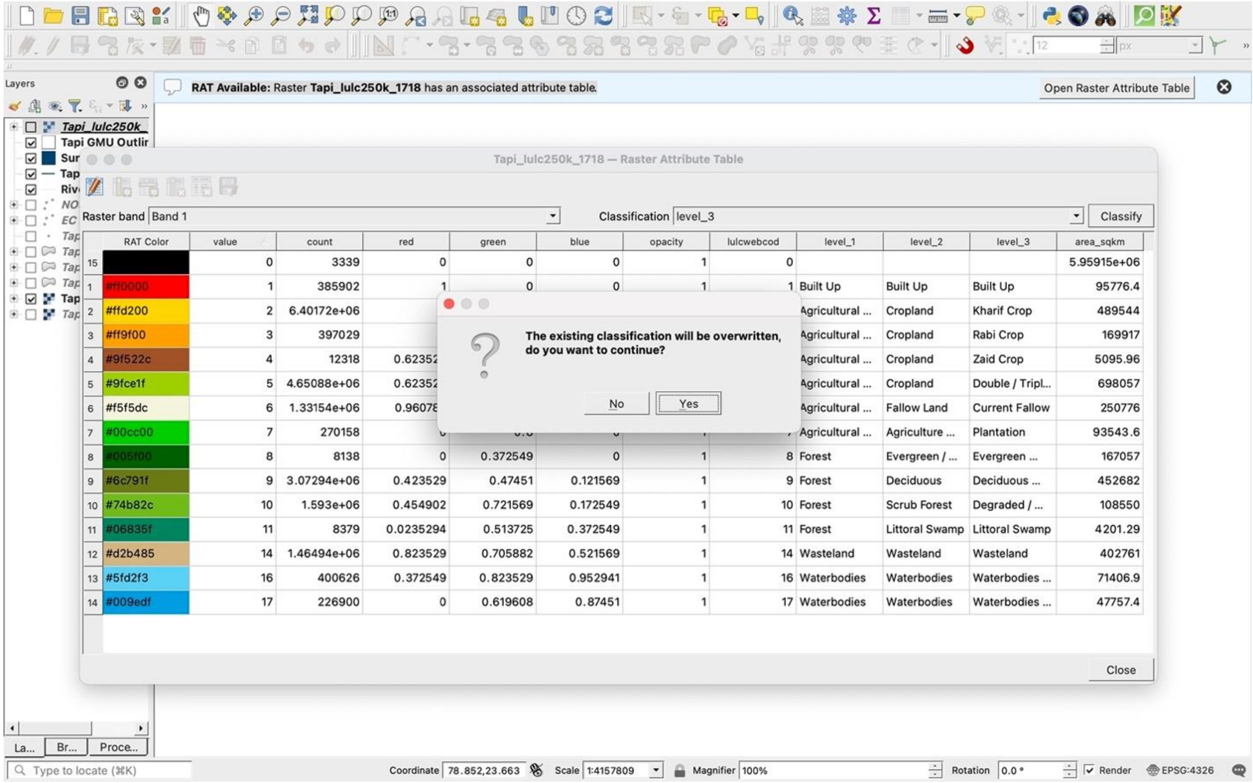
8 rating vote(s), 17139 downloads

More info homepage bug tracker code repository
Author Alessandro Pasotti
Installed version 1.2
Available version (stable) 1.2 updated at Wed Sep 28 09:54:11 2022

Once the plugin is installed, when you open the LULC raster file, you will get the message *RAT Available: Raster Tapi_lulc250k_1718 has an associated attribute table.*

Click on **Open the Raster Attribute Table** and it will open with all the standard colours and attribute information.

Select **Classification: level_3** and agree to overwrite the existing classification.



RAT Available: Raster **Tapi_lulc250k_1718** has an associated attribute table.

Tapi_lulc250k_1718 — Raster Attribute Table

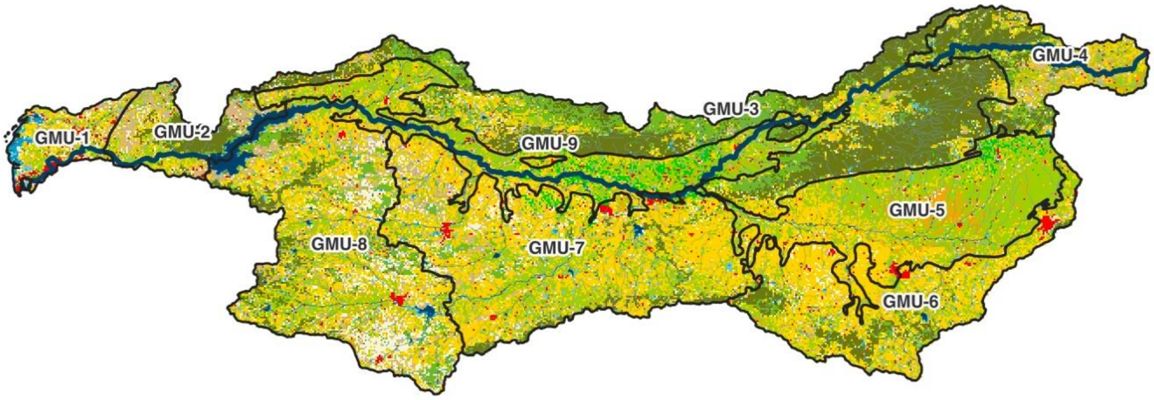
Raster band: Band 1

Classification: level_3

	RAT Color	value	count	red	green	blue	opacity	lulcwebcod	level_1	level_2	level_3	area_sqkm
15		0	3339	0	0	0	1	0				5.95915e+06
1	#ff0000	1	385902	1	0	0	1	1	Built Up	Built Up	Built Up	95776.4
2	#ffd200	2	6.40172e+06						Agricultural ...	Cropland	Kharif Crop	489544
3	#ff9f00	3	397029						Agricultural ...	Cropland	Rabi Crop	169917
4	#9f522c	4	12318	0.62352					Agricultural ...	Cropland	Zaid Crop	5095.96
5	#9fce1f	5	4.65088e+06	0.62352					Agricultural ...	Cropland	Double / Tripl...	698057
6	#f5f5dc	6	1.33154e+06	0.96078					Agricultural ...	Fallow Land	Current Fallow	250776
7	#00cc00	7	270158	0	0.8	0	1	7	Agricultural ...	Agriculture ...	Plantation	93543.6
8	#005f00	8	8138	0	0.372549	0	1	8	Forest	Evergreen / ...	Evergreen ...	167057
9	#6c791f	9	3.07294e+06	0.423529	0.47451	0.121569	1	9	Forest	Deciduous	Deciduous ...	452682
10	#74b82c	10	1.593e+06	0.454902	0.721569	0.172549	1	10	Forest	Scrub Forest	Degraded / ...	108550
11	#06835f	11	8379	0.0235294	0.513725	0.372549	1	11	Forest	Littoral Swamp	Littoral Swamp	4201.29
12	#d2b485	14	1.46494e+06	0.823529	0.705882	0.521569	1	14	Wasteland	Wasteland	Wasteland	402761
13	#5fd2f3	16	400626	0.372549	0.823529	0.952941	1	16	Waterbodies	Waterbodies	Waterbodies ...	71406.9
14	#009edf	17	226900	0	0.619608	0.87451	1	17	Waterbodies	Waterbodies	Waterbodies ...	47757.4

The existing classification will be overwritten, do you want to continue?

You should end up with the river basin classified in the correct colors. Overlay and label the GMUs.



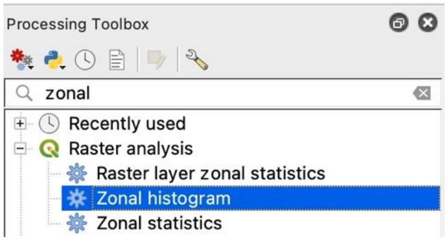
Determination of Land Cover-Landuse (LCLU) statistics for each GMU in QGIS

The next step is to measure the areas covered by the different land use classes. The land use classes of the LULC raster have been loaded from the VAT file and are shown in Table 11 below. Note that each pixel will have a value of 0 to 17, and all we will do is to count how many pixels there are of each of the 18 classes inside of each GMU.

Table 11: LULC legend

value	red	green	blue	opacity	level_1	level_2	level_3
1	1.00000	0.00000	0.00000	1	Built Up	Built Up	Built Up
2	1.00000	0.82353	0.00000	1	Agricultural Land	Cropland	Kharif Crop
3	1.00000	0.62353	0.00000	1	Agricultural Land	Cropland	Rabi Crop
4	0.62353	0.32157	0.17255	1	Agricultural Land	Cropland	Zaid Crop
5	0.62353	0.80784	0.12157	1	Agricultural Land	Cropland	Double / Triple Crop
6	0.96078	0.96078	0.86275	1	Agricultural Land	Fallow Land	Current Fallow
7	0.00000	0.80000	0.00000	1	Agricultural Land	Agriculture Plantation	Plantation
8	0.00000	0.37255	0.00000	1	Forest	Evergreen / Semi Evergreen	Evergreen Forest
9	0.42353	0.47451	0.12157	1	Forest	Deciduous	Deciduous Forest
10	0.45490	0.72157	0.17255	1	Forest	Scrub Forest	Degraded / Scrub Forest
11	0.02353	0.51373	0.37255	1	Forest	Littoral Swamp	Littoral Swamp
14	0.82353	0.70588	0.52157	1	Wasteland	Wasteland	Wasteland
16	0.37255	0.82353	0.95294	1	Waterbodies	Waterbodies	Waterbodies Max
17	0.00000	0.61961	0.87451	1	Waterbodies	Waterbodies	Waterbodies Min
0	0.00000	0.00000	0.00000	1			

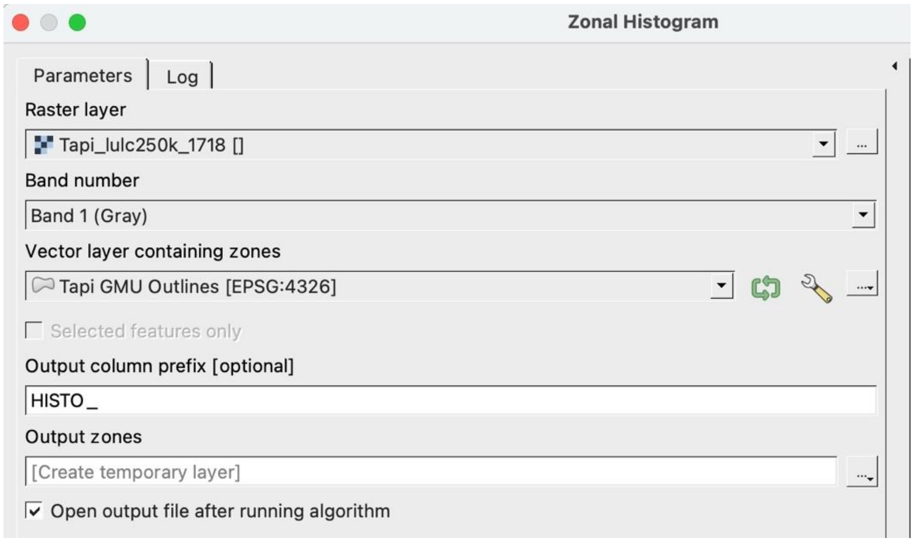
For this we will use the Zonal Histogram tool. In the Processing Toolbox, look for “zonal” and select the **Zonal histogram** tool.



Set the parameters as follows:

- Raster layer: LULC raster layer *(Tapi lulc 250k_1718)*
- Band number: Band 1 (Gray)

- Vector layer containing zones: GMU polygon layer *(Tapi GMU Outlines)*
- Output column prefix: HISTO_
- Output zones: [Create temporary layer]
- Check the box Open output file after running algorithm.



Raster layer: Tapi_lulc250k_1718 []

Band number: Band 1 (Gray)

Vector layer containing zones: Tapi GMU Outlines [EPSG:4326]

☐ Selected features only

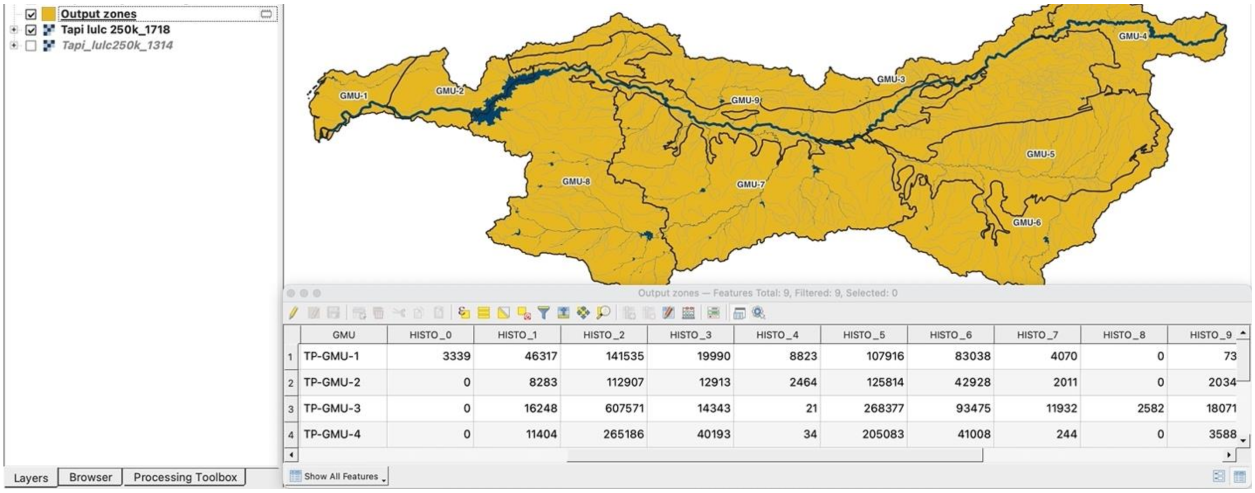
Output column prefix [optional]: HISTO_

Output zones: [Create temporary layer]

☑ Open output file after running algorithm

Run the Zonal histogram tool.

The output is a temporary polygon layer. Right-click the layer & **Open Attribute Table**

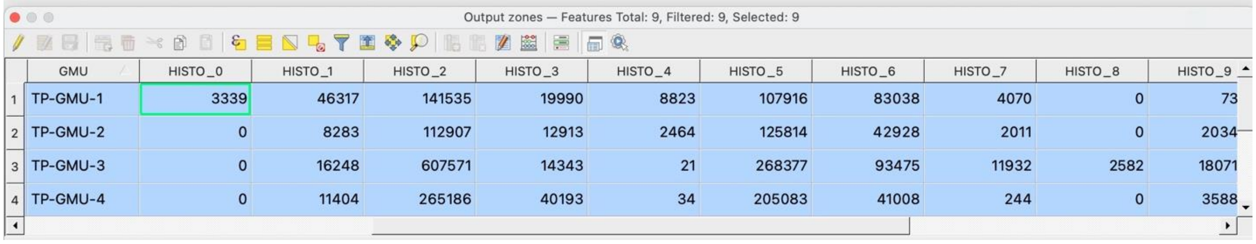


Output zones — Features Total: 9, Filtered: 9, Selected: 0

	GMU	HISTO_0	HISTO_1	HISTO_2	HISTO_3	HISTO_4	HISTO_5	HISTO_6	HISTO_7	HISTO_8	HISTO_9
1	TP-GMU-1	3339	46317	141535	19990	8823	107916	83038	4070	0	73
2	TP-GMU-2	0	8283	112907	12913	2464	125814	42928	2011	0	2034
3	TP-GMU-3	0	16248	607571	14343	21	268377	93475	11932	2582	18071
4	TP-GMU-4	0	11404	265186	40193	34	205083	41008	244	0	3588

Histo_0 means the number of pixels with a value of 0. Histo_1 means the number of pixels with a value of 1, and so on.

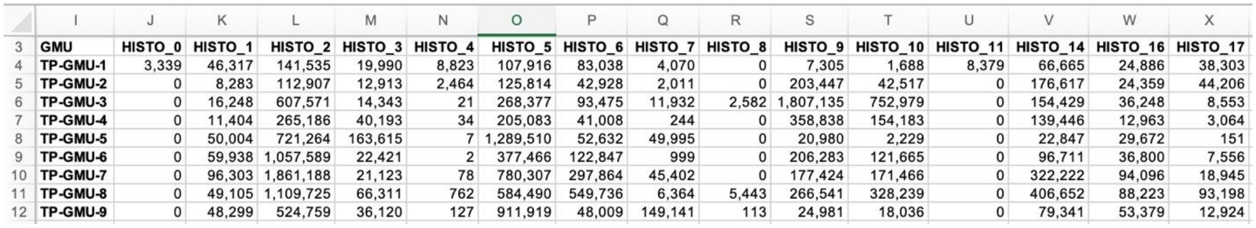
Select the entire attribute table by clicking in the top left square.



	GMU	HISTO_0	HISTO_1	HISTO_2	HISTO_3	HISTO_4	HISTO_5	HISTO_6	HISTO_7	HISTO_8	HISTO_9
1	TP-GMU-1	3339	46317	141535	19990	8823	107916	83038	4070	0	73
2	TP-GMU-2	0	8283	112907	12913	2464	125814	42928	2011	0	2034
3	TP-GMU-3	0	16248	607571	14343	21	268377	93475	11932	2582	18071
4	TP-GMU-4	0	11404	265186	40193	34	205083	41008	244	0	3588

On the top menu: **Edit – Copy Features**

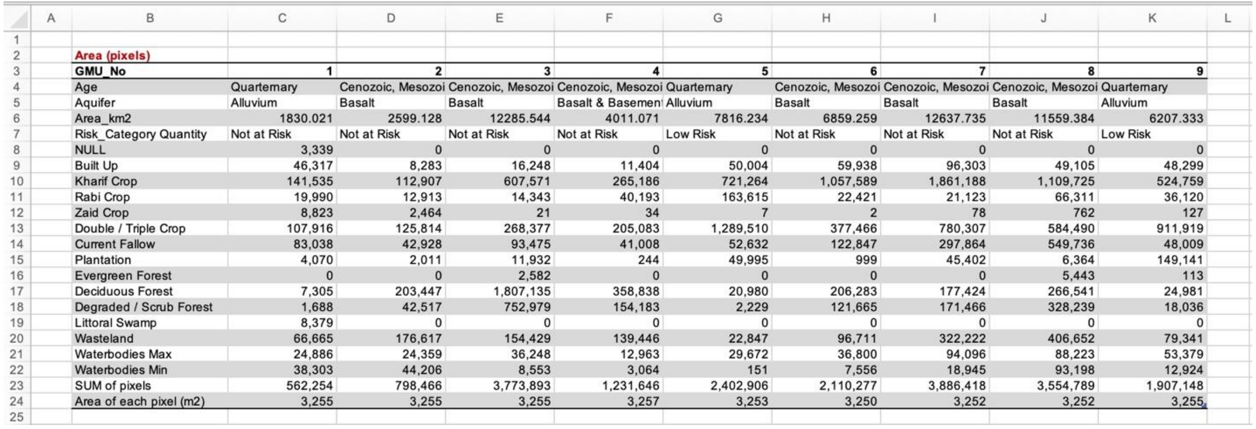
Open Excel & Paste the values



GMU	HISTO_0	HISTO_1	HISTO_2	HISTO_3	HISTO_4	HISTO_5	HISTO_6	HISTO_7	HISTO_8	HISTO_9	HISTO_10	HISTO_11	HISTO_14	HISTO_16	HISTO_17
TP-GMU-1	3,339	46,317	141,535	19,990	8,823	107,916	83,038	4,070	0	7,305	1,688	8,379	66,665	24,886	38,303
TP-GMU-2	0	8,283	112,907	12,913	2,464	125,814	42,928	2,011	0	203,447	42,517	0	176,617	24,359	44,206
TP-GMU-3	0	16,248	607,571	14,343	21	268,377	93,475	11,932	2,582	1,807,135	752,979	0	154,429	36,248	8,553
TP-GMU-4	0	11,404	265,186	40,193	34	205,083	41,008	244	0	358,838	154,183	0	139,446	12,963	3,064
TP-GMU-5	0	50,004	721,264	163,615	7	1,289,510	52,632	49,995	0	20,980	2,229	0	22,847	29,672	151
TP-GMU-6	0	59,938	1,057,589	22,421	2	377,466	122,847	999	0	206,283	121,665	0	96,711	36,800	7,556
TP-GMU-7	0	96,303	1,861,188	21,123	78	780,307	297,864	45,402	0	177,424	171,466	0	322,222	94,096	18,945
TP-GMU-8	0	49,105	1,109,725	66,311	762	584,490	549,736	6,364	5,443	266,541	328,239	0	406,652	88,223	93,198
TP-GMU-9	0	48,299	524,759	36,120	127	911,919	48,009	149,141	113	24,981	18,036	0	79,341	53,379	12,924

The next step is to Copy & Paste Special – Transpose the data, so that all the GMU headers are along the top as column headers & all the values of the different land use types are as rows.

- Replace the land use codes (0 to 17) with the classes of level_3.
- Select the data and **Home – Format as Table**.
- Add up all the pixels in each GMU under **SUM of pixels**.
- Calculate the **Area of each pixel (m2)** by dividing the Area_km2 by the Sum of pixels.

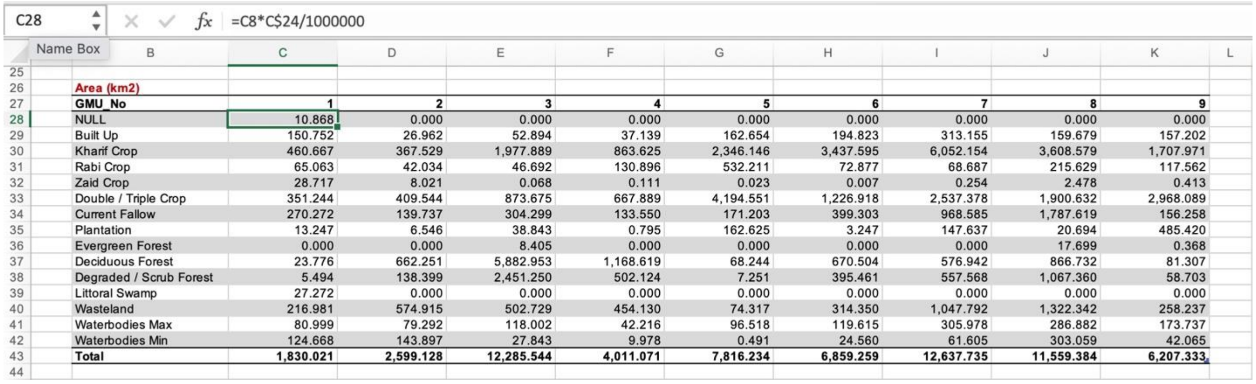


Area (pixels)

GMU_No	1	2	3	4	5	6	7	8	9
Age	Quarternary	Cenozoic, Mesozoi	Cenozoic, Mesozoi	Cenozoic, Mesozoi	Quarternary	Cenozoic, Mesozoi	Cenozoic, Mesozoi	Cenozoic, Mesozoi	Quarternary
Aquifer	Alluvium	Basalt	Basalt	Basalt & Basemen	Alluvium	Basalt	Basalt	Basalt	Alluvium
Area_km2	1830.021	2599.128	12285.544	4011.071	7816.234	6859.259	12637.735	11559.384	6207.333
Risk_Category Quantity	Not at Risk	Not at Risk	Not at Risk	Not at Risk	Low Risk	Not at Risk	Not at Risk	Not at Risk	Low Risk
NULL	3,339	0	0	0	0	0	0	0	0
Built Up	46,317	8,283	16,248	11,404	50,004	59,938	96,303	49,105	48,299
Kharif Crop	141,535	112,907	607,571	265,186	721,264	1,057,589	1,861,188	1,109,725	524,759
Rabi Crop	19,990	12,913	14,343	40,193	163,615	22,421	21,123	66,311	36,120
Zaid Crop	8,823	2,464	21	34	7	2	78	762	127
Double / Triple Crop	107,916	125,814	268,377	205,083	1,289,510	377,466	780,307	584,490	911,919
Current Fallow	83,038	42,928	93,475	41,008	52,632	122,847	297,864	549,736	48,009
Plantation	4,070	2,011	11,932	244	49,995	999	45,402	6,364	149,141
Evergreen Forest	0	0	2,582	0	0	0	0	5,443	113
Deciduous Forest	7,305	203,447	1,807,135	358,838	20,980	206,283	177,424	266,541	24,981
Degraded / Scrub Forest	1,688	42,517	752,979	154,183	2,229	121,665	171,466	328,239	18,036
Littoral Swamp	8,379	0	0	0	0	0	0	0	0
Wasteland	66,665	176,617	154,429	139,446	22,847	96,711	322,222	406,652	79,341
Waterbodies Max	24,886	24,359	36,248	12,963	29,672	36,800	94,096	88,223	53,379
Waterbodies Min	38,303	44,206	8,553	3,064	151	7,556	18,945	93,198	12,924
SUM of pixels	562,254	798,466	3,773,893	1,231,646	2,402,906	2,110,277	3,886,418	3,554,789	1,907,148
Area of each pixel (m2)	3,255	3,255	3,255	3,257	3,253	3,250	3,252	3,252	3,255

The next step is to calculate the area in square kilometres of each landuse type for each GMU. To do this multiply the number of pixels by their area and divide by 1 million to go from m^2 to km^2.

Calculate the sum of all the areas. It should be the same as the original area calculated for each GMU.



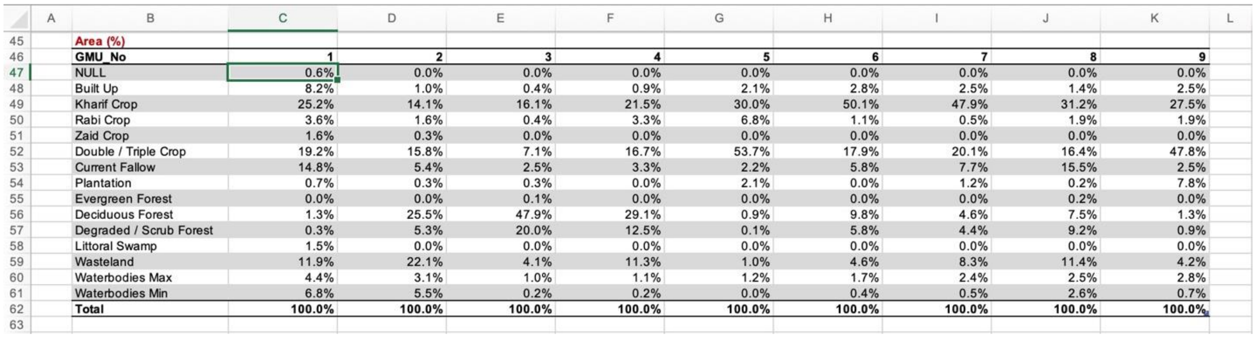
C28 =C8*C$24/1000000

Area (km2)

GMU_No	1	2	3	4	5	6	7	8	9
NULL	10.868	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Built Up	150.752	26.962	52.894	37.139	162.654	194.823	313.155	159.679	157.202
Kharif Crop	460.667	367.529	1,977.889	863.625	2,346.146	3,437.595	6,052.154	3,608.579	1,707.971
Rabi Crop	65.063	42.034	46.692	130.896	532.211	72.877	68.687	215.629	117.562
Zaid Crop	28.717	8.021	0.068	0.111	0.023	0.007	0.254	2.478	0.413
Double / Triple Crop	351.244	409.544	873.675	667.889	4,194.551	1,226.918	2,537.378	1,900.632	2,968.089
Current Fallow	270.272	139.737	304.299	133.550	171.203	399.303	968.585	1,787.619	156.258
Plantation	13.247	6.546	38.843	0.795	162.625	3.247	147.637	20.694	485.420
Evergreen Forest	0.000	0.000	8.405	0.000	0.000	0.000	0.000	17.699	0.368
Deciduous Forest	23.776	662.251	5,882.953	1,168.619	68.244	670.504	576.942	866.732	81.307
Degraded / Scrub Forest	5.494	138.399	2,451.250	502.124	7.251	395.461	557.568	1,067.360	58.703
Littoral Swamp	27.272	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wasteland	216.981	574.915	502.729	454.130	74.317	314.350	1,047.792	1,322.342	258.237
Waterbodies Max	80.999	79.292	118.002	42.216	96.518	119.615	305.978	286.882	173.737
Waterbodies Min	124.668	143.897	27.843	9.978	0.491	24.560	61.605	303.059	42.065
Total	**1,830.021**	**2,599.128**	**12,285.544**	**4,011.071**	**7,816.234**	**6,859.259**	**12,637.735**	**11,559.384**	**6,207.333**

The next step is to calculate the relative percentages of the different land use areas for each GMU.

- Divide the area of each landuse type by the total area of the GMU.
- Format the answer as a percentage.
- Check that the percentages add up to 100%

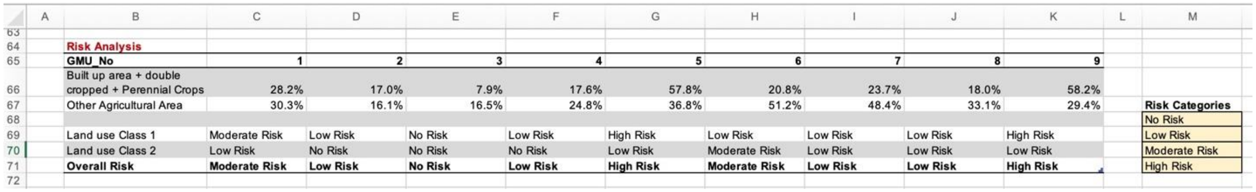


Area (%)

GMU_No	1	2	3	4	5	6	7	8	9
NULL	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Built Up	8.2%	1.0%	0.4%	0.9%	2.1%	2.8%	2.5%	1.4%	2.5%
Kharif Crop	25.2%	14.1%	16.1%	21.5%	30.0%	50.1%	47.9%	31.2%	27.5%
Rabi Crop	3.6%	1.6%	0.4%	3.3%	6.8%	1.1%	0.5%	1.9%	1.9%
Zaid Crop	1.6%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Double / Triple Crop	19.2%	15.8%	7.1%	16.7%	53.7%	17.9%	20.1%	16.4%	47.8%
Current Fallow	14.8%	5.4%	2.5%	3.3%	2.2%	5.8%	7.7%	15.5%	2.5%
Plantation	0.7%	0.3%	0.3%	0.0%	2.1%	0.0%	1.2%	0.2%	7.8%
Evergreen Forest	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
Deciduous Forest	1.3%	25.5%	47.9%	29.1%	0.9%	9.8%	4.6%	7.5%	1.3%
Degraded / Scrub Forest	0.3%	5.3%	20.0%	12.5%	0.1%	5.8%	4.4%	9.2%	0.9%
Littoral Swamp	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wasteland	11.9%	22.1%	4.1%	11.3%	1.0%	4.6%	8.3%	11.4%	4.2%
Waterbodies Max	4.4%	3.1%	1.0%	1.1%	1.2%	1.7%	2.4%	2.5%	2.8%
Waterbodies Min	6.8%	5.5%	0.2%	0.2%	0.0%	0.4%	0.5%	2.6%	0.7%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Determination of water quality risk categories for each GMU
Once the landuse statistics have been calculated for each GMU, the final step is to allocate the risk class.

- Calculate the total % area of the GMU which corresponds to
  Built up area + double cropped + Perennial Crops
  [Perennial crops = plantations]
- Calculate the total % area of the GMU which corresponds to
  Other Agricultural Area
  [Kharif Crop + Rabi Crop + Zaid Crop]



Risk Analysis

GMU_No	1	2	3	4	5	6	7	8	9
Built up area + double cropped + Perennial Crops	28.2%	17.0%	7.9%	17.6%	57.8%	20.8%	23.7%	18.0%	58.2%
Other Agricultural Area	30.3%	16.1%	16.5%	24.8%	36.8%	51.2%	48.4%	33.1%	29.4%
Land use Class 1	Moderate Risk	Low Risk	No Risk	Low Risk	High Risk	Low Risk	Low Risk	Low Risk	High Risk
Land use Class 2	Low Risk	No Risk	No Risk	No Risk	Low Risk	Moderate Risk	Low Risk	Low Risk	Low Risk
Overall Risk	**Moderate Risk**	**Low Risk**	**No Risk**	**Low Risk**	**High Risk**	**Moderate Risk**	**Low Risk**	**Low Risk**	**High Risk**

Risk Categories
No Risk
Low Risk
Moderate Risk
High Risk

Calculate the risk class for:

- Land use Class 1(Built up area + double cropped + Perennial Crops)
- Land use Class 2 (Other Agricultural Area)
- Overall Risk

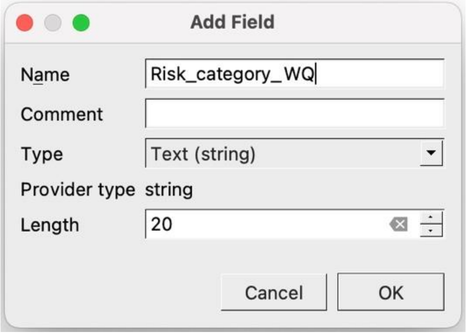
In Excel 365, you can use the following formulas:

Cell	Formula
C69	=IF(C66<0.1,"No Risk",IF(C66<0.25,"Low Risk",IF(C66<0.5,"Moderate Risk","High Risk")))
C70	=IF(C67<0.25,"No Risk",IF(C67<0.5,"Low Risk",IF(C67<0.75,"Moderate Risk","High Risk")))
C71	=INDEX($M$68:$M$71, MAX(XMATCH(C69:C70,$M$68:$M$71)))

Produce initial water quality risk categories map

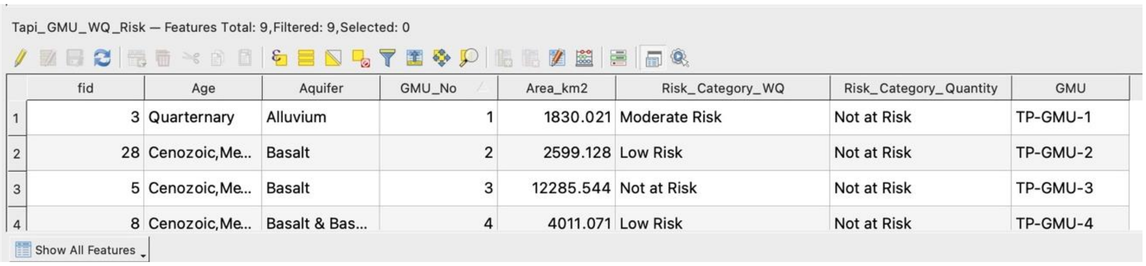
The next step is to produce the initial water quality risk map for the GMUs.

- Right-click the GMU layer in QGIS & select Open Attribute Table
- Toggle Editing mode by clicking on the yellow pencil (Ctrl + E)
- Click on New Field (Ctrl + W)
- Call it **Risk_Category_WQ**, type = text, length = 20



Name: Risk_category_WQ
Comment:
Type: Text (string)
Provider type: string
Length: 20

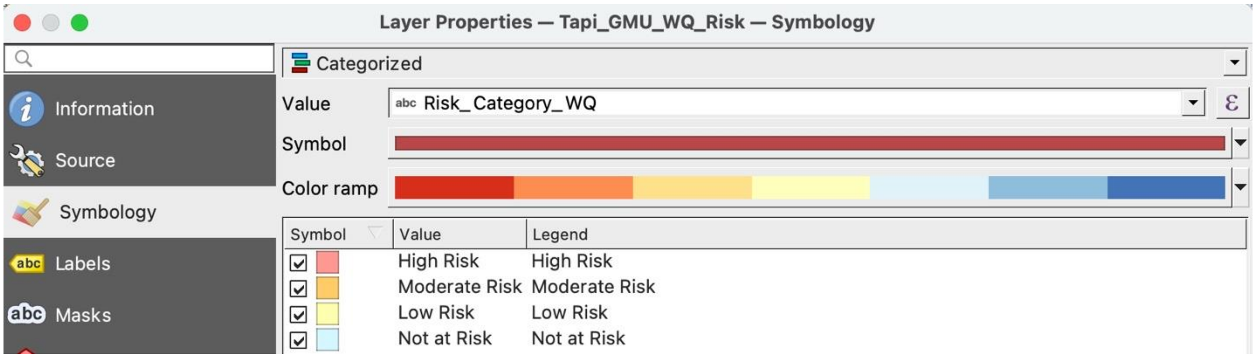
- Copy-paste the correct Quality risk category for each GMU



Tapi_GMU_WQ_Risk — Features Total: 9,Filtered: 9,Selected: 0

	fid	Age	Aquifer	GMU_No	Area_km2	Risk_Category_WQ	Risk_Category_Quantity	GMU
1	3	Quarternary	Alluvium	1	1830.021	Moderate Risk	Not at Risk	TP-GMU-1
2	28	Cenozoic,Me...	Basalt	2	2599.128	Low Risk	Not at Risk	TP-GMU-2
3	5	Cenozoic,Me...	Basalt	3	12285.544	Not at Risk	Not at Risk	TP-GMU-3
4	8	Cenozoic,Me...	Basalt & Bas...	4	4011.071	Low Risk	Not at Risk	TP-GMU-4

- Right-click the GMU layer in QGIS & select Properties – Symbology
- Select Categorized & Risk_Category_WQ
- Click on Classify
- Edit the legend to reflect the risk category



Layer Properties — Tapi_GMU_WQ_Risk — Symbology

Categorized

Value: Risk_Category_WQ

Symbol

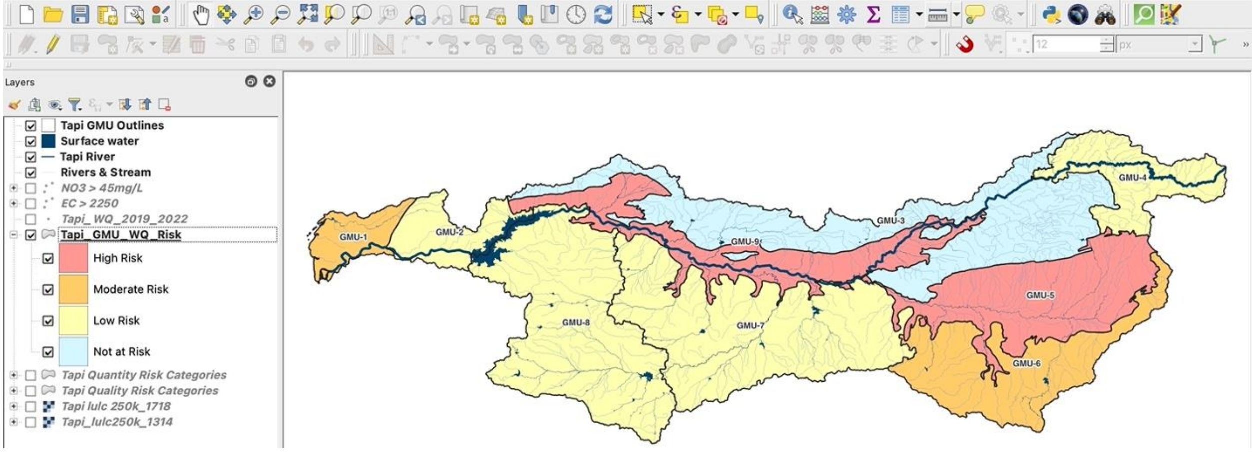
Color ramp

Symbol	Value	Legend
☑ 🟥	High Risk	High Risk
☑ 🟧	Moderate Risk	Moderate Risk
☑ 🟨	Low Risk	Low Risk
☑ 🟦	Not at Risk	Not at Risk

The colours used in the above symbology are as follows:

Table 12: Legend colours for Risk Categories

Category	Red	Green	Blue	HTML
High Risk	254	127	124	#fe7f7c
Moderate Risk	255	190	77	#ffbe4d
Low Risk	255	255	160	#ffffa0
Not at Risk	205	245	255	#cdf5ff


Layers

☑ Tapi GMU Outlines
☑ Surface water
☑ Tapi River
☑ Rivers & Stream
☐ NO3 > 45mg/L
☐ EC > 2250
☐ Tapi_WQ_2019_2022
☑ Tapi_GMU_WQ_Risk
  ☑ High Risk
  ☑ Moderate Risk
  ☑ Low Risk
  ☑ Not at Risk
☐ Tapi Quantity Risk Categories
☐ Tapi Quality Risk Categories
☐ Tapi lulc 250k_1718
☐ Tapi_lulc250k_1314

Concept of water quality hotspots

The output so far is a general groundwater quality risk assessment map based on the land use of each GMU. There could also be a few locations within the GMU where the groundwater has been contaminated or polluted. If these isolated locations are used to downgrade the entire risk category of GMU, it would give an unnecessarily pessimistic impression of the GMU.

The best way to integrate this information to the map is to add these contaminated or pollution groundwater locations as hotspots.

Water Quality hotspots - Urban Areas

The built-up areas have a value of 1 in the LULC raster. These pixels need to be extracted as a merged polygon to make an urban area polygon.

The procedure is as follows:

- Create a new raster of the built-up areas from the LULC raster using the Raster calculator. e.g., use the equation "Tapi lulc 250k_1718@1"=1
- This will produce a raster with a value of 1 for all built-up pixels and a 0 for all other pixels.
- In the Processing Toolbox, under GDAL – Raster Extraction – run Contour Polygons
- The output is a single polygon of the Built-up areas.
- Split the polygon into individual polygons using SAGA – Vector polygon tools – Polygon parts to separate polygons.
- Right-click & open attribute table
- Open the field calculator & create a new field called Numbers. Run row-number.
- In the field calculator update the fid column with these row-numbers.
- Create a new field called Area_km2 & calculate the area of each polygon using area($geometry) /1000000
- Select all built up area polygons with an area > 1km^2 & save.
- Smooth the polygon using Vector geometry – smooth.
- Save the Urban areas layer and put it on top of the GMU Water Quality risk map.

Water Quality hotspots – High Nitrates & Electrical Conductivity (EC)
Areas where water quality analysis show excessively high values of nitrate (NO3) and electrical conductivity (EC) need to be highlighted as hotspots on the map. The procedure is as follows:

- Create a table of the water quality data and format it as a table in Excel.
- Create a columns showing which water analysis have ion balances of >5% and >10%
- Create a column showing which analysis have NO3 > 45mg/L
- Create a column showing which analysis have EC > 2,250 µS/cm
- Create an export table with only those analysis with an ion balance <=5%
- Drop the export table into QGIS.
- Run Vector creation – Vector points from table to create a point layer from the data.
- Show the points where NO3 > 45mg/L
- Show the points where EC > 2,250 µS/cm

6.2.4 Groundwater quantity

Introduction
Assuming that the GMUs have been defined, the Pressure/Impact Analysis and Risk Assessment for groundwater quantity is carried out following a 3-step approach:

- **Step 1:** Consideration of (i) the categorization of assessment units based on quantity, (ii) groundwater level trends and (iii) saline and other intrusions.
- **Step 2:** Expert judgement considering the conceptual understanding of the GMU and field observations.
- **Step 3:** Final synthesis with the final risk assignment, including all related significant pressures and the confidence level of the risk assessment result.

Step 1: Identify Risk Category for each GMU
Comprehensive assessments are available for each individual Groundwater Block (usually a Taluka) which are based on reliable and long-established time series of monitoring data and therefore build a solid basis and starting point for the Pressure/Impact Analysis and Risk Assessment. The latest assessment system is GEC-2022, which has been incorporated into the methodology used for the groundwater quantity risk assessment of the GMUs.

The categorization of groundwater assessment units based on quantity is based on (i) the availability of the groundwater resource and (ii) the stage of groundwater extraction.
The availability of the groundwater resource is the Annual Extractable Groundwater Resource (EGR) which is calculated by deducting the Total Annual Natural Discharge from the Total Annual Groundwater Recharge. It is reported as a depth of water in mm. The annual extractable groundwater resource is categorized into Class-A (>150mm), Class-B (>75 and <=150mm) and Class-C (<=75mm).

The Stage of Ground Water Extraction (SOE) is the percentage of the Existing Gross Groundwater Extraction for all uses divided by the Annual Extractable Groundwater Resource. The stage of groundwater extraction results in three categories: Safe (<=70%), Alert (>70% and <=100%) and Over Exploited (>100%).

Both categories are combined so that each groundwater block is in one of nine possible categories (Class A: Safe-Alert or Over Exploited; Class-B: Safe-Alert or Over Exploited and Class C: Safe-Alert or Over Exploited). The three overexploited classes are further subdivided into three categories based on the last 10-year post monsoon trend which can be either <10cm/year, 10-20cm/year or >20cm/year.

The categorization of groundwater assessment units based on quantity is reported at the Groundwater Block (usually Taluka) level, based on calculations performed separately for each aquifer. As the GMUs are based on aquifers rather than administrative boundaries, the category of groundwater assessment needs to be calculated for each GMU based on the sum of all data for a particular aquifer which may come from one or more Groundwater Blocks.

Part of step 1 is also to identify evidence of saline or other intrusion of substances into the groundwater due to human activities. The interim risk assessment of step 1 is undertaken according to the assessment matrix shown in Figure 23.

Note that the Risk Category is a general assessment for the entire GMU. There may be some **hotspots** within the GMU which are more heavily overexploited. These should be shown as hatched areas. This avoids having to break the GMU into too many small units which will not result in better groundwater management.

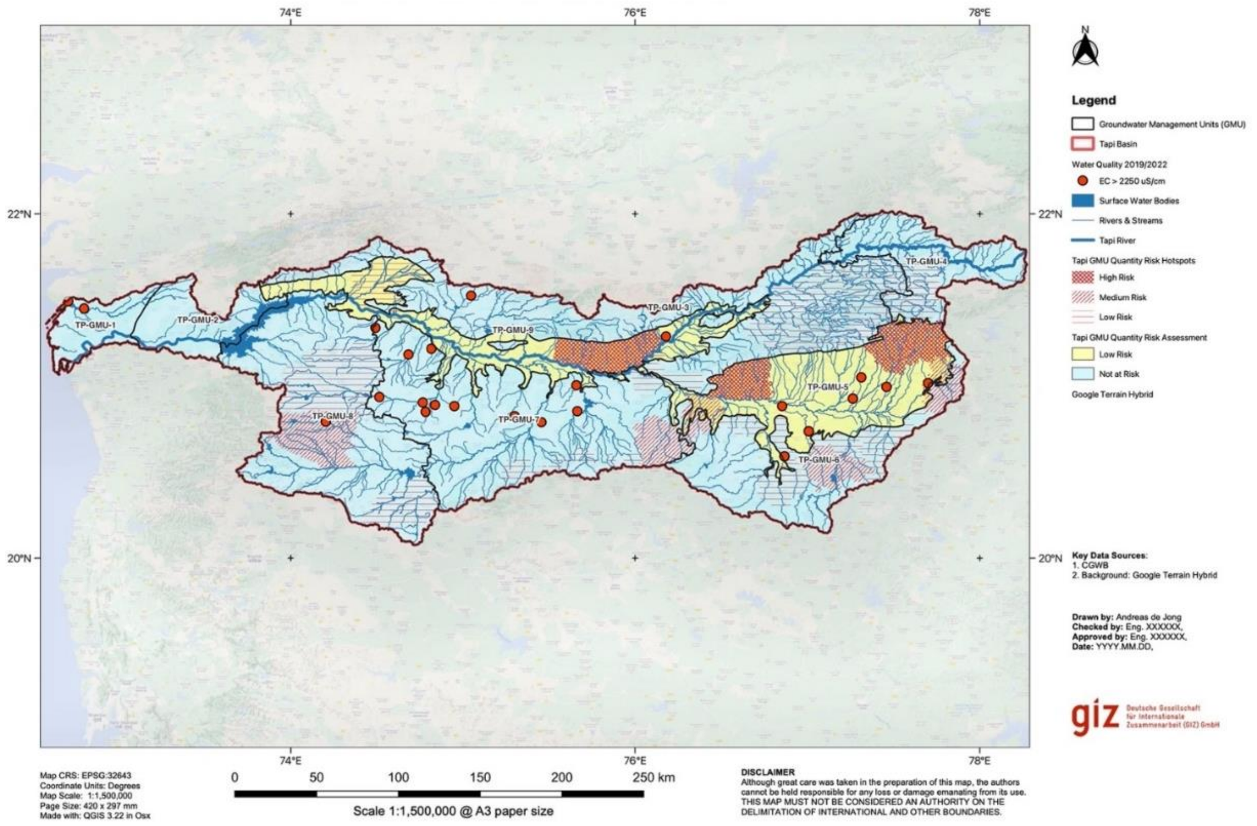
Table 13 GMU Risk Category

SoE (%)	**SoE > 100%**

Class	**Resource (mm)**	**SoE (%) <70%**	**70-100%**	**>100%**	**Min 10 years post-monsoon trend (<10cm/year)**	**Min 10 years post-monsoon trend (10-20 cm/year)**	**Min 10 years post-monsoon trend (>20cm/year)**
Class A	>150 mm	Class A - Safe	Class A - Alert	Class A – Over Exploited	Low Risk	Medium Risk	High Risk
Class B	75-150 mm	Class B - Safe	Class B - Alert	Class B – Over Exploited	Medium Risk	High Risk	High Risk
Class C	<75 mm	Class C - Safe	Class C - Alert	Class C – Over Exploited	High Risk	High Risk	High Risk

Not at risk	🟦
Low Risk	🟨
Medium Risk	🟧
High Risk	🟥

Figure 23: Groundwater quantity risk assessment categories



The calculation of the risk category for each GMU is mostly an exercise that can be completed in MS Excel. It is important that the GMU name in the Excel spreadsheet is consistent with the name used in the GIS layer to be able to link the data together.

Database Rule 3: Always include a unique identifier.

The same applies to the hotspots which will have to be linked with the groundwater blocks/talukas in the GIS.

ID	S. No.	State	District	Taluka	Unique ID	Recharge worthy Area (ha)	Annual Extractable Ground water Resource (ham)	Stage of Ground Water Extraction (	Categorization of	Resource in mm (GWRA 2022)	New Category	Risk
1	1	Maharashtra	Akola	Akola	Maharashtra_Akola_Akola	99521.87	4318.842359	60.73381105	safe	43.39591247	Class C - Safe	Low Risk
2	2	Maharashtra	Akola	Akot	Maharashtra_Akola_Akot	80449.23	4363.652605	64.44498974	safe	54.24107359	Class C - Safe	Low Risk
3	3	Maharashtra	Akola	Balapur	Maharashtra_Akola_Balapur	67013.08	4251.272064	63.51593792	safe	63.43943696	Class C - Safe	Low Risk
4	4	Maharashtra	Akola	Barsi Takli	Maharashtra_Akola_Barsi Takli	68347.37	5344.095296	75.35737226	Semi-Critical	78.19021121	Class C - Alert	Medium Risk
5	5	Maharashtra	Akola	Murtizapur	Maharashtra_Akola_Murtizapur	76798.03	4991.154221	69.56669651	safe	64.99065433	Class C - Safe	Low Risk
6	6	Maharashtra	Akola	Patur	Maharashtra_Akola_Patur	59873.3	5461.868814	68.5651332	safe	91.22378112	Class C - Safe	Low Risk
7	7	Maharashtra	Akola	Telhara	Maharashtra_Akola_Telhara	62161.99	6879.289299	63.68462078	safe	110.6671344	Class B - Safe	Not at Risk
8	8	Maharashtra	Amravati	Achlapur	Maharashtra_Amravati_Achlapur	63812	7655.746375	100.2922705	Over-Exploited	119.9734591	Class B – Over Exploited	High Risk
9	9	Maharashtra	Amravati	Amravati	Maharashtra_Amravati_Amravati	80309	7247.262972	79.97691831	Semi-Critical	90.24222655	Class C - Alert	Medium Risk
10	10	Maharashtra	Amravati	Anjangaon Surji	Maharashtra_Amravati_Anjangaon Surji	52089	5155.437493	60.67511193	safe	98.97363153	Class C - Safe	Low Risk
11	11	Maharashtra	Amravati	Bhatkuli	Maharashtra_Amravati_Bhatkuli	57991	379.8193138	55.53058597	safe	6.54962518	Class C - Safe	Low Risk
12	12	Maharashtra	Amravati	Chandur Bazar	Maharashtra_Amravati_Chandur Bazar	66563	6502.28073	143.0068263	Over-Exploited	97.68611286	Class B – Over Exploited	High Risk
13	13	Maharashtra	Amravati	Chikhaldara	Maharashtra_Amravati_Chikhaldara	31728	2987.42671	64.65123738	safe	94.15742278	Class C - Safe	Low Risk
14	15	Maharashtra	Amravati	Dharni	Maharashtra_Amravati_Dharni	39180	3744.5075	47.7029078	safe	95.57191169	Class C - Safe	Low Risk
15	16	Maharashtra	Aurangabad	Sillod	Maharashtra_Aurangabad_Sillod	117696	12736.24479	71.57702136	Semi-Critical	108.2130641	Class B - Alert	Not at Risk
16	17	Maharashtra	Buldhana	Chikhali	Maharashtra_Buldhana_Chikhali	93581	10660.22437	79.21873945	Semi-Critical	113.9144097	Class B - Alert	Not at Risk
17	18	Maharashtra	Buldhana	Jalgaon	Maharashtra_Buldhana_Jalgaon	54218	5213.14988	116.5882639	Over-Exploited	96.15164484	Class B – Over Exploited	High Risk
18	19	Maharashtra	Buldhana	Khamgaon	Maharashtra_Buldhana_Khamgaon	96087	9947.81072	70.52489278	Semi-Critical	103.529205	Class B - Alert	Not at Risk
19	20	Maharashtra	Buldhana	Malakapur	Maharashtra_Buldhana_Malakapur	44372	4741.40764	77.09250105	Semi-Critical	106.8558469	Class B - Alert	Not at Risk
20	21	Maharashtra	Buldhana	Mehkar	Maharashtra_Buldhana_Mehkar	90285	10747.80366	62.15342815	safe	119.0430709	Class B - Safe	Not at Risk
21	22	Maharashtra	Buldhana	Motala	Maharashtra_Buldhana_Motala	56018	5116.770762	84.3508169	Semi-Critical	91.34154668	Class C - Alert	Medium Risk
22	23	Maharashtra	Buldhana	Nandura	Maharashtra_Buldhana_Nandura	53625	4867.057606	81.74409715	Semi-Critical	90.760981	Class C - Alert	Medium Risk
23	24	Maharashtra	Buldhana	Sangrampur	Maharashtra_Buldhana_Sangrampur	51627	4213.949782	113.6685169	Over-Exploited	81.62298375	Class B – Over Exploited	High Risk
24	25	Maharashtra	Buldhana	Shegaon	Maharashtra_Buldhana_Shegaon	50979	3251.473706	58.19320964	safe	63.78064901	Class C - Safe	Low Risk
25	26	Maharashtra	Dhule	Dhule	Maharashtra_Dhule_Dhule	182626	18336.01722	64.313196	safe	100.4020086	Class B - Safe	Not at Risk
26	27	Maharashtra	Dhule	Sakri	Maharashtra_Dhule_Sakri	196767	19520.38827	48.5317412	safe	99.20559987	Class C - Safe	Low Risk
27	28	Maharashtra	Dhule	Shirpur	Maharashtra_Dhule_Shirpur	130779	16461.76	46.09464602	safe	125.8746435	Class B - Safe	Not at Risk
28	29	Maharashtra	Dhule	Sindkheda	Maharashtra_Dhule_Sindkheda	131960	13948.72451	50.08821406	safe	105.704187	Class B - Safe	Not at Risk
29	30	Maharashtra	Jalgaon	Amalner	Maharashtra_Jalgaon_Amalner	89266	11802.17872	72.33938444	Semi-Critical	132.2135944	Class B - Alert	Not at Risk
30	31	Maharashtra	Jalgaon	Bhadgaon	Maharashtra_Jalgaon_Bhadgaon	49142	10545.2801	75.55316648	Semi-Critical	214.5879309	Class A - Alert	Not at Risk

Figure 24: Tapi Basin groundwater risk assessment table

Step 2: Expert judgement (Common sense approach)

The next step in the assessment is to look at the output of Step 1 and to ask the following key questions:

- Do the results make sense?
- Are they comparable with the conceptual hydrogeological model?
- How do the long-term groundwater level trends compare with the risk assessment?
- If they are different, what is the reason for this and is it acceptable or should the risk category be changed?

One of the key independent tools available to us is the long-term groundwater level records. Where areas of excessive groundwater over-abstraction/mining has been identified, either over the entire GMU or as a hotspot, this should be confirmed by a decline in the groundwater levels. If this is not visible, either the monitoring system is not representative of the aquifers, or there is a calibration problem with the assessment.

This water level check can be made with the groundwater level database set up as described in Section 0.

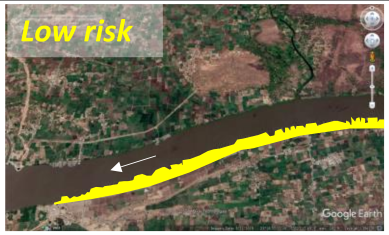
Step 3: Final synthesis with the final risk assignment

The final step of the risk assignment is to decide on the risk category for each GMU, and make sure that all hotspots have been identified. We can think of Step 2 & 3 as standard quality control steps which any professional hydrogeologist should do to check his/her work.

6.2.5 River morphology & Sediment

The present risk assessment can be presented by using definitions of the risk categories as follows:

1	“**no risk**”: Those sites show no hydro-morphological alterations due to sand mining; only some minor disturbances are observed (e.g. roads in the main channel during low flow).
2	“**low risk**”: Sites with this risk classifications contain obvious sand mining activities. Their spatial extent, however, is limited to only half of the cross sectional bankfull width.
3	“**at risk**”: Sand mining activities which affect the entire cross sectional bankfull width and major hydro-morphological alterations as a consequence.



(a)

(b)

(c)

Then the results of the risk analysis can be presented graphically as follows:

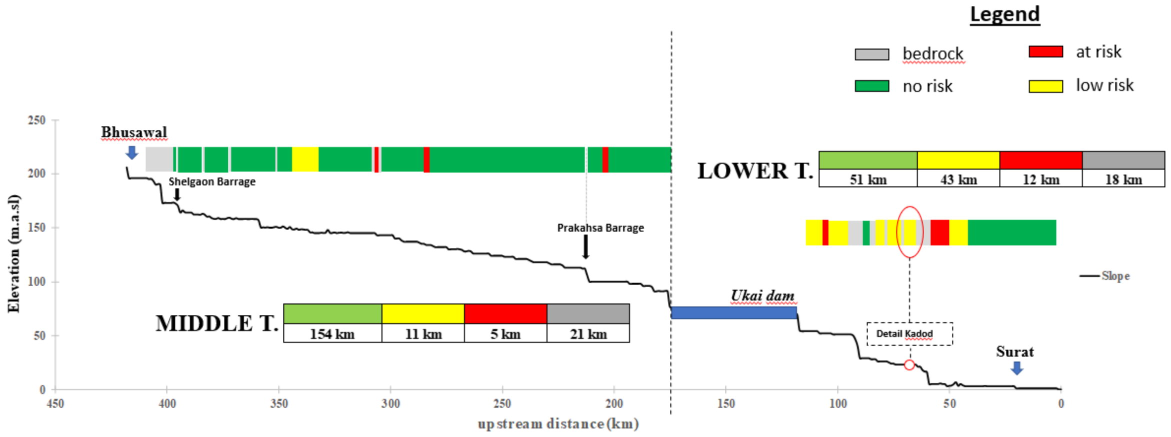


Figure 25 Results of the Risk Assessment for sand mining for the LOWER and MIDDLE Tapi River

(black solid line = longitudinal profile extracted of the 1-D hydrodynamic-numerical model (n = 412 cross sections); Ukai dam highlighted by blue bar; dashed lines = a detailed section investigated for the framework of exposed bedrock and sand mining activities; major dams and major cities are additionally indicated by black and blue arrows respectively).

Evaluation of the methodology

The risk analysis classification relies basically on the assumption that the actual situation will continue: sand mining is actually observed on Google Earth images. However, the risk should be connected with expected morphological changes. The approach tries to do so via expected replenishments.
From the figures erosion may be concluded, however chances are that pictures have been taken during low discharges, leading to the conclusion of erosion. Pictures taken during high discharges may cover rocks and may lead to the conclusion of sedimentation or even equilibrium. The planform changes can also be inflicted by other anthropogenic actions, like building dams and reservoirs, river constrictions, etc. Bedrock will not prevent erosion between bedrock sites. Erosion can very well continue and cause failure of banks and structures. Surely bedrock sites will slow down the erosion. However a deficit of sediment from upstream will continue to cause erosion, also downstream of the rock sites.
Future sand mining in actual "no risk sites", can lead to "at risk" situations, also downstream, when a shortage of sediments through mining is created.

The possible replenishing depends to a large extend on the sediment supply-rates and the absolute magnitude of flood discharge and not to some general hydraulic differences related to the river

bathymetry (as quoted above) is the essence of a morphological risk analysis. If no information on sediment supply and differences in sediment transports is available a morphological risk is not reliable. The images give the actual picture, however this situation cannot predict the future situation. For that a predictive morphological model is required. Expected replenishment is the key trigger to define 'no risk'. However, it is not known whether and to what extent this sediment is transported past the mining site. ‘In regime’ stretches are also a criterion of the actual risk assessment. Bed erosion will indeed lower the water levels, however it is not known why the bed has been eroded. This can also be from a natural shortage of sediment or by anthropogenic actions, e.g. through dams and barrages.
Moreover, the applied method is very and time-consuming. For application on many rivers morphological models have to be used.

Alternative risk assessment approach for KWMI 5 (Alterations of River Morphology through Sand Mining) based on morphological models
If a methodology must be developed for many more Indian rivers, the actual risk assessment approach is too labour-intensive and not very reliable. It is proposed to extend the existing 1D HEC-Ras model with the morphological possibilities offered by the software. To apply morphological models besides hydraulic and bathymetric data, sedimentological data are required, especially grain sizes. Field studies can provide this data.

The model should be run using daily, weekly or monthly discharges of the Tapi River and its tributaries. The sediment transport capacities along the river are computed. Increasing sediment transport capacities result in erosion, decreasing sediment transport capacities in sedimentation. Then, in theory at sedimentation spots dredging could be permitted, however taking out sediment will be eroded downstream by scouring. In a hydraulic model these morphological changes will not be represented.
To define a suitable sediment transport equation (e.g. Engelund-Hansen), these equations should be calibrated with measured sediment transport data at various locations along the river. For this the existing 4 sediment transport measuring stations are not enough. At every location where a serious change in sediment flux can be expected the sediment transport should be measured. For this special survey vessels should be used.

With the selected sediment transport equation the morphological changes in the riverbed can be computed by the model, for the next e.g. 20 years. Maybe also a new equilibrium bed level can be estimated using a time window of 50 years. Aggrading spots can be distinguished. Dredging spots could be defined, by simulating the effects of sand mining at various locations in the model.
A preliminary feasibility study should be carried out whether even a 2D morphological model should be used, as the effort to build a 2D model today maybe the same or even less than building a 1D model, as less schematisation is required.

6.3 Presentation of the results of the Risk Assessment

For example, to present the results for all five KWMI’s in the Tapi River Basin regarding the risk to fail the Overall Tapi River Basin Aims and objectives, the Risk Assessment results for all KWMI’s are presented based on the scale of the assessment:

- KWMI 1 and 2: are based on the analysis of the 34 identified SWMU’s for the whole Tapi basin;
- KWMI 3: is based on the 10 hydrological sub-catchments in the Tapi basin;

- KWMI 4: is based on the 9 identified GMU’s for the whole Tapi basin;
- KWMI 5: is based on 1,546 river kilometres that has been investigated.

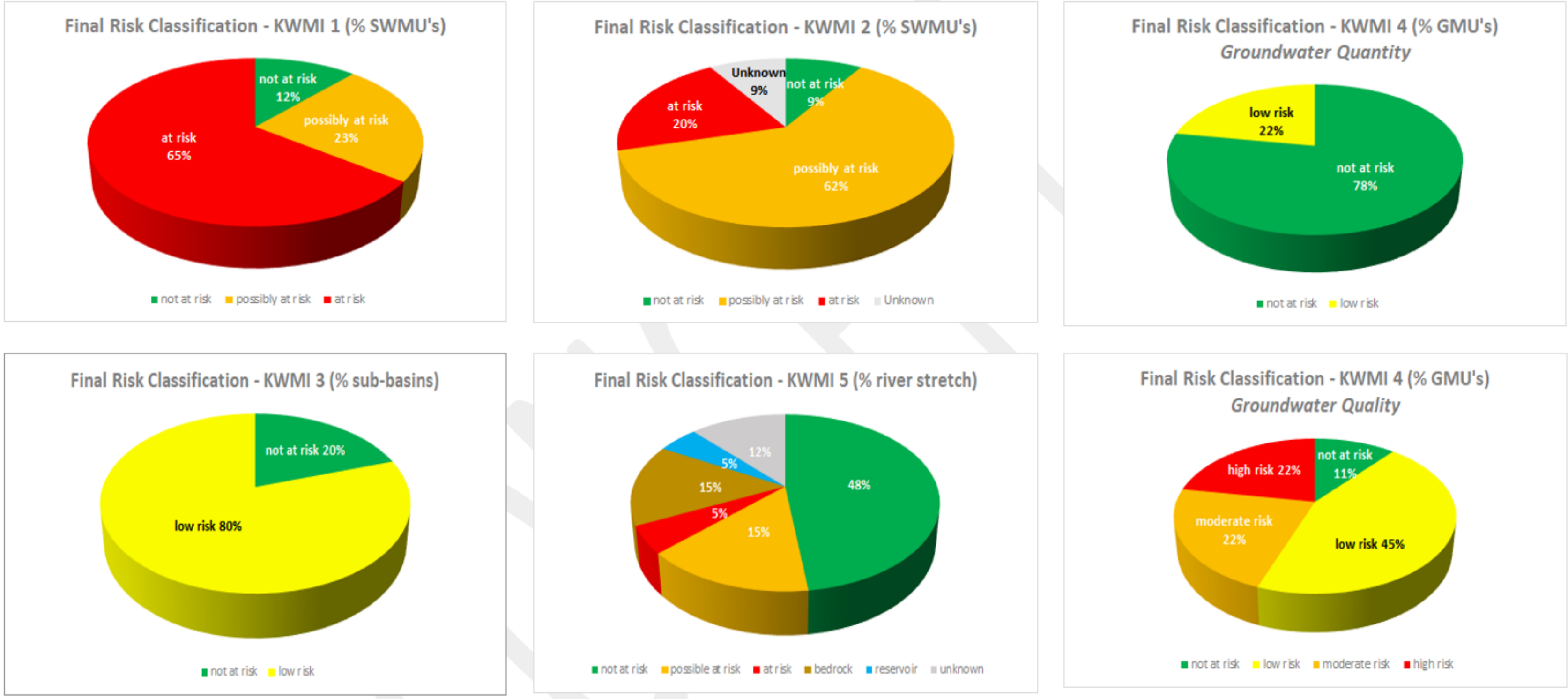


Figure 26 Example of a presentation of the final Risk Assessment for all KWMIs based on the Tapi RBM plan 2023

7 Modelling Surface water, Groundwater and E-Flows in a river basin

- ***Defining the <u>impact</u> of the drivers and pressures on the water system.***

7.1 Use of models

*See **Annex 3** – Training Module on RIBASIM & E-Flows Assessment in Ramganga Basin.*

Many models provide a large variety of settings and options. These options have been developed because many different modelling objectives require specific options. This implies that the model developer must carefully consider the objective of her/his model before starting to develop a model application.

Every model application is suitable to be used for the purposes it was designed for, but is probably unsuitable, without adaptation, to be used for another objective. For example, several different RIBASIM model applications may be developed for the same basin. Before the software is used it is recommended to carefully think about what it exactly that the model is expected to do and whether the required information is available.

Every model application also has its specific data needs. If for example, the objective of the model is to evaluate future scenarios of demand development, then it is important that the present needs and allocation or diversion rules are understood and known, otherwise the model settings cannot be set at sensible values and scenario comparisons become useless because it is not known whether the settings are realistic.

It a good modelling practise to document the choices made in application development and to consider whether the model is suitable to assess the new question before a new model run is made. Maybe the application first needs to be adapted, or that a different model application needs to be developed or even another model (software) is more suitable.

Almost all professional model software that is available performs well in the sense that the functionality works well. However, this does not automatically mean that a model application that is developed with such software results in a good or sensible model application. The expertise, experience and choices of the modeller define the result, not the software.

7.2 Overview of models that can be used on RBM planning

River basin management (RBM) planning involves assessing and managing various aspects of surface water, groundwater, and environmental flows (E-flows) within a river basin. Here's an overview of models commonly used for RBM planning in these three components:

1. Surface Water:

- Rainfall-Runoff Models: These models simulate the transformation of rainfall into runoff and are used to estimate the hydrological response of a catchment. Examples include the SCS Curve Number method, HEC-HMS, and SWAT.
- Hydrological Models: These models provide a more comprehensive representation of surface water processes, including rainfall-runoff, stream-flow routing, and basin-wide water balance. Popular hydrological models used for RBM planning include SWAT, RIBASIM, HEC-HMS, MIKE SHE, and TOPMODEL.
- Hydraulic Models: These models simulate the flow of water in rivers, including flood routing, sediment transport, and river channel hydraulics. Prominent options are HEC-RAS, MIKE Flood, and Flood Modeller.

2. Groundwater:

- Groundwater Flow Models: These models simulate the movement of water through porous subsurface media, aiding in understanding aquifer behavior, groundwater availability, and developing management strategies. Commonly used groundwater flow models include MODFLOW, FEFLOW, and MIKE SHE.
- Transport Models: These models focus on simulating the transport of dissolved contaminants in groundwater, providing insights into pollution risk assessment and mitigation strategies. Examples include MODFLOW-based groundwater contaminant transport models or specialized software like MT3DMS and SEAWAT.
- Coupled Surface Water-Groundwater Models: These integrated models simulate the interaction between surface water and groundwater systems, enhancing the understanding of the water balance, baseflow contributions, and the effects of pumping or recharge activities. Models like MIKE SHE and GSFLOW can be used for surface water-groundwater interaction analysis in RBM planning.

3. Environmental Flows (E-Flows):

- Habitat Suitability Models: These models assess the habitat requirements of different aquatic species and help determine the environmental flow requirements necessary to maintain their ecological health. Examples of habitat suitability models include MesoHABSIM, Instream Flow Incremental Methodology (IFIM), River2D, and PHABSIM.
- Ecohydraulic Models: These models combine hydraulic and ecological components to assess the impacts of flow alterations on river ecosystems, including fish migration, habitat connectivity, and riverine biodiversity. Well-known ecohydraulic models include CASiMiR, River2D, and BASEMENT.
- Decision Support Systems (DSS): These tools integrate multiple modeling approaches to support decision-making related to environmental flow management. DSS platforms like RiverWare, WEAP (Water Evaluation and Planning System), and AQUATOOL provide a framework for assessing and exploring different E-flow scenarios.

These are just a few examples of models available for RBM planning in surface water, groundwater, and E-flows. The choice of model depends on factors such as the specific objectives, data availability, computational resources, and the complexities of the river basin being studied. It is essential to consider the strengths and limitations of each model before selecting the most appropriate one for a given RBM planning exercise.

7.3 Basic principles for setting up a model

Setting up a hydrological model involves several principles that guide the process of simulating the behaviour of water within a river basin. Here are some basic principles for setting up a hydrological model:

1. System Conceptualization: Understand the hydrological system by delineating the boundaries of the watershed and identifying the main components such as precipitation, surface runoff, evapotranspiration, groundwater flow, and streamflow.

2. Data Collection: Gather relevant data including meteorological data (rainfall, temperature, humidity, wind speed), terrain information (elevation, slope, land cover), hydrological data (streamflow, groundwater levels), and soil properties (texture, infiltration rates). These data are crucial inputs for the model.

3. Spatial Discretization: Divide the watershed into manageable spatial units or sub-basins based on topography, land use, or other characteristics. This allows for capturing spatial heterogeneity and variabilities.

4. Temporal Discretization: Decide on an appropriate time step for modeling, considering the temporal resolution of input data and the hydrological processes of interest. Common time steps include daily, hourly, or even sub-hourly intervals.

5. Model Selection: Choose an appropriate hydrological model based on the objectives, data availability, computational resources, and level of detail required. There are various models available, from simple conceptual models (e.g., unit hydrographs) to physically based distributed models (e.g., SWAT, RIBASIM, MIKE-SHE).

6. Calibration: Adjust the model parameters to best fit the observed data, typically streamflow or groundwater levels, using optimization techniques. Calibration is essential to enhance model accuracy and improve its predictive capabilities.

7. Validation: Assess the model's performance using independent datasets that were not used during calibration. This step helps evaluate the model's ability to simulate hydrological processes under different conditions.

8. Sensitivity Analysis: Investigate the sensitivity of the model to changes in input parameters, initial conditions, or model structure. This analysis can help identify the most influential factors affecting model outputs.

9. Uncertainty Assessment: Quantify the uncertainties associated with the model, inputs, and processes. Uncertainty analysis can be performed using statistical methods, ensemble simulations, or Bayesian frameworks.

10. Scenario Evaluation: Use the calibrated model to simulate the impact of different scenarios or management alternatives. This allows for evaluating potential hydrological responses under changing conditions or for assessing the effectiveness of various water management strategies.

Remember that setting up a hydrological model is an iterative process, and it often requires collaboration with domain experts, careful interpretation of results, and continuous refinement to improve the model's accuracy and reliability.

7.4 SWAT

Over the past 20 years, the Soil and Water Assessment Tool (SWAT) has become widely used across the globe. Various applications of the model have revealed limitations and identified model development needs. Numerous additions and modifications of the model and its individual components have made the code increasingly difficult to manage and maintain. In response to these issues and in order to face present and future challenges in water resources modeling, the SWAT code has undergone major modifications over the past few years, resulting in SWAT+, a completely restructured version of the model. Even though the basic algorithms used to calculate the processes in the model have not changed, the structure and organization of both the code (object based) and the input files (relational based) have been modified significantly. This is expected to facilitate model maintenance, future code modifications, and foster collaboration with other researchers to integrate new science into SWAT modules. Additionally, SWAT+ provides a more flexible spatial representation of interactions and processes within a watershed.

SWAT was developed by USDA-ARS and Texas A&M scientists: SWAT | Soil & Water Assessment Tool (tamu.edu).

7.5 RIBASIM

An integrated approach to the water system and its surroundings is the basis for long-term, sustainable management of environment. Multi sector planning to allocate scarce resources at the river basin level is increasingly needed in the water sector, as water users and governmental agencies become more aware of the trade-offs occurring between quantity, quality, costs and reliability. The RIBASIM (RIver BAsin SIMulation) model package provides an effective tool to support the process of planning and resource analysis. Since 1985 RIBASIM has been applied in more than 30 countries world-wide and is used by a wide range of national and regional agencies (see example of Tapi in Figure 27). More info can be found on the website *www.deltares.nl/en/software/ribasim*.

RIBASIM is a generic model package for simulating the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and to see the results in terms of water quantity, water quality and flow composition. RIBASIM can also generate flow patterns which provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs.

RIBASIM is a WINDOWS-based software package and includes a range of Delft Decision Support Systems Tools.

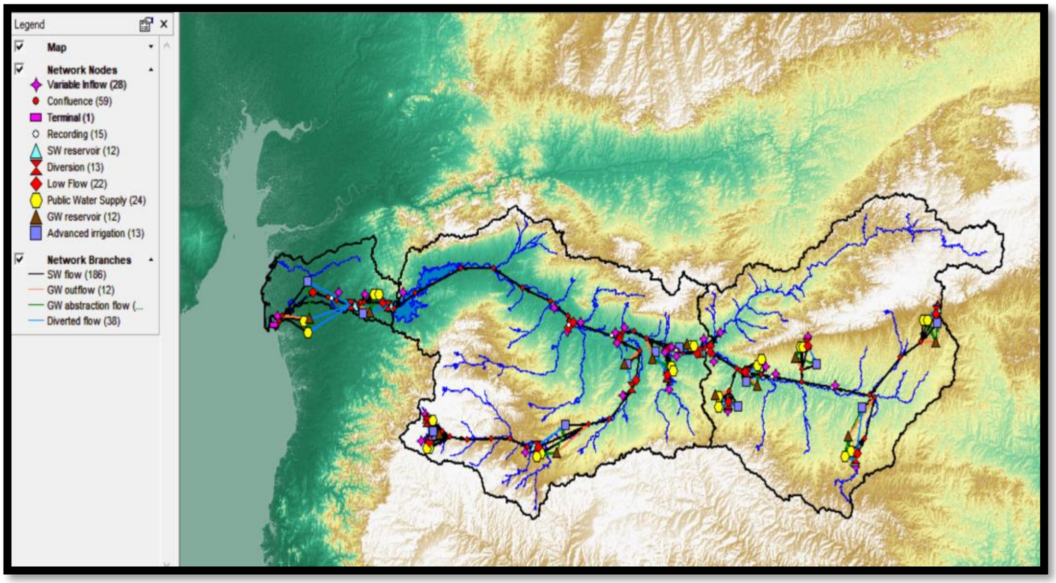


Figure 27 RIBASIM network schematization of Tapi river basin

Structure of the analysis

The main RIBASIM user interface is presented as a flow diagram of blocks representing the tasks to be carried-out, and their order, to complete the simulation process. The interface guides the user through the analysis from data entry to the evaluation of results. The blocks change colour on the computer screen to show the user which tasks have already been finished, which are in progress, and which still have to be done. The results of various simulation cases can be analysed together. The user does not need to work with the underlying file and directory structures nor with file management. The DELFT tools provide an environment which organises these user functions. These tools have an open structure which makes it possible to add or remove blocks from the flow diagram and to adapt the interface to project requirements.

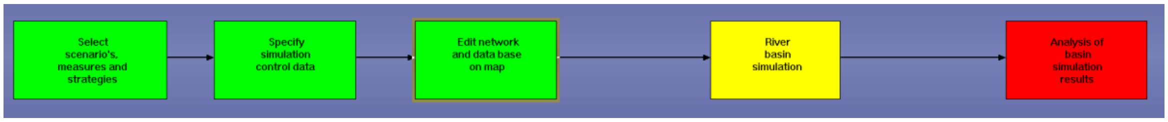


Figure 28 The user interface of RIBASIM presented by block flow diagram

Principles of river basin schematization

To perform simulations with RIBASIM, a model network schematization of the basin has to be made, in which all the necessary features of the basin are represented by nodes connected by links. Such a model schematization is a translation - and a simplification - of the "real world" into a format, which allows the actual simulation. Roughly speaking there are four main groups of elements to be schematized:

1 Infrastructure (surface and groundwater reservoirs, rivers, lakes, canals, pumping stations, pipelines), both natural and man-made;

2 Water users (public water supply, industry, cooling water, agriculture, hydropower, aquaculture, navigation, nature, recreation), or in more general terms: water related activities;

3 Management of the water resources system (reservoir operation rules, allocation methods);
4 Hydrology (river flows, runoff, precipitation, evaporation) and geo-hydrology (groundwater flows, seepage).

These groups are each schematized in their own way. The result of the schematization is a *network of nodes and links* which reflects the *spatial relationships* between the elements of the basin, and the data characterizing those nodes and links.

Interactive schematization of the river basin

RIBASIM enables a schematization of the river basin to be prepared interactively from a map. This schematization consists of a network of nodes connected by branches or links. The nodes represent reservoirs, dams, weirs, pumps, hydro-power stations, water users, inflows, man-made and natural bifurcations, intake structures, natural lakes, swamps, wetlands, etc. The links transport water between the different nodes. Such a network represents all of the basin’s features which are significant for its water balance and it can be adjusted to provide the exact level of detail required. The river basin is presented as a map over which the network schematization is superimposed as a separate map layer. The background map can be produced by any Geographical Information System. The attribute data of the network elements are entered interactively and linked to the map of the river basin and its network schematization. Data consistency tests are an integral part of this.

Scenarios, measures and strategies

RIBASIM is setup by a model data base of the river basin network schematization and a hydrological data base of time series, see Figure 29. The model data base contains the data describing the network schematization of all existing and potential (inactive) infrastructure and water users, the node and link characteristics, the source priority list and the water allocation priorities. The hydrological data base contains historical and alternative hydrological time series of runoff, flow, groundwater exfiltration, rainfall and evaporation stored in one or more hydrological scenarios.

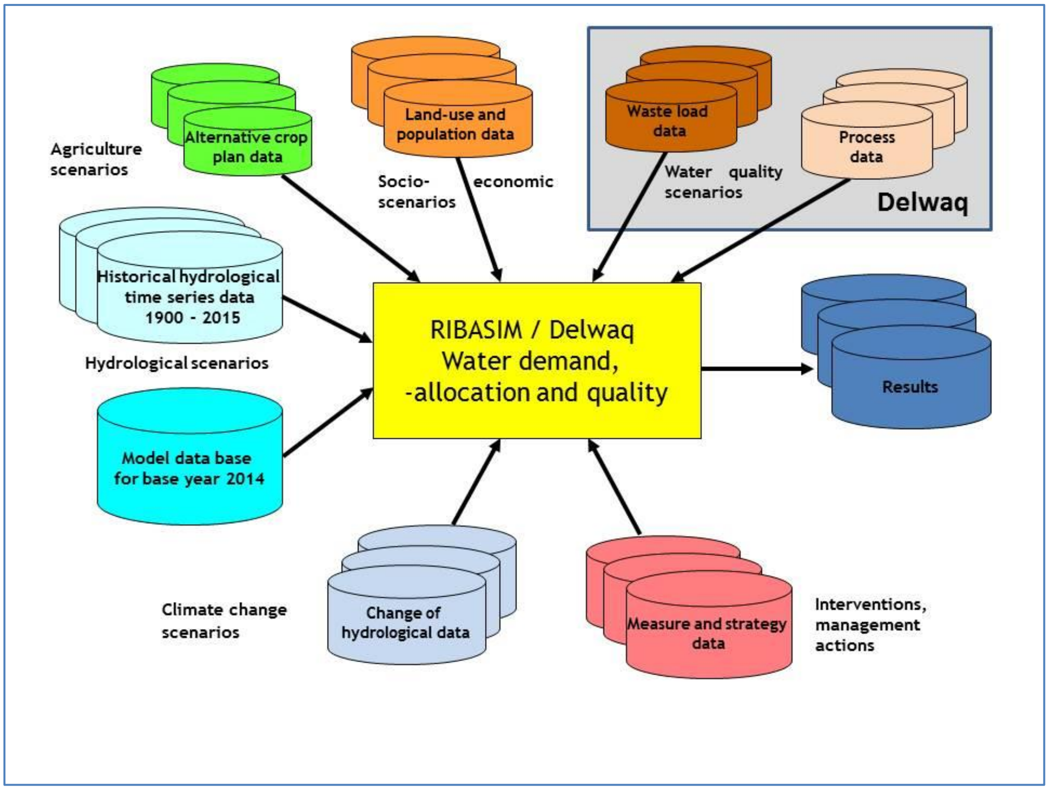


Figure 29 Input- and output structure of the RIBASIM with Delwaq model

Various future and potential situations and system configurations can be modelled by defining scenarios and management actions (strategies, interventions). The following options are available:

1 Hydrological scenarios. This scenario type covers multiple years and annual time series of runoff, flow, rainfall, groundwater exfiltration and evaporation;
2 Climate change scenarios. This scenario type contains the percentage change of the hydrological variables defined in the hydrological scenarios due to climate changes;
3 Land-use and population scenarios. This socio-economic scenario type contains the percentage change in irrigated area, population numbers and industrial demand per catchment of base year (stored in the model data base) for future demand years;
4 Agriculture scenarios. This scenario type contains the alternative future crop plans per catchment;
5 Water quality scenarios. Depending on the run mode one of the following scenarios are used:
   a Basic water quality scenario. This scenario type is used in the run mode without Delwaq and contains the definition of substances and associated waste load lookup tables;
   b Delwaq water quality scenario. This scenario type is used in the run mode with Delwaq and contains the waste load related data like emission factors and treatment efficiency, and chemical and biological process data. The data is used by the waste load estimation model to compute the industrial, domestic and agriculture waste loads;
6 Measure and strategies. One or more management actions (strategies, interventions) can be defined. Each management action consists of a combination of defined potential measures. A large variety of measures are valid. Measures can also be labelled with a time stamp to specify when the measure must become active or can be site specific then the measure becomes active when a certain site condition occurs.

River basin simulation

Simulations are usually made over long (multiple years) time series to include the occurrence of dry and wet periods. The simulation time steps used are variable and are defined by the user. Within each time step, the water demand is determined, resulting in targets for water releases from reservoirs, aquifers, lakes, weirs and pumping stations. Then, the water is allocated to the users according to the release targets, water availability, operation rules and water allocation priorities.

Water allocation to users can be done in several ways: at its simplest, water is allocated on a "first come, first served" basis along the natural flow direction. This allocation can be amended by rules which, for example, allocate priority to particular users, or which result in an allocation proportional to demand.

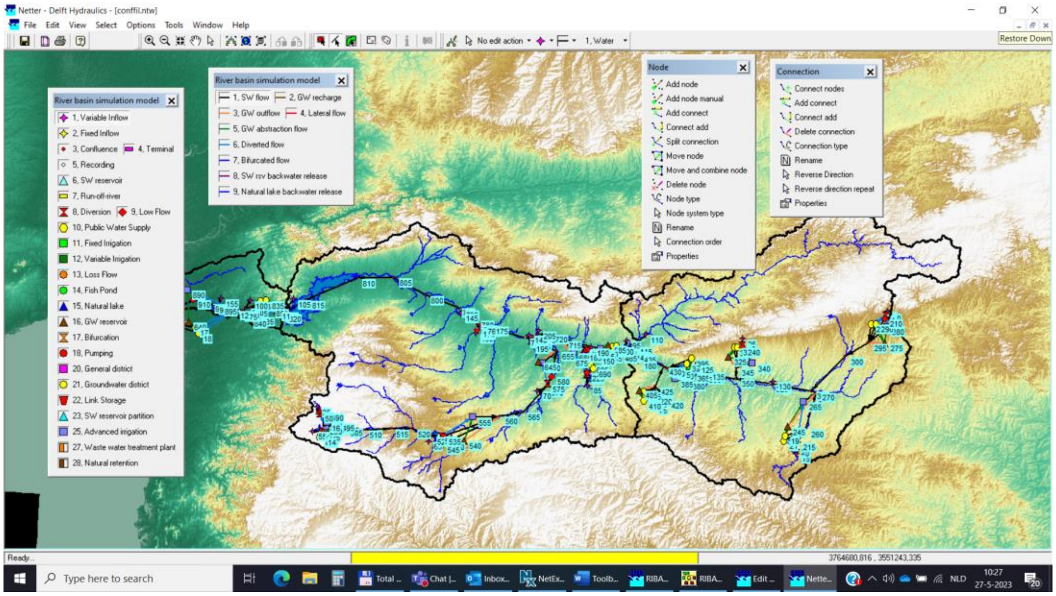
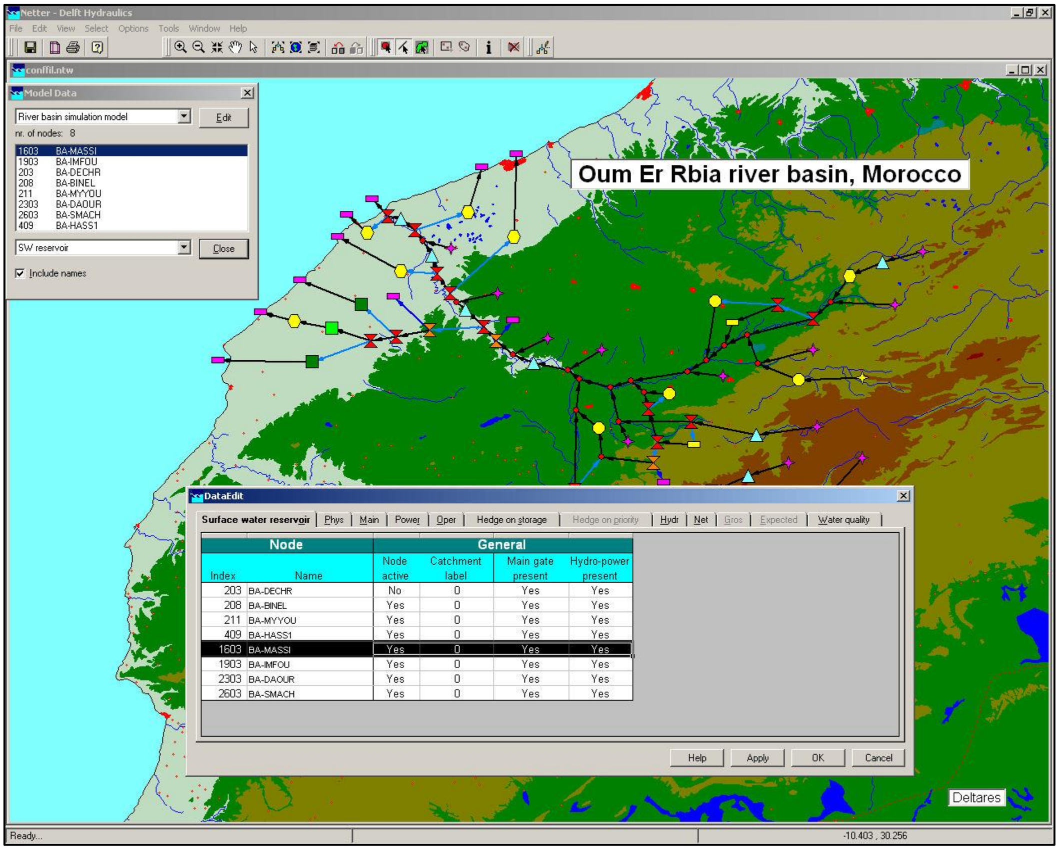


Figure 30 Interactive design of river basin network schematization for Tapi River basin



River basin simulation model

nr. of nodes: 8

1603 BA-MASSI
1903 BA-IMFOU
203 BA-DECHR
208 BA-BINEL
211 BA-MYYOU
2303 BA-DAOUR
2603 BA-SMACH
409 BA-HASS1

SW reservoir

☑ Include names

Node		General			
Index	Name	Node active	Catchment label	Main gate present	Hydro-power present
203	BA-DECHR	No	0	Yes	Yes
208	BA-BINEL	Yes	0	Yes	Yes
211	BA-MYYOU	Yes	0	Yes	Yes
409	BA-HASS1	Yes	0	Yes	Yes
1603	BA-MASSI	Yes	0	Yes	Yes
1903	BA-IMFOU	Yes	0	Yes	Yes
2303	BA-DAOUR	Yes	0	Yes	Yes
2603	BA-SMACH	Yes	0	Yes	Yes

Figure 31 Spreadsheet based interactive entry of reservoir node model data

Evaluation of results

Using a set of simulations, usually made for a range of alternative development or management strategies, the performance of the basin is evaluated in terms of water allocation, water shortages, firm and secondary hydropower production, overall river basin water balance, flow composition, crop production, flood control, water supply reliability, groundwater use, etc.

The user can select how the output data will be shown and in which format: graphs, thematic maps, tables or spreadsheet. A wide range of functions are available to provide insight into the behaviour of large and complex river basins. For instance, it is possible to make an animation of the basin in which flow is indicated with arrows and the size of the flow is shown in different colours and/or line thickness. In a similar way, other output parameters, can be shown. By clicking the item on the map and then selecting the desired output parameter, time diagrams can be presented. Moreover, all output data can be simply exported into other formats.

Additional features

RIBASIM has a number of additional features that can be very useful for the advanced use of the software, and the analysis of the behaviour of a river basin. Such features include:

Fraction computation

RIBASIM supports a default and user-defined source analysis (*fraction computation*) that gives insight in the water's origin and residence time at any location of the basin and at any time within the simulation period. As an example, in Figure 32 the change in composition of the water is shown for a surface water reservoir over a number of years, expressed in fractions (0,0 – 1,0), allowing also for the assessment of the residence time (indicated by red arrow, time needed for the original water content of the reservoir to be entirely renewed).

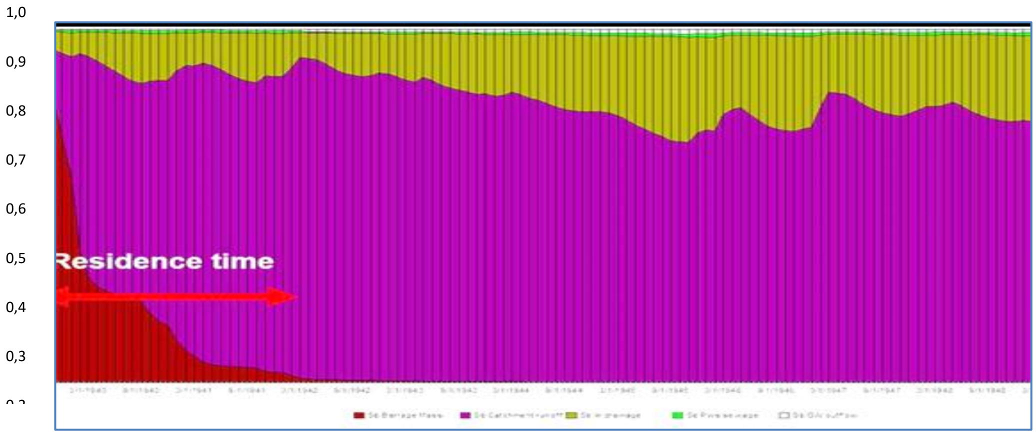


Figure 32 Flow composition of water in Massira reservoir from 1940-1949 (Oum Er Rbia River basin, Morocco)

Evidently, this option allows for the 'tracking' of the water from different sources and makes it possible to follow the changes in the source of the water in time, e.g. the percentage of water coming from an upstream reservoir or from certain tributaries in different seasons and in wet / dry years. In the Tapi model this was not used. An example of such a tracking activity is shown in Figure 33, where the inflow from a tributary, and the return flow from irrigation and waste water, slowly takes over the original uniform composition (red colour from top source). This is a very strong tool for analysis of the system behaviour of a river basin and can be used in the future to show the change in behaviour due to development scenarios and climate change.

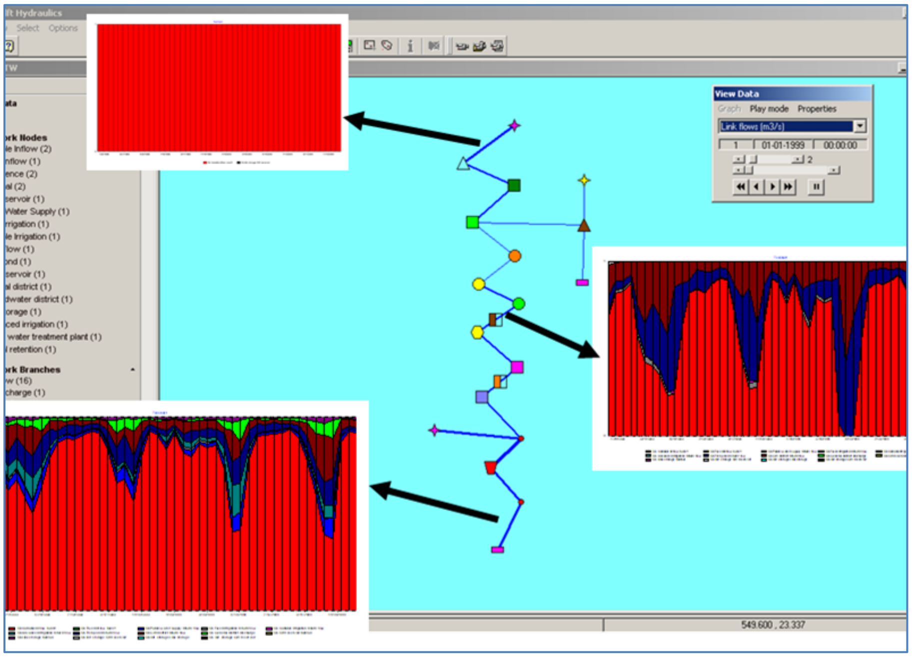
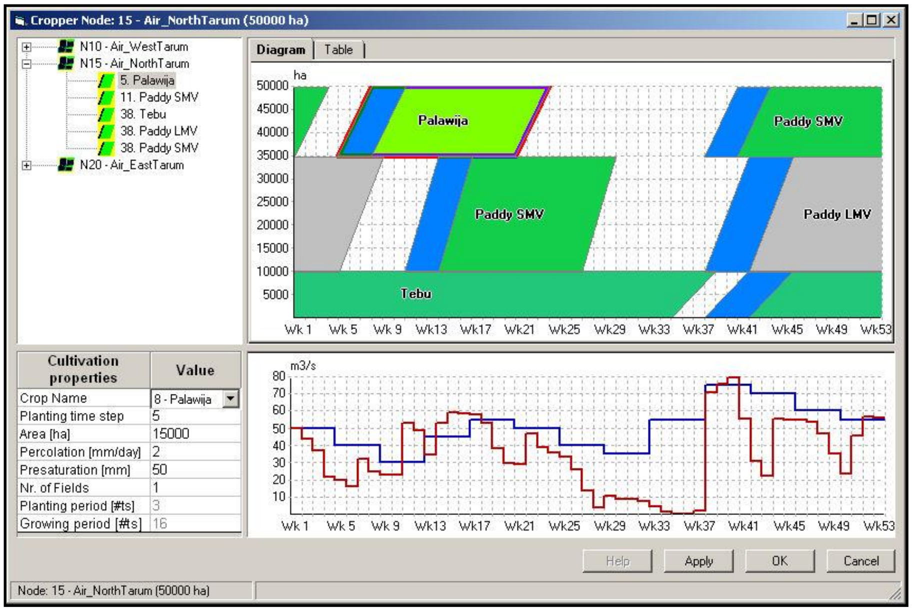


Figure 33 Change in flow composition in downstream direction over several years of simulation (wet / dry cycle visible)

Advanced irrigation simulation

RIBASIM has an integrated agriculture water demand, water allocation, crop yield and production costs model based on crop and soil characteristics, crop plan, irrigation and agriculture practise, expected and actual rainfall, reference evapotranspiration, seepage, actual field water balance, potential crop yield and production costs.
RIBASIM has a fully graphical user interface for designing the river basin network but also for crop cultivation planning, see Figure 34.



Cultivation properties	Value
Crop Name	8 - Palawija
Planting time step	5
Area [ha]	15000
Percolation [mm/day]	2
Presaturation [mm]	50
Nr. of Fields	1
Planting period [#ts]	3
Growing period [#ts]	16

Node: 15 - Air_NorthTarum (50000 ha)

Figure 34 Interactive graphical design tool of a crop plan for the North Citarum irrigation area (Indonesia)

In the Tapi model, this advanced irrigation option has been used as it allows for a sophisticated assessment of the water demand for irrigated agriculture.

Source priority list

The source priority list is an important input data item for the water allocation in the model. The network schematization can contain the following demand nodes: Advanced Irrigation, Fixed irrigation, General district, Public water supply, Industrial use, Cooling water, low-flow node (identifying the non-consumptive demand such as environmental flow). For each of those nodes a list must be prepared containing all nodes which are a (potential) source for the supply of water. This list is the source priority list. Those potential sources can be:

- Inflow / runoff: Variable inflow, Groundwater, Snow melt and Glacier melt
- Drainage / return flow: Public water supply, Industrial use and Cooling water
- Drainage: irrigation
- Discharge: General district

The order of the source nodes in the list is the order in which the nodes are chosen by the model to fulfil the water demand. So, the order of the nodes in the list is important. The model initially generates a default source priority list when the network was designed and setup on the map. The order in which the different node types are included in the default list is defined in the fixed data of RIBASIM. In the Tapi model not all node types are used. The generated list is in most of the situations correct and no additional checking and updating is needed. However, it can be overruled by the user, using the source priority list editor, e.g. in case the user decides that a certain source should be avoided.

Water allocation priority

The water allocation priority outlines the order in which the various water users or water demands get the available water from the various sources specified in the source priority list. Table 14 lists all node types for which a water allocation priority can be specified. All priorities in this example are set as 1.

Table 14 Water allocation priorities

Node type	Priority	Description
Public water supply	1	Domestic water uses
Fixed irrigation	1	Irrigation demand
Industrial use	1	Industrial water use
Cooling water	1	Cooling water at (nuclear) power plants
General district	1	Lignite mining water use

By default, the RIBASIM model allocates water in downstream direction, which is called '*first come, first serve*'. There are, however, situations that this leads to undesirable consequences, e.g. in case a city is located downstream from an irrigation area. In order to force the model to give priority to the city, despite its location, the standard order of allocation can be overruled by changing the priority settings and e.g. give a higher priority to public water supply. For this option, it is possible to use priority settings from 1 (highest) to 99 (lowest) priority. It is also possible to assign different priorities to a percentage of a water demand in a demand node, e.g. giving a higher priority to the first 50% of the demand of a public water supply, and a much lower priority to the remaining 50% of that demand.

Additional features

- RIBASIM includes a basic water quality component which allows for the simulation of the concentration of any number of user-specified substances. Waste loads are connected at various user- and boundary nodes. Natural and artificial retention of substances are introduced at any location in the network schematization. Substances are routed thru the network based on the simulated water distribution assuming complete mixture;
- For most basin planning purposes, the RIBASIM basic water quality modelling is enough. If detailed simulation of chemical and biological processes is required, then RIBASIM can be linked with the water quality process model DELWAQ;
- Groundwater can be modelled as separate source for various users with its own characteristics and water management;
- Extreme long simulation periods for example of synthetically generated time series of 5000 or more years can be simulated;
- RIBASIM offers various flow routing procedures like Manning, 2-layered multi-segmented Muskingum, time-delayed Puls method, Laurenson non-linear "lag and route" method, etc.

For more information on RIBASIM see the Ribasim webpage: https://oss.deltares.nl/web/ribasim/home which also contains a number of instruction videos or consult the User and Technical reference manual:

- Van der Krogt, W.N.M., Boccalon, A., River Basin Simulation Model RIBASIM Version 7.00 User Manual, Deltares, 2013
- Van der Krogt, W.N.M., River Basin Simulation Model RIBASIM Version 7.01 User Manual Addendum, Deltares, 2015
- Van der Krogt, W.N.M., River Basin Simulation Model RIBASIM Version 7.00 Technical Reference manual, Deltares, 2008

7.6 MesoHabsim

The core of the methodology applied for estimating E-Flows is the Mesohabitat Simulation Model (MesoHABSIM). Conceptually, the approach is well grounded in the current river ecosystem theory and practices that are particularly relevant for habitat simulation type E-Flows methods and their upscaling from site/reach scale to larger, regional scales, such as the basin and river network scale. In particular, it draws on a multi-scale, hierarchical framework for developing process-based understanding of catchment-to-reach hydromorphology for sustainable river management applications such as E-Flows (see Gurnell et al. 2016, for further details).

MesoHABSIM uses a computer model, Sim-Stream, that predicts the quantity of habitats available at different flow levels for aquatic communities in rivers and streams. Changes in the quantity of habitats available can then be evaluated for different water management (flow alteration) scenarios. The system is based on data resolution that reflects animal responses to changes in the environment and their effective extrapolation to a scale that allows planning and management. MesoHABSIM has been created and developed in last 20 years and has been applied in numerous environmental flow studies ranging from E-Flow determination for individual facilities to prescriptions for entire regions and countries (e.g., Parasiewicz et al 2008a, 2018, Pegg et al. 2014, Vezza et al 2012).

The methodology applying MesoHABSIM has already been adapted for the local context, based on the lessons learned during a test application in the Ramganga River Basin in early 2020, during the IEWP Action Phase 1 Ramganga pilot study (Nale et al. 2020a). Standard methods for the collection of data necessary for the application of the MesoHABSIM model are detailed in a field data collection manual (Parasiewicz and Suska 2020). The steps of the method were adapted as needed during the course of its application in the Ramganga River Basin.

The procedure of computing MesoHABSIM model results consists of seven steps. Each step is described briefly below.

7.6.1 Selection of river reaches for meso-habitat simulation

River reaches for detailed meso-habitat simulation were chosen to represent the range of fish community macrohabitat types (MacHT) present in the Ramganga River Basin. The procedure begins with a desktop analysis, using basin characterization data presented in Appendix 1, to identify the most useful subset of variables for describing river features across the basin, including: altitude, slope of river segment, stream order, catchment size, geology, and bioclimatic conditions. These features have been shown to determine fish community structure through such habitat characteristics as flow velocity, riverbed width and depth, and longitudinal profile. Further, land cover and water pollutants were not selected as habitat determining attributes, as these are the most sensitive to human induced alteration. River reaches were classified, using standard multivariate statistical techniques (e.g., K-means clustering, ANOSIM), into a meaningful and practical number of clusters of reaches of similar character, representing different fish community macrohabitat types.

For each macrohabitat type, in discussion with experts familiar with local conditions, individual reaches were identified for detailed field surveys to collect the flow-hydraulic habitat and ecological information needed to establish E-Flows meso-habitat simulations. As each of the sites represents a type of river within the basin, it is possible, in a precautionary way, to extrapolate the calculated E-Flows figures for any site to other reaches of the same type, wherever they are located in the basin.

These representative sites were selected, with the premise to find the least anthropogenically modified portions of the river. Available maps of irrigation/diversion canal networks, barrages, population density and land use were used to guide the selection process. An estimated 5-10 representative reaches were to be identified as potential E-Flows sites, for subsequent validation during the first of three proposed field surveys. A field reconnaissance trip was conducted as part of the assessment. A rapid reconnaissance of the sites, including aerial imagery, was done during the May, 2022, field mission, leading to final selection of suitable sites.

7.6.2 Establishment of biological targets

The biological targets are the fish species groups for which E-Flows will be identified, using the Target Fish Community approach of Bain and Meixler (2009). Accordingly, it is necessary to determine what species, in what numbers, can be expected at the location during different times of the year. To establish such biological targets, seasons are defined (bioperiods), in which different fish communities and life stages occur in the river. Biologists on the Task Team then identify the fish species that typically occur in the area and group them into assemblages (guilds) using similar habitats. Abundances of the expected assemblages are then ranked as a proxy for determination of dominance structure of assemblages in the fish community. The ranks are used to compute a fish community model (Bain and Meixler 2008) presenting the expected proportion of assemblages in the community (community structure). Each assemblage is assigned conditional habitat suitability criteria, which can be applied for all rivers in India.

7.6.3 Hydrological analyses

Hydrologic characteristics were identified for the preliminary E-Flows reaches. Annual hydrographs were constructed, which show changes in flow over the year at a specific location, for both naturalized (near-natural) and present-day conditions. The hydrographs illustrated flow variability between and within years, and were used to identify periods of high flows and low flows. Annual Flow Duration Curves (FDCs) were developed for each site of interest in the basin, supplying additional data about the flow characteristics of each river reach, across all modelled (or recorded) discharges. Using the FDCs, specific flow percentiles (percentage of time a particular discharge is equalled or exceeded) were obtained. To allow transferring of corresponding flow values between distant locations, the flows were standardized to specific discharge per unit area of upstream basin (litres/second/km2).

7.6.4 Morphological assessment

While, a comprehensive geomorphological analysis was beyond the project scope, geomorphology was in part assessed through the hydraulic habitat assessments at the sites.

7.6.5 Field data collection and survey methods

A range of field data were collected in the E-Flows study reaches to determine the spatial proportions of mesohabitat units following Parasiewicz and Suska 2020. Mesohabitat units correspond with Hydromorphological Units (HMUs; i.e. pools, riffles, runs), which are river sections with similar morphologic, hydraulic, and cover attributes. The data collection was done using a combination of remote sensing and on-site surveys. The procedure varies depending on the size of the river (Figure 35**Error! Reference source not found.**) but generally one site and flow condition can be completely surveyed in one day. Data were also collected on fish ecology and water quality.

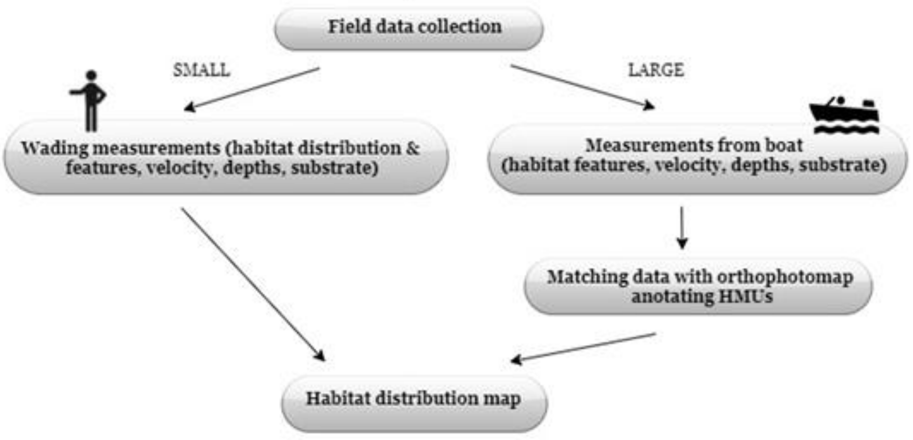


Figure 35 Habitat survey process for small and large rivers (modified from AMBER Field Manual date).

While in the field, the Task Team also assessed the present ecological condition of the study reaches. Present ecological condition is needed to assess the degree of ecohydrological alteration from natural conditions that has already occurred in each river reach. It also helps identify if each of the individual reaches/sites for which E-Flows will be calculated is on a downward (negative, degrading condition), stable or positive (i.e. improving in condition) trajectory.

7.6.6 Hydrodynamic model development

Two numerical models were applied to the study reaches in order to simulate fish habitat variables under different flow conditions. Flow depth and velocity were modelled in two dimensions using the River 2D model (Ghanem et al 1995). River 2D creates a digital representation of the river that can be used to simulate the movement of water through the river and predict how habitat factors change over time. Grain (substrate) sizes of sediments in different units of the study reaches were simulated using the SubDisMo model (Parasiewicz and Suska 2020), which uses depth and velocity data derived from the

River 2D model and annotations of hydromorphologic units according to MesoHabsim protocols. Both models were developed and calibrated using measured variables from the Seohara and Bareilly sites on the mainstem Ramganga River and the Jalalabad site on the Baigul River. They were further used to simulate hydraulics and substrate distributions at three flow conditions that have not been measured. It served as a foundation for desktop mapping of Hydromorphologic Units.

Since repeated mapping of remaining sites become impossible due to staffing and resource limitations, we used Digital Elevation Model calculated from aerial imagery obtained with UAV on the upstream sites in Kosi River in Garampani and Boar River in Kaladhungi to serve as an input for River2D model. This is much less accurate option especially for the low flows, but since the water transparency (or lack of water at Khaladhungi allowed for relatively good terrain model accuracy we decided to try this option as the only alternative. Modelling results may be found in Appendix 2.

7.6.7 Flow-habitat modelling

The Sim-Stream Software by Rushing Rivers Institute (Parasiewicz et al 2006; www.mesoHABSIM.org) was applied to organize the collected habitat data and to calculate the suitable habitat area for each fish guild in different units of the study reaches and at different flow levels. Results are presented on habitat suitability maps in which every mapped unit is colour coded as unsuitable, suitable or optimal habitat (Figure 36).

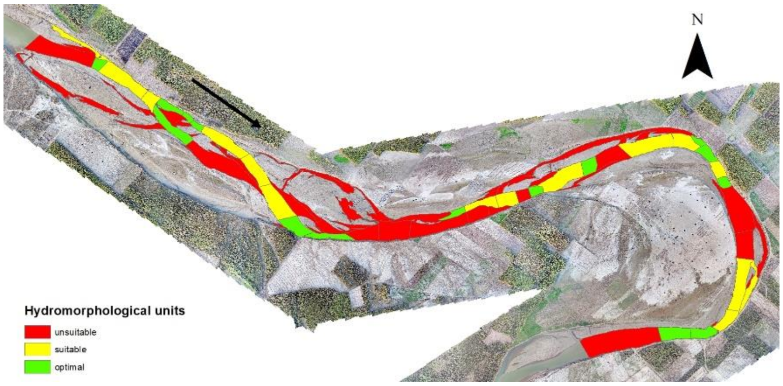


Figure 36: Habitat suitability maps for Rheophilic water column sand-gravel habitat use guild in Seohara site of Ramganga River at flow of 3 m^3/s (defined in pilot project 2020)

The results of simulations of suitable habitat areas for different fish guilds at different flow levels were then plotted to produce habitat rating curves. The flow habitat rating curve for the fish **community** is developed by weighting the habitat area of each guild by its proportions. It is presented together with wetted area and **generic fish** habitat, which is the total habitat surface area used by the all the members of the fish community (Figure 37). This curve is applied to calculate habitat time series for past and future scenarios of flow.

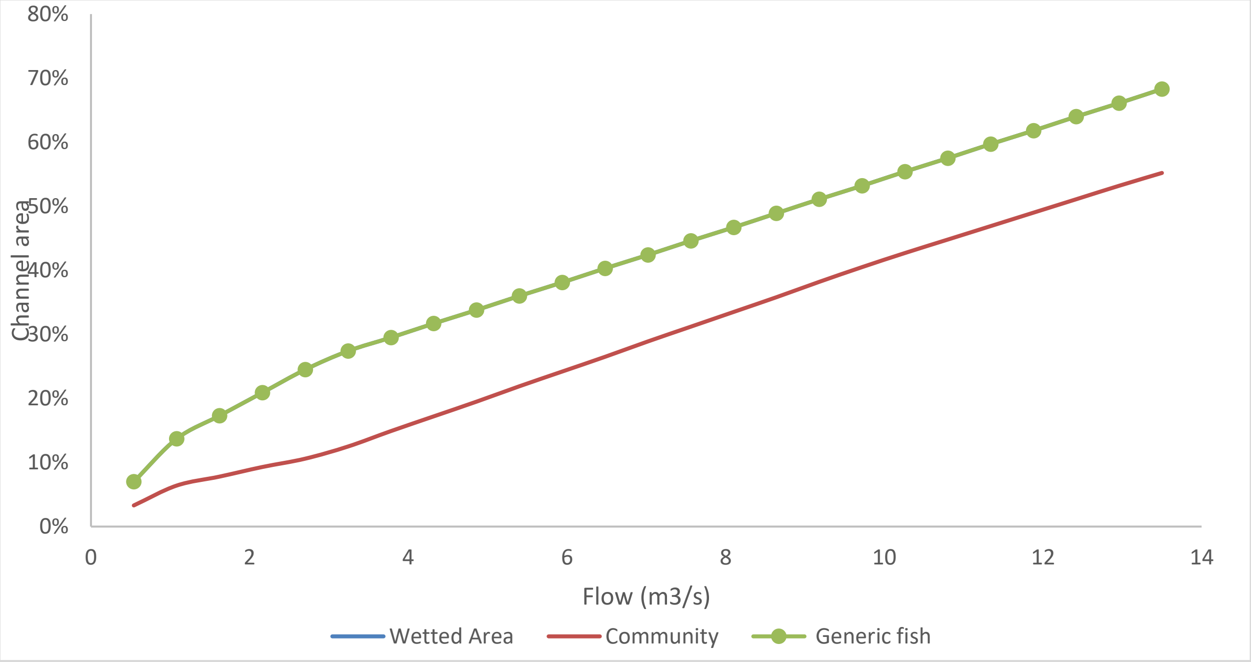


Figure 37: Habitat rating curves for fish community and Generic Fish Habitat at Seohara Site of Ramganga River

7.6.8 Establishment of E-Flow criteria

One of the most important underlying characteristics of any riverine environment is its continuous change over time due to the fluctuations of water flows. Since flow rates during different seasons create various habitat conditions, habitat availability is also in flux. Consequently, fauna is shaped by varying environments rather than by static conditions. To investigate the habitat availability and the flows that create them, the temporal patterns that occur in the time series were analysed.

The habitat time series is based on the amount of flow in the river recorded on any given day. With help of the fish community rating curve, flows are evaluated for how much habitat they provide and this value is plotted as a habitograph instead of flow value for every day in the record. The habitograph depicts fluctuation patterns of habitat occurring in the river over time. The adequacy of the available habitat for the survival of the fauna needs to be analysed with a reference habitograph for close to natural conditions. The assumption is that the native fish community is adapted to natural flow patterns. Following the theory of habitat templates, we also assume that this adaptation is oriented on the predictability of the events (Parasiewicz 2007ab, Poff and Ward 1990) hence, conditions that occur rarely in nature create stress to aquatic fauna. For this reason, we observe frequency of habitat area occurrence as the basis for determining **habitat thresholds**, which specify a boundary of conditions necessary to support the native fish community structure.

To assess the temporal patterns, the habitat time series was analysed using Uniform Continuous Under Threshold (UCUT) analysis, a habitat duration analysis method which observes the frequency of continuous events with low habitat availability and identifies rare and common habitat conditions associated with subsistence and habitat base flow conditions. Detail of this method is presented in

Appendix 5 Habitat Time Series Analysis. Four E-Flow thresholds were calculated for each study reach (see Ramganga pilot study report for biological justification):

- **habitat base flow** offers stable and sufficient living conditions for the fish community**;**
- **trigger flow** alerts for required management actions preventing subsistence conditions;
- **subsistence flow** provides short-term survival conditions for the fish community;
- **absolute Minimum** is the lowest flow on record and is used as a reference point and not a management objective.

In addition to E-Flow threshold values, the UCUT analysis specifies allowable and catastrophic durations of flow deficits at each level. The latter are equivalent to events with 10 years occurrence interval. More detail on the methodological process can be found in Appendix 5.

7.6.9 Extrapolating E-flows to MacHTs

In order to offer E-flow criteria for the Macrohabitat types represented by the surveyed sites, the specific E-flow values are divided by the mean annual flow for the site location. Such obtained index p-values can be used to compute E-flow for any location within the watershed for the investigated MacHTs using following formula:

$$\mathbf{Q_{ef,b} = \boldsymbol{p_b} \cdot Q_{MAF,k}}$$

Where: $Q_{ef,b}$ = E-flow for bioperiod in m^3s^{-1},

p_b = tabulated value of habitat index obtained from representative site studies according to the bioperiod and MacHT. It is E-flow calculated for the site expressed as a proportion of q_{MAF} at the site location,

$Q_{MAF,k}$ = mean annual flow at the cross-section k.

8 Development and implementation of the Program of Measures

- ***Defining the <u>response</u> based on the risk analysis to improve the water system and achievement of the basin / KWMI management objectives.***

8.1 Introduction: rationale of a Program of Measures

*See **Annex 2** – Training Module on (i) Surface Water (quantity & quality); (ii) Ground Water (quantity & quality) and (iii) River morphology and Sediment Transport.*

The Programme of Measures (PoM) for a River Basin builds upon the Pressure/Impact Analysis and the results of the Risk Assessment. In relation to the possible impacts that have been analyzed for surface water and groundwater, the PoM proposes measures that will support the improvement of the situation in the entire basin. Overall, PoM aims to achieve the Overall Basin aim and the related management objectives.

The PoM targets the individual problems identified for each of the KWMIs. While the specific programme of measures to solve individual problems are important, 'scale effects' are extremely important in river basin management. At the basin scale, the measures adopted to solve one type of problem might have implications for another problem, which can be either negative or positive. For instance, any activity to reduce non-point pollution from agriculture that involves improved agricultural practices such as efficient use of fertilizers will directly impact on quality of local groundwater positively. It might also affect quality of water in streams and rivers, if the runoff from the agricultural fields end up in them as return flows, thereby having significant impact on river water quality in the lower stretches of the river. Augmentation of flows in rivers during the season through release of water from upstream regulatory reservoirs might also affect the groundwater regime, positively owing to greater infiltration of water through river bed, depending on the soil characteristics. On the other hand, reduced release of water from reservoirs could negatively impact groundwater conditions downstream due to reduced return flows to shallow aquifers. Changes in operation of multi-purpose reservoirs for increasing their flood cushioning capacity could adversely affect their drought-proofing ability and hydropower generation potential, as water will have to be released from such reservoirs before the onset of the season during which floods occur. Further, there can be multiple ways of addressing one type of problem with each one having a different effect on the basin water resources (in terms of quantity and quality) and water users in different areas.

Because of the inter-connectedness of the different components of the physical or hydrological system (that affects water availability) and the socioeconomic system (that affects water use) and the interaction between the two, the analysis of the problems, the process of identification of key programme of measures to solve them and ascertaining the scale at which they should be implemented should be carried out in an integrated manner on a spatial and temporal scale to be effective in a physical and economic sense.

8.2 Improving river basin management through a dedicated PoM calls for institutional change

Before we embark on the programme of measures, it is important to know how they are likely to impact on the user behaviour with regard to resource use and finally the resource condition. A good amount of knowledge exists about the impact of technologies and institutions on water, available from the research done in different parts of the world.

First of all, improving river basin management calls for institutional change, i. e., changes in the overall institutional architecture, the roles of individual organizations, and capacity building of those organizations (Saleth and Dinar, 2004; Kumar, 2014; Kumar et al., 2019). First of all, international experience shows that there has to be an agency with the mandate of water resources management and inter-sectoral water allocation at the basin level that is different from the agencies that appropriate water (such as the Water Resources Departments and Water Supply Departments of the states) (see Kumar et al., 2019 for details). This will induce costs on the agencies that divert excessive amount of water for competitive uses, especially irrigation. Similarly, the agency which monitors water quality and pollution should not be involved in enforcing pollution control norms. Currently, the same agency (the State Pollution Control Boards) performs both the functions. This creates conflict of interest. If two independent agencies perform these functions, it will create more pressure on the latter to perform better as it will be assessed by WQM by the former (Kumar et al., 2019).

8.3 Timeline for the implementation of a PoM and prioritization of measures

The RBM Plan implementation is aligned to the steps and timeline of River Basin Management Cycle. The the consecutive RBM Cycles will continue implementation of measures until the set aims and objectives will be achieved. In order to ensure effective planning and implementation, the prioritization of measures is taking an important role. In this context, each measure in the PoM indicates:

- an implementation priority aligned to 3 classes (high / medium / low priority), and;
- an estimated implementation timeline as well as the expected improvement target.

The following prioritization has been applied within the Tapi PoM:

Implementation Priority Class	Criteria for Assignment to Implementation Priority Class
1 *(high implementation priority: within 6 years / before 2030)*	• Implementation of measure for surface water and groundwater bodies that are: ***At risk* to fail the aims and objectives in 2023 and/or show a water quality index class worse than …;** • Implementation of ongoing national / regional programmes; • Measures related to legal, policy and regulatory framework.
2 *(medium implementation priority: before 2035)*	• Implementation of measures for surface water and groundwater bodies that are: ***Possibly at risk* to fail the aims and objectives in 2023 and/or show a water quality index class worse than …**

3 ***(low implementation priority: later than 2035)***	- Implementation of measures for surface water and groundwater bodies that are: ***Not at risk*** to fail the aims and objectives in 2023 and/or show a water quality index class ….

8.4 Structure of the PoM

The PoM relates to all Key Water Management Issues that have been identified for a River Basin addressing both surface waters and groundwater. It fully considers the related management objectives in order to achieve the Overall River Basin Aim and related management objectives. Figure 38 illustrates the structure of the PoM as basis for implementation.

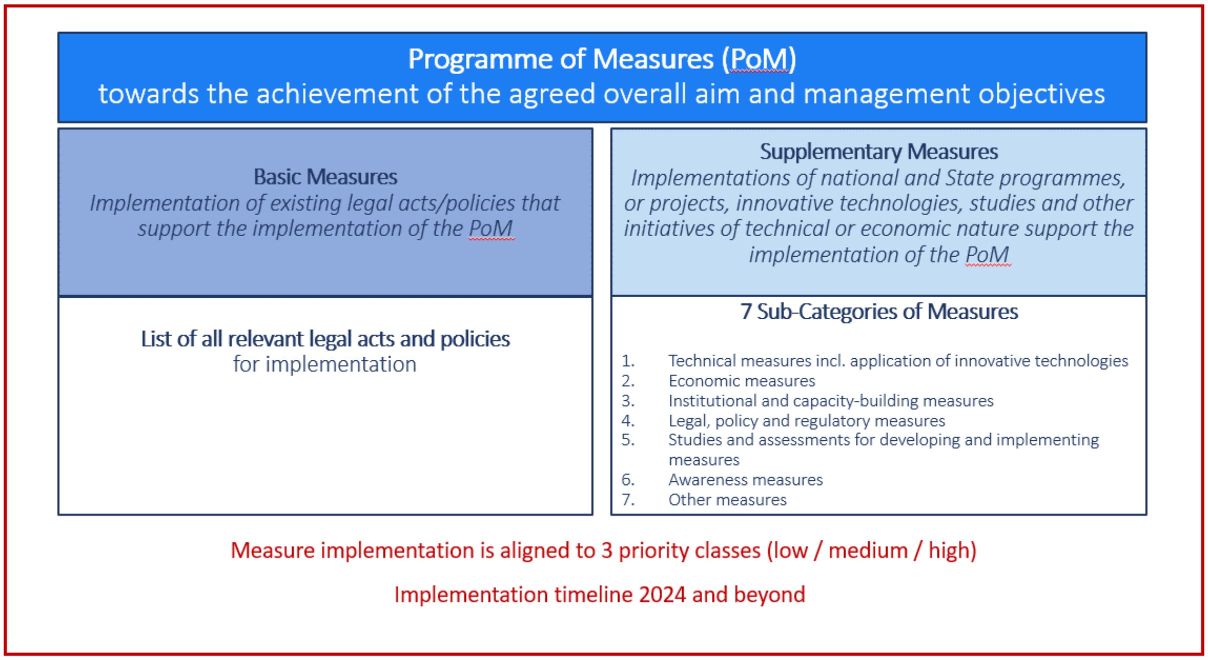


Figure 38 Structure of the Programme of Measures (PoM) for a River Basin.

As a basic structure the PoM holds two categories of measure, which are:

1. Basic measures, and
2. Supplementary measures.

The *basic measures* include the implementation of legal acts and policies on national and state level, which will support the achievement of the overall River Basin aims and management objectives. If necessary, these have to be complemented by the *supplementary measures* in order to meet the aims and objectives.

In addition to legal/rules/acts, the basic measures can also include convergence opportunities with other relevant national and/or state level missions and programmes.

Supplementary measures as part of this PoM complement the basic measures. They have been identified for implementation in a River Basin in case the basic measures cannot ensure the achievement of the overall aim and management objectives. They importantly include the implementation of national and regional programmes as well as measures that foresee the implementation of projects, innovative technologies, studies and other initiatives of technical or economic nature in order to achieve the overall aims. Further, the measures include actions to supplement the existing legal, policy and institutional framework in order to improve river basin management and measure implementation.

Table 15 presents the long list of examples of supplementary measures as identified for the Tapi Basin. The supplementary measures are subdivided in 7 sub-categories holding concrete measures for each KWMI.

Table 15 Sub-categories of supplementary measures and a long list of examples for measures.

#	Sub-Category of Measures	Selected Examples for Types of Measures
1	**Technical measures including the application of (innovative) technologies**	• Introduction and implementation of innovative technologies • Construction and/or upgrade of urban and industrial Waste Water Treatment Plants (WWTPs) • Emission reduction (municipal and industrial; hazardous substances) • Reduction of nutrient pollution from agriculture • Reduction of pesticide pollution from agriculture • Improvement of water quality, quantity and sediment monitoring networks/programmes • Reuse of treated wastewater and water harvesting • Promote conjunctive use of groundwater and surface water • Promote groundwater recharge • Crop Diversification in areas where water intensive crops are irrigated • Water use efficiency, technical measures for irrigation, industry, energy and households • Construction of municipal sewage and waste infrastructure • Storm water management structures • Protection of drinking water (e.g. safeguard and buffer zones) • Register of groundwater abstractions, inventory of solar pumping • Inventory and remediation of contaminated sites • Reduction of sediment and soil erosion and surface run-off • Restoration of bank structure and wetlands • Setting minimum environmental flow requirements (E-Flows) and ensuring longitudinal river continuity • Structural river reach restoration and improvement • Creation of enhanced buffer zones for floodplain management • Habitat restoration (aquatic/terrestrial) • Flood mitigation structures • Designed/sacrificial flood inundation areas • Dam operation and management • Climate change adaptation
2	**Economic measures**	• Water pricing policy measures for the implementation of cost recovery for water services from industry, agriculture and households (e.g. taxes and charges) • Funds to support the implementation of certain programs • Water pricing policy measures to control solar pumping
3	**Institutional and capacity building measures**	• Strengthen coordination between national and regional level • Strengthen coordination between neighbouring countries (upstream and downstream) • Research, improvement of knowledge base reducing uncertainty • RBO institution strengthening • Advisory devices for agriculture and farmers • Training of wastewater treatment plant operators • Training on proper handling of agrochemicals • Disaster risk reduction and flood risk management • Effects of climate change on the basin's water resources

#	Sub-Category of Measures	Selected Examples for Types of Measures
4	**Legal, policy and regulatory measures**	• Implementation of existing national and regional programmes • Improve implementation of regulatory enforcement • Control and prevention of pollution from agriculture, industry, households, transport and infrastructure • Permitting and licensing (environmental, discharges, industry) • Groundwater abstraction permitting and metering • Control and prevention of impacts on aquatic fauna and flora • Planning strengthening and improvements (e.g. Zoning, land use requirements) • Introduction and improvement of agricultural practice codes • Certification schemes • Water pricing guidelines for irrigators and industry • Land use planning • Fertilizer/pesticide taxation • Groundwater protection zones
5	**Studies and assessments for developing and implementing measures**	• Research studies • Technical studies to better understand the situation in certain areas or topics •
6	**Awareness measures**	• Awareness campaigns on RBM, water quality/quantity, human health and water, pollution discharge and other topics • Water stewardship programmes (i.e. industry, farms, hospitals) • Groundwater depletion and efficient use of water • Raising awareness of farmers and industry on pollutants • Pesticide and fertilizer use • … • …
7	**Other measures**	• Data, Knowledge and information management systems • … • …

8.5 Setting up a Program of Measures

Process

The process of setting up PoMs for risks associated with alterations in surface hydrology involves considering the degree of risk. We have already discussed the methodology to be followed for assessment of the risk induced by alterations in surface hydrology. Prior to risk assessment, the unit of analysis should be decided, i.e., whether it is a district of a sub-basin or a smaller catchment. Smaller the unit, greater would be the difficulty in obtaining the data for the different variables involved in risk assessment.

The selection of PoMs involve several complex considerations: 1) the physical environment (hydrology, geohydrology, climate, topography); 2) the socioeconomic conditions (social status, economic status, livelihoods, etc. of the people, overall economic structure); 3) culture; and, 4) the existing legal and institutional regimes. It should be based on the knowledge of ‘what works and under what conditions’, and this knowledge can come from experts and a review of the past experience with the application of the various management tools under various conditions. For instance, willingness to pay for good quality water will be high in localities where people are educated and know the importance of consuming good quality treated water. Or else, raising the tariff for domestic water supply can lead to undesirable outcomes in terms of the community members choosing to use contaminated water at the cost of public health (Noll et al., 2000). Similarly, drip irrigation system is likely to have a significant impact on reduction in consumptive use of water in areas with arid (or semi-arid) climate, sandy soils, deep water table conditions and when used for distantly spaced crops (Kumar, 2016).

The assessment units which experience high risks would require harder measures than those which experience moderate and low risks. In the case of basic measures, this can be in the form of stringent laws and regulations. In the case of supplementary measures, this can be in terms of high scale of adoption of physical and institutional interventions (such as wastewater treatment and reuse), strict rationing of water allocation to individual farmers, very high volumetric water charges, limited energy quota for the farmers who own agro wells, high electricity tariff (high unit rates), etc.

One the scale of interventions are decided and their impacts on the basin water balance and the resource base identified with the help of modelling tools, it would be ideal to reassess the risks. Ideally, if the right interventions are chosen at the right scale, the degree of risk would reduce or become nil.

Location / scale

Transboundary, National, basin, municipality, surface water body / groundwater body, site.

Quantifying measures

Once the types of management measures to be introduced are identified, the next challenge is to ascertain the scale at which each measure is to be taken up to achieve the goal of reduced environmental stress of the river and its tributaries. In the case of technical measures, the questions that need to be answered are: what should be the scale of treatment of wastewater (or what should be the capacity of the wastewater treatment plants) and what should be the degree of treatment to achieve recycling or reuse of wastewater in the planned sectors of use? What should be the scale of technical interventions such as lining of canals, adoption of efficient irrigation technologies that help save irrigation water supplied through (like drips + mulching) to achieve the desired reduction in irrigation water demand in the command area?; what should be the volume of water that needs to be imported to augment the river flows to reduce the environmental water stress in different seasons? What should be the unit price of electricity supplied for the agriculture sector to cause reduction in demand for groundwater through improved energy and water use efficiency? Answering these questions would require the use of water balance modelling tools that can handle technical and economic questions. One of the technical questions to be answered by the model, for example, is: what will be the reduction in demand for water per unit area for a crop due to shift from traditional method of irrigation to drip + mulching or drip alone? Similarly, three of the economic questions that need to be answered by econometric model will be: i) what will be the price elasticity of the demand for canal water? Ii) What will be the price elasticity of energy/water demand of agro well owners?; and iii) What will be the income elasticity of per capita demand for water in urban areas?

Cost estimate

Once the scale of the intervention is ascertained, the cost of these interventions need to be worked out. The reason being that the combination of interventions to achieve the desired outcome (in terms of augmented river flow in different seasons) should be chosen in such a way that these become the least-cost alternative. For this, it is important to get the unit cost figures for various interventions. Some of the typical ones are: i) what is the unit cost of wastewater treatment technology (INR/KL of water) that can achieve a certain desired level of reduction in pollution?; Ii) what is the cost of an efficient irrigation technology per unit area of a given crop that helps save ‘X’ m^3 of water?; and iii) What will be the cost of lining of canals that helps save unit volume of applied water or what is the cost per km of canal lining that helps save ‘X’ m^3 of water? Such data many not be readily available and will have to be obtained through extensive review of empirical research on these topics.

In parallel to the implementation of the programme of measures, relevant economic instruments of agri-environmental policies (such as incentives/differentiated taxes based on the hazardous nature of the pesticide/quotas for pesticides within critical zones or ban of pesticide use in close proximity to drinking water wells). A relevant taxation system would help subsidizing farmers to implement measures.

It is necessary to develop indicators aimed at monitoring the implementation of the Programme of Measures and its effectiveness. Assessment of all costs related to the implementation of the measures will help assess the Cost-Effectiveness of the Programme of Measures.

9 Recommendations and Next Steps

9.1 IWRM at river basin level: lessons learned from implementing the EU WFD in Europe

An important question is how governmental institutions at all relevant levels, i.e., at the level of the Gram Panchayats, the municipalities, the districts, the states and the nation, dedicate themselves to working towards evolving a shared vision and aims for the river basin and implementing them? Building onto lessons learned in Europe and applied contextualization during the work on the Tapi River basin, the following 10 recommendations / lessons learned can be made:

1. ***River basin management is key to improve water quality and water availability***: water does not follow administrative boundaries, of countries or States or districts or villages. Cooperation at the basin level to come to mutual agreements within the basin is vital to evolving a shared vision for the basin and gradually improving the basin water resources and water systems.

2. ***Transparency is vital for river basin management***: clearly defined KWMI's with a vision and objectives, transparent environmental standards, result-oriented agreements, transparency in process (cyclic implementation timeline) and transparency in sharing data obtained from monitoring are vital conditions for river basin management. In this way, decision-makers and water management officials responsible for capacity, budget and planning, are able to justify the investments. Mapping this out for all public authorities provides a sense of confidence and motivate them for joint effort to realize the objectives set. Consequently, the river basin water policy is also transparent for the public authorities, the civil-society organizations and the citizens.

3. ***Aim for an ambitious vision with realistic intermediate goals***: the implementation of the shared vision, aims and objectives for the river basin cannot be met within a one 6-year cycle. Instead, phasing out the implementation and following a cyclic implementation approach with an updated risk assessment every consecutive period is essential. The long-term vision and objectives might be ambitious, but the intermediate goals should be realistic. This will also keep relevant stakeholders motivated and involved.

4. ***Cooperation within a River Basin Committee supports the implementation of IWRM within a river basin***: even in large basins such as the Rhine and Danube in Europe, the cooperation within international RBCs and at the national scale sub-basin RBC's resulted in feasible and affordable packages of measures to work on the river basin vision, aims and objectives. The success of the cooperation at basin level lies in the joint-fact-finding while carrying out the risk assessment for the identified KWMIs and jointly working on an RBM plan for the basin, including a detailed PoM. The RBCs are essential cooperation mechanisms to steer and coordinate the implementation of the RBM plan and facilitate the participation of all relevant stakeholders (governmental and non-governmental). The RBC's should meet on a regular basis (3 - 4 times per year) and the agenda should be prepared jointly with the involvement of all members of the committee.

5. ***Awareness of the values of clean and healthy water***: implementing IWRM principles at the basin level and working jointly on an RBM plan result in a better understanding of the KWMI's, and the potential interventions to address them. It is now increasingly recognized that water security with a clean water and a health water ecosystem is essential for social development and economic growth. The basin's stakeholders are now sharing this outlook towards water management.

6. ***Top down and bottom-up approach***: the EU WFD sets the framework for defining environmental quality standards and reference conditions for ecological objectives (top down), but the detailing of the ecological objectives is defined at the regional level (for each surface water and groundwater body). Therefore, regional water authorities themselves are more connected and committed to the set of targets for water quality and ecology. Of course, reference conditions of the chemical quality of water are defined at National level and should be applied to all water bodies.

7. ***The effect of a 'result obligation'***: the implementation of the measures of the EU WFD to obtain the targets is subject to a result obligation, with penalty from a European Court of Justice as the ultimate deterrent. This 'top-down' pressure from the European Commission is working quite effectively within the EU and it keeps all parties on their toes.

A second important question is how to provide incentives for different stakeholders, sectors and water users to collaborate and contribute to water quality management and pollution prevention?

8. ***Licensing, enforcement and supervision***: important incentive for different sectors is proper legislation for water quality and ecosystem health. The WFD approach is an example on how a water-related legislation is incorporated within a Union of independent states and a national legislation. With only a legislation, the water system will not improve. It is therefore important to set up a transparent and properly functioning system of licensing, enforcement and supervision by the responsible and concerned authorities.

9. ***Cooperation with the River Basin Committee***: the collaboration between public authorities and representatives of different sectors of society resulted in a better understanding of the shared vision, aim and objectives for the river basin. The conviction of the importance of a healthy water system for human consumption, agriculture, industry, livestock, tourism, etc., is a major incentive for those sectors to support the work on IWRM. If sectors themselves are not convinced, it will be very difficult to implement water quality improvement measures.

10. ***Participation boosted communication about water quality***: within the EU, the need to communicate about the EU WFD activities and products has raised the knowledge and awareness about water quality and ecology. Participation is not merely an obligation under the EU WFD. Instead, it is intended to generate local knowledge and to provide residents, businesses and organizations the opportunity to express their interests and concerns and to be involved in water policy making. In the end, this strengthens the support for implementing and executing the measures.

9.2 Development of the Tapi RBM plan: lessons learned, recommendations and next steps

KWMI 1

Monitoring and data management
Instead of a vast, robust but incomplete monitoring, we need to have a more goal-oriented approach (plan-do-check-act).

Monitoring plans should be developed, based on an area/river stretch approach, focusing on the water quality problems that are known or anticipated.

An online monitoring station, equipped with the latest technologies and working 24/7 can be located at the entrance of the river basin to enable regular monitoring (early warning system or ‘’water watch’’). Refining and extension can take place over time.

Training and capacity building needs to be aligned with technical innovations, especially on the issue of monitoring, data management (processing, analyses) and yearly evaluation.

Existing improvement schemes/programmes/policies
A project organization is needed to investigate, follow up and implement what has already been planned and what is been proposed as Class 1 measures in the PoM. The execution of the programme of measures as proposed can integrated into the already planned measures. For this, highlighting the impact of ‘quick wins’ can be motivating for the involved stakeholders and positively influence the public opinion.

Pollution reduction
Pollution reduction should focus on prevention strategies rather than treatment of polluted water. This is very relevant for industrial pollution.
The system of transport, collection and treatment of urban wastewater can be improved on an area-based approach where removal rates of pollutants (COD, BOD, N, P) can be increased.
For industries, the focus could be more on toxic micro-pollutants that in small quantities can cause serious pollution water quality problems where treatment of toxins at the source (sub-streams) can be efficient and effective to improve the performance of the WWTP’s.
Special attention is needed for small rural settlements where improvement of water quality can be achieved for example by raising awareness, developing and executing faecal management plans, with solutions like efficient collection networks, constructed wetlands, etc.

Spatial planning
The most environmentally hazardous water uses should be planned in the least vulnerable areas.

Institutional reform
More economic incentives for the municipalities and industries to set up sewage treatment plants and industrial effluent treatment plants are needed through institutional reform (‘polluter pays principle’). Water quality monitoring should become more efficient and effective, and polluters will try to avoid paying penalties for discharging untreated effluent to the agency concerned with water quality management. In the case of urban areas, the financial resources required for setting up and running

wastewater treatment plants will have to come from the municipal water users as sewage tax. If the municipalities are not capable of treating the wastewater, they can pay the tax collected from the municipal water users to the resource management agency, which in turn can set up treatment systems to ensure that water quality standards are adhered to. The State Pollution Control Boards can set the effluent standards and continue monitoring water quality of the rivers, lakes and groundwater as it is done currently.

KWMI 2

The implementation of the programme of measures needs to be targeted, more so if some funding is found to encourage farmers to implement the measures as they become cost effective. The implementation of measures (related to KWMI2) in Europe over the last twenty years has shown that, to be effective, measures need to be targeted at critical zones.

In this RBMP it has been possible (based on the information available to date) to identify the sub-basins at risk. The next step will be to identify the critical catchments within these sub-basins. However, this will require prior knowledge of the level of water pollution from pesticides to have a baseline against which to assess the effectiveness of the PoMs. This will first require a series of analyses using commercially available analytical methods and high-performance equipment, followed by continuous monitoring of pesticide concentrations in watercourses, particularly in the sub-basins at risk. Once the baseline of water pollution status has been established, it will be necessary to collect information on crop practices and active ingredients crop-wise and district-wise within the Tapi River basin.

All this information will allow the most appropriate measures to be precisely defined and localized, and then applied either through regulation or through economic instruments such as subsidies, taxes or quotas. Regarding the monitoring of pesticide pollution of water bodies, it is recommended to have at least one sampling station at the outlet of the sub-basin at risk.

KWMI 3

Improving river basin management on surface water hydrology calls for changes in the overall institutional architecture, the roles of individual organizations, and capacity building of those organizations. First of all, international experience shows that there has to be an agency with the mandate of water resources management and inter-sectoral water allocation at the basin level that is different from the agencies that appropriate water (such as the Water Resources Departments and Water Supply Departments of the states) (see Kumar et al., 2019 for details). This will induce costs on the agencies that divert excessive amount of water for competitive uses, especially irrigation. Similarly, the agency which monitors water quality and pollution should not be involved in enforcing pollution control norms.

Once such institutional reforms are conducted, there will be strong economic incentive for the agencies to go for interventions such as modernization of irrigation systems. For the irrigation agencies at the state level, system modernization will enable introduction of volumetric water delivery and pricing in the command areas at the outlet level. Through modernization and pricing reforms, they will not only be able to regulate the demand for water (as a result of efficient use of water by the farmers), but also achieve cost recovery. Part of the revenue generated from the collection of water charges can be transferred to the organization that is concerned with water resources management at the basin level.

Similarly, with the institutional reform in WQM, there will be more economic incentives for the municipalities and industries to set up sewage treatment plants and industrial effluent treatment plants, respectively (relation with KWMI 1). This is because with the new institutional set up proposed, water quality monitoring will become more efficient and effective and the polluters will try to avoid paying penalties for discharging untreated effluent to the agency concerned with water quality management (Kumar et al., 2019). In the case of urban areas, the financial resources required for setting up and running wastewater treatment plants will have to come from the municipal water users as sewage tax. If the municipalities are not capable of treating the wastewater, they can pay the tax collected from the municipal water users to the resource management agency, which in turn can set up treatment systems to ensure that water quality standards are adhered to. The State Pollution Control Boards can set the effluent standards and continue monitoring water quality of the rivers, lakes and groundwater as it is done currently.

RIBASIM modelling

On the model development

Given the close fit that is needed between the rainfall-runoff model, which in this case is the SWAT, and the water allocation model, which in this case is RIBASIM, it is highly recommended to have the two modelling exercises done by the same team so that consistent assumptions are used and the RIBASIM modeler knows exactly what is already included in the SWAT model.

The purpose for which the model(s) will be used will determine how the schematization is set up, what data will be needed to make the model useful and which strategies or scenarios will be developed. With much of the information still unavailable, the present RIBASIM application must be considered a first version. Essential information that is needed to make the present scenarios more realistic are:

- Which towns are served with drinking water allocated from the public reservoirs or from the river diversion systems?
- The availability of groundwater as a full or partial source for conjunctive use and the extent to which groundwater meet various competing water demands.
- The actual rules used for the water release/diversion from the public reservoirs.
- The priorities between demands from PWS, agriculture and E-flows.
- The physical characteristics of the reservoir for all reservoirs.

On the modelling results

It is advised that further work is undertaken to understand the causes of the observed flow at Savkheda and if the observations are the result of reservoir operations, gauge error or an alternative explanation. Model results are influenced strongly by priority settings between different users, identified sources (can demands only be reserved from first upstream reservoir, or also from more upstream reservoirs), release and diversion rules, and whether demand can be met fully or partially by conjunctive use of groundwater to supplement surface water shortages. For most of these parameters assumptions were used in the present runs. Consequently, no strong conclusions can be drawn in the present run results.
The increase in rainfall predicted for the climate change scenarios is likely to increase the risk of floods in the absence of good water management.

More analysis should be done to check how the lower Tapi is allocating water and explore the differences between climate scenarios. It is possible reservoir operation and thresholds cause small changes in flow to have a large impact on reservoir release and water availability for abstraction downstream.

KWMI 4

Monitoring of Groundwater Levels

There are plans for installing approximately 300 new high frequency monitoring wells in the Tapi Basin, which will provide useful new data sets. When these new monitoring wells should replace existing ones, the latter should be maintained for at least another five years to provide a historical record, with sufficient overlap. In monitoring wells where groundwater levels are monitored manually, measurements really need to be done at least once or preferably twice a month, rather than only four times a year.

Monitoring of Groundwater Quality

The standard annual suite of water quality parameters needs to be augmented with relevant new parameters, though the new parameters could be targeted according to the land use in the vicinity of the monitoring well, e.g., pesticides in agricultural areas, hydrocarbons in certain industrial areas etc. Temperature & Electrical conductivity (EC) should be recorded in all wells simultaneously with water level measurements. This is particularly relevant in areas where there is a risk of saline intrusion, such as along the coast in certain inland areas of the Tapi River Basin.

Management of groundwater data

There is a need to improve the integration of the national and state level groundwater monitoring data, so that all data can be accessed easily and in a useful format by hydro-geologists at state and national levels. This will be particularly relevant once the high frequency data becomes available. New IT infrastructure, software, and associated capacity building of hydro-geologists at the river basin and national level will be required.

Groundwater Management

Irrigation is the largest user of groundwater in the basin. Yet, little data is available on irrigation water withdrawal and consumption. The current estimates of groundwater withdrawal for irrigation, domestic and industrial sectors, as available from CGWB, are not reliable. Monitoring of a well-designed sample of irrigation wells for discharge and hours of running is needed, to improve the sustainability of groundwater use. The impact of use of fertilizers and pesticides in agricultural areas on groundwater quality is an area that requires more investigations, as is the impact of landfill sites. Managed aquifer recharge (MAR) projects should only be implemented after careful study of individual projects vis-à-vis the hydrological regime of the catchment in which the schemes are proposed, the geology, geohydrology and geo-hydrochemistry of the catchment, assisted by improved groundwater monitoring data. These MAR studies should also consider the committed flows from the catchment for downstream uses impact on downstream water users and the environment.

KWMI 5

The data on the annual volume of sand extracted from all the sand mining sites in the Tapi River must be used to predict the impact of the sand mining on the bed level of the river and the bank erosion.

The impact of sand mining can be simulated by morphological models. It is recommended to extend the existing 1D HEC-RAS model of the Tapi River with its morphological possibilities. To apply morphological models, in addition to hydraulic and bathymetric data, sedimentological data are required, especially data on grain sizes. Suspended load and bed load should be measured at many more locations than the existing four locations to determine the sediment transport along the entire river stretch. In general, a regular monitoring program should be established.

To prevent bed and bank erosion, sand mining should be stopped in the main channel of the river. The Room for the River concepts allows sand mining in the river outside the main channel that does not cause bed and bank erosion. Sand mining in the flood plains can be combined with interests of flood protection, ecology and landscape planning.

Strong cooperation with stakeholders is required for accepted designs of Room for the River measures.

Program of Measures

As the PoM holds a detailed description of necessary immediate actions based on the risk assessment, it will need to be operationalized through formulating an Implementation Action Plan, where the prioritized measures are quantified in terms of volume and cost estimates and scheduled in an operational implementation plan (program) for each State.

Once the PoM measures are implemented in the basin, they are likely to produce positive impacts on the basin performance, particularly in terms of the quality and quantity of stream-flows in different seasons, the groundwater regime and the overall ability of the basin to meet various water demands. However, it is important to have continuous monitoring of the outcomes to avoid or minimize unintended impacts which can occur in the event of the conceptualization of the programme of measures not being sound or not having considered the local specific situation. There should be clear indicators for monitoring these outcomes.

One illustrative example is the ‘lining of canals’ to reduce seepage and increase the service area of the canal in the command area. In localities where the canal seepage replenishes the shallow aquifer and gets recycled back for irrigation, lining is likely to impact the performance of irrigation wells en route the canal. If the seepage is excessive and groundwater is not used in the area (due to salinity, etc.), lining will reduce the environmental damage caused by waterlogging and salinity. If the ‘recharge of groundwater from seepage’ is not recognized while designing the PoMs in that area, the performance assessment exercise might end up looking only at the area irrigated by the canal before and after the intervention. Once it is recognized, then the water levels in the surrounding area, area affected by salinity and the yield of irrigation wells en route the canal shall become part of the performance indicators for the adopted management interventions.

Both the Implementation Action Plan and the Indicators for Monitoring are beyond the scope of the Tapi RBM plan 2023 and should be developed as soon as the RBM plan has been adopted. That does not mean that ongoing programs and Basic- and Supplementary measures that can be implemented now should be delayed.

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11 Annexes

1. Annex 1 – Training Module on River Basin Management in a broader perspective: lessons learned from India and Europe.

2. Annex 2 - Training Module on (i) Surface Water (quantity & quality); (ii) Ground Water (quantity & quality) and (iii) River morphology and Sediment Transport.

3. Annex 3 – Training Module on RIBASIM & E-Flows Assessment in Ramganga Basin.

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