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Planning and Decision Support Tools for Integrated Water Resources Management (IWRM) on River Basin Level in the Southeast-Asian Region on the Example of Vietnam – Tools for Water Quantity and Quality Risk Assessment

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1. Introduction

A lot of countries worldwide suffer from emerging water related problems. Droughts, floods and water contamination are the most pressing issues. According to the United Nations (UN, 2008), in 2008 over 880 million people of the developing world's population were without access to safe drinking water and over 2.5 billion lacked adequate sanitation.

Considering a rapid global change driven by climate, land use and demographic changes, one of the most important tasks of the global community is to find means of using and protecting natural resources in a responsible way in order to support a holistic and sustainable development. The integrated approaches of the international R&D projects funded by the German Federal Ministry of Education and Research (BMBF) are helping to understand, interpret and solve problems in the water sector.

One specific program in this framework is called "Integrated Water Resources Management" (IWRM). The primary focus of the program is to establish cooperation between science, administration and economy between Germany and foreign countries. The R&D projects in the program should develop management concepts and implement action plans in the water sector in cooperation with partners of the project regions. Another task is the contribution of adapted water related technologies and the transfer of know-how.

Vietnam is one of the model regions of the funding program. Since 2007, the German-Vietnamese joint R&D project Integrated Water Resources Management in Vietnam (IWRM-Vietnam) funded by the BMBF is developing methods and technologies adapted to Vietnamese conditions.

The institute of Environmental Engineering and Ecology (eE+E) at the Ruhr University Bochum (Prof. Dr. Harro Stolpe) coordinates the R&D project IWRM-Vietnam and

contributes “Planning and Decision Support Tools” in order to improve decision processes of Vietnamese decision makers in the water sector.

2. Subject for research

Water quality and quantity issues are limiting factors for the socio-economic and environmental development of Southeast-Asian societies. IWRM plays a crucial role in order to cope with the negative side effects of dynamic population and economic growth rates, expansion and intensification of agricultural land use and deforestation. The issues are further intensified by an insufficient water supply and lacking sanitation infrastructure.

Vietnam is a country with rich water resources. A dense river network provides an abundant supply of water. Despite this comfortable situation Vietnam faces numerous challenges that require large investments during the coming decades in order to implement an effective remedy. Major challenges are:

- an uneven distribution of the river network, an uneven rainfall across Vietnam and prolonged dry seasons resulting in water supply problems in some areas;
- Vietnam partly is a downstream country. Important rivers drain from bordering countries into Vietnam. The quantity and quality of the surface water depends on the water usage in the upstream countries;
- deficient water supply infrastructure, deficient wastewater management, inadequate flood protection etc;
- a fast urbanization, industrialization and the intensification of agriculture in Vietnam leads to a rapidly increasing water demand and to severe water contamination;
- an increase of conflicting water uses (e.g. agriculture vs. hydro power);
- an increase of problems stemming from untreated waste water disposal into the rivers (especially close to major cities and industrial centers);
- diffuse contamination risks from agricultural sources (pesticides, fertilizers);
- forming institutions in Vietnam that have the capacity to efficiently plan water resources usage and control water contamination.

This wide range of challenges leads to a complex problem situation that requires a holistic and sorting research approach. Research is needed to merge a multitude of approaches in an integrating manner. Developed methods within the research approach of the R&D project IWRM-Vietnam have to image the given situation as broad as possible. An important matter is to include (preferably) all institutions and stakeholders involved in the process.

The developed method should enable decision makers to plan and manage the pressing challenges in an efficient way. During the development, it has to be considered that financial resources for water management are often very limited in countries like Vietnam. Thus, the method has to be able to prioritize the challenges in order to render economical and targeted decisions possible.

Following this, the methods developed within the research have to be integrating, cost- and time-efficient and target-oriented in order to cope with the challenges of the water sector in Vietnam.

3. Background

3.1 IWRM

Since the International Conference on Water and the Environment, hosted in Dublin, and the United Nations Conference on Environment and Development, hosted in Rio de Janeiro (both in 1992), IWRM finds a stronger consideration worldwide. According to the Global Water Partnership (GWP), IWRM is “a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment” (GWP, 2000).

According to the Agenda 21 “Integrated Water Resources Management” is based on the perception of water as an integral part of an ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. Water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perennality of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems” (UNCED, 1993).

The overall objective is “to satisfy the freshwater needs of all countries for their sustainable development”. Additionally, IWRM should include “the integration of land- and water-related aspects and should be carried out at the level of the catchment basin or sub-basin” (UNCED, 1993). According to their capacity and to available resources all states worldwide should “have designed and initiated costed and targeted national action programs and [...] have put in place appropriate institutional structures and legal instruments” (UNCED, 1993).

3.2 Administration/laws

In Europe, the European Water Framework Directive (EU-WFD) is a legal instrument to implement the concept of water management on river basin scale since the year 2000. In Vietnam the legal basis of IWRM is the Prime Minister Decree 120 on River Basin Management (No: 120/2008/NĐ-CP dated 01.12.2008) and the National Target Program Water (NTP-WR 2010). The Vietnamese water law from 1999 will be amended in 2011 and will be another important legal basis of IWRM in Vietnam.

The Decree 120 on River Basin Management from 2008 regulates the principles and main tasks of river basin management as well as responsibilities for the river basin management. The decree demands an action plan for the prevention and protection of water contaminations and the restoration of contaminated water resources on river basin scale.

Essential preconditions for a successful implementation of IWRM in Vietnam will be to overcome the existing fragmentation of administrative responsibilities in the water sector and the strengthening and reorganization of the existing River Basin Organizations (RBOs). The RBOs should be authorized to raise wastewater charges and to spend these financial means on their own responsibility for required IWRM measures according to the priorities identified by the method developed in the R&D project IWRM-Vietnam.

The development in the environmental and water sector in Vietnam shows that the country already started to implement a legal framework according to the IWRM concept defined by the GWP and the Agenda 21 during the last years (cf. Zschesche et al., 2008).

3.3 Risk assessment

Although initial steps for IWRM have been taken in Vietnam, the implementation of the entire IWRM concept, including the identification of measures for water and environmental protection, is still lacking. Within the R&D project IWRM-Vietnam and in response to this situation, the authors developed a method in order to identify areas with high priority need for action on a regional scale (Planning and Decision Support Tools).

The method follows the basic ideas of risk assessment for water quality and water quantity. It is based on concepts for the ecological risk analysis, which in Germany have been originally developed for example by Kiemstedt, Bachfischer (1978) and later completed during the further development according to the European Law of Environmental Impact Assessment from 1985 and amended in 1997, 2003 and 2009 (EC, 2011). Comparing to the European concept, the Environmental Protection Agency in the United States published their Guidelines for Ecological Risk Assessment in 1998 (EPA, 1998).

The developed method consists of a contamination risk assessment (water quality) and a water balance estimation (water quantity). Following the contamination risk assessment, the water balance estimation concludes in a risk assessment, too. Here, the risk of the occurrence of water deficit by overexploiting the water resources (or the occurrence of water surplus) are evaluated (cf. Jolk et al., 2010).

The principle idea for the contamination risk assessment is to combine contamination potentials (originating from land uses) and the sensitivity of natural resources (here of water resources), which results into a contamination risk. Two-dimensional matrices are used to aggregate the contamination potential and the sensitivity of water resources into the risk. The matrices are applied to determine the risk on a scale with the classes "low", "medium" and "high".

The principle idea of water balance risk assessment is based on the aggregation of the estimated water resources quantity on the one hand and the estimated water demands of water users on the other hand. This results in a water balance revealing deficit (and surplus). The assessment of the estimated deficit is applied to determine the risk of water deficit on a scale with the classes "low", "medium" and "high" (cf. Greassidis et al., 2011).

4. Solution oriented approach

In order to sort the method and IWRM into the given conditions in Vietnam, it is necessary to define an overall planning context. For this purpose IWRM-Vietnam designed two planning concepts.

- The IWRM planning levels provide a planning framework for the IWRM process in Vietnam and sort the method into this framework (cf. 4.1).
- Water Management Units help to show the results of the risk assessment in a structured and spatially differentiated way (cf. 4.2).

4.1 IWRM planning levels

According to the European Water Framework Directive (EU-WFD), IWRM-Vietnam designed a planning level concept suitable for IWRM in countries like Vietnam (cf. figure 1 and 2). “Planning and Decision Support Tools” were developed on the “river basin” planning level (scale approx. 1 : 300.000) to identify and prioritize areas within the river basins (Water Management Units = WMUs) with higher problem intensity and thus higher need for action through IWRM measures.

The identification and prioritization is based on an estimation of the water balance deficit (e.g. due to overexploitation) and on contamination risk assessment (e.g. due to diffuse agricultural sources or industrial point sources) and finally on a ranking according to problem intensities. This enables decision makers to distribute available financial means for the realization of IWRM measures in a practical and targeted manner.

The method was developed and discussed in close cooperation with the Vietnamese Ministry of Natural Resources and Environment, Department of Water Resources Management (MoNRE-DWRM) in Hanoi, provincial authorities (Departments of Natural Resources and Environment, DoNREs) and along with further stakeholders. Vietnamese legal demands have been considered.

Depending on its specific purpose, IWRM is being accomplished on different scales. A planning level concept based on the EU-WFD and suitable for the conditions in Vietnam has been developed within IWRM-Vietnam.

The planning level concept is a framework for IWRM in Vietnam under consideration of national and international standards. The planning level pyramid (see figure 1) structures existing and future measures and concepts of the IWRM process.

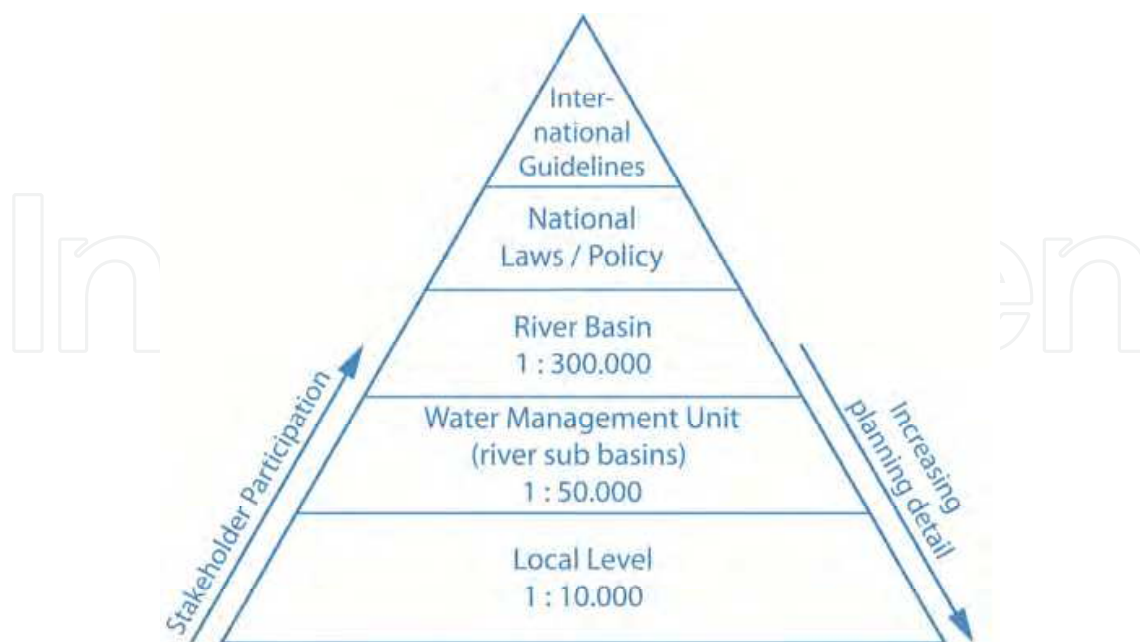


Fig. 1. Graduated IWRM planning levels (planning level 3 “River Basin”: R&D project IWRM-Vietnam).

The planning levels focus on the purposes that result from the given spatial scale (see figure 2):

1. **International Level:** International scientific discussion; sharing international experience; guidelines for IWRM (e.g. Global Water Partnership)
2. **National Level in Vietnam:** Legislation (e.g. National Target Program Water); technical and water quality standards etc.; implementation of River Basin Organizations; identification of river basins with higher problem intensity and priority need for IWRM-measures (cf. Cuddihy&Frederiksen, 1996)
3. **River Basin Level:** Organization, financing and refinancing of the IWRM process by River Basin Organizations; identification of WMUs with higher problem intensity (“hot spots”) and priority need for IWRM-measures (waste water treatment, water resources protection, monitoring etc.) utilizing a GIS-based evaluation of spatial and statistical information
4. **WMU Level:** Spatial planning of water management measures through the identification of most suitable locations in the areas identified on planning level 3 (river basin) by conducting detailed investigations (field investigations to confirm and complement the water balance, water quality, water demand, waste water discharge, socio-economy, water models etc.)
5. **Local Level:** Object planning of measures as identified on planning level 3 and 4 (examples for measures: monitoring, waste water treatment, water extraction, water supply etc.)

Planning Level	Planning Objectives
1. International 	International guidelines for IWRM e. g. Global Water Partnership, international research projects etc.
2. National 	Legislation, standards, identification of river basins with higher problem intensity and need for IWRM measures (scale approx. 1:1.000.000)
3. River Basin 	Identification of Water Management Units (WMUs) with higher problem intensity and need for IWRM measures (scale approx. 1:300.000)
4. WMU 	Identification of most suitable locations for IWRM measures (scale approx. 1:50.000)
5. Local 	Object planning: monitoring, waste water treatment, water supply etc. (scale approx. 1:10.000)

Fig. 2. Overview of IWRM planning levels in Vietnam and their objectives (planning level 3 “River Basin”: R&D project IWRM-Vietnam).

The planning level concept is adjusted to fit the scarce data availability on site. All decision relevant information for the identification of WMUs (Water Management Units) with higher problem intensity and priority need for IWRM measures on the river basin planning level could be gathered. This database consists of satellite images (land use etc.), statistical data

(drinking water demand, industry demand, number of population etc.), maps (topography, administration, geology, soils, land use etc.), point data (wells, industries, monitoring stations etc.), studies, reports, laws, quality standards etc. Data that was considered to be used in the method has to meet the following requirements:

- satisfying detail grade for considered planning level and goal of planning (here: prioritize areas with need for IWRM measures)
- as detailed as needed for decision, but as easy as possible
- accessibility, homogeneity, replicability of data processing

4.2 Project areas and WMUs

The method developed within the R&D project IWRM-Vietnam has been applied in different project areas in Vietnam. The specific characteristics of these areas regarding water management, topography and land use have been taken into account during the development of the method. Thus, the Planning and Decision Support Tools can easily be assigned to other regions in Vietnam. The project areas (cf. figure 3) are:

- Red River part basin: Province Nam Dinh in the Red River Delta
- Upper Dong Nai basin: Province Lam Dong in the southern highlands
- Cuu Long part basin: City Can Tho in the Mekong Delta



Fig. 3. Project areas in the R&D project IWRM-Vietnam. Planning and Decision Support Tools have been developed for Red River part basin, Upper Dong Nai basin and Cuu Long part basin.

In order to develop tools that fit the needs and target the right issues of the water resources situation, it is imperative to grasp all essential characteristics of the system. The result of a thorough system analysis is the basis for all further investigations and developments. Figures 4 to 6 are showing block diagrams of the water resources systems of all three project areas.

The block diagrams show information on the hydrologic system of the Red River part basin (Nam Dinh province), the Upper Dong Nai basin (Lam Dong province), and the Cuu Long part basin (Mekong Delta, Can Tho City) including elements contributing to the available water resource and all relevant water users.

The investigated Red River part basin (see fig. 4) is located in province Nam Dinh (northern Vietnam). The geological situation of this project area is dominated by alluvial and marine sedimentations. Aquifers typically are found in sand and gravel layers. Nam Dinh is a deltaic landscape with almost no elevation differences. The area is managed using polder structures. Each polder serves as a single management unit. The irrigation (and possible salt-water intrusion) is controlled by sluices in the polder dykes. The water resources are abundant but threatened by salt-water intrusion and contaminations from industries and handicraft villages within the polders (or often on the dykes). The main water user is the agriculture. Urban and rural population and the industry are further water users (as well as the watering of livestock and the tourism industry).



Fig. 4. Block diagram of Red River part basin (province Nam Dinh).

The investigated Upper Dong Nai basin (see fig. 5) is (mainly) located in province Lam Dong (southern-central Vietnam). The massif of the Lang Bian plateau and the mountain

ranges of the Di Linh-Bao Loc plateau consist of basalts, granites and jurassic shales and sandstones. Quaternary deposits are located in the river valleys and the floodplains of the Dong Nai river system. Upper Dong Nai aquifers are found in the basaltic layers. The plateaus are mainly characterized by fertile soils. The south-eastern part of the province Lam Dong descends to the low-lying plains north of Ho Chi Minh City. The water resource is controlled by precipitation and groundwater abstractions. It is partly controlled by storages (major dams). The main water user is the agriculture. Urban and rural population and the industry are further water users (as well as the watering of livestock and the tourism industry).

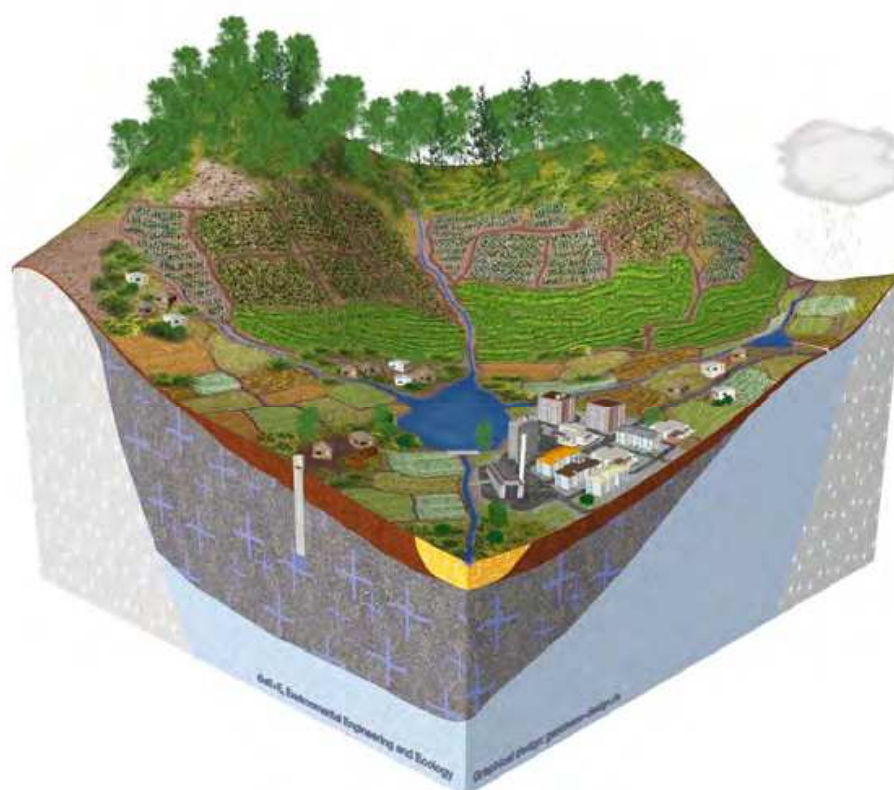


Fig. 5. Block diagram of Upper Dong Nai basin (province Lam Dong).

The investigated Cuu Long part basin (Mekong Delta) is located within the surroundings of the city of Can Tho (southern Vietnam). The Mekong Delta is composed of alluvial sediments from the Holocene with a high amount of silt. Aquifers mostly consist of sand and are covered by thick clay layers. The Mekong Delta is a deltaic landscape with almost no elevation differences. It is characterized by a large network of rivers and artificial canals. The rivers and canals are mainly used for irrigation and for transportation of goods and people. The canal system is connected to the open sea. The water resources are abundant but threatened by salt-water intrusion. The main water user is the agriculture followed by the industry and urban population. The rural population is a further water user (as well as the watering of livestock and the tourism industry).



Fig. 6. Block diagram of Cuu Long part basin (City of Can Tho, Mekong Delta).

The Planning and Decision Support Tools originally have been developed based on the project area Upper Dong Nai river basin. After having established a basic system, the tools were adapted to fit the additional conditions of the delta regions.

After analyzing the characteristics of the project areas, basic spatial units were defined. The Planning and Decision Support Tools are being applied on planning level 3 (river basin). In order to show the results of the risk assessment in a structured and spatially differentiated way, the R&D project IWRM-Vietnam defined Water Management Units (WMUs). WMUs are sub-basins of a river basin that are defined for the purpose of IWRM in the basin.

These units should enable an effective management of both water quantity and water quality. Therefore, each water management unit combines sub basins with similar management tasks that can be joined appropriately. The following criteria are applied to delineate WMUs:

- The boundaries of the WMUs are delineated along the **natural river basins or sub-basins** and are valid for both surface- and groundwater resources
- The natural river basins are **subdivided at hydrological significant points**, i.e. confluence of a large branch river and/or the outlet of a large reservoir. Furthermore, they are **subdivided according to criteria of geomorphology, land use and administrative regions**
- If natural river basins or sub-basins do not exist (delta areas) the WMUs are divided along the main rivers, canals or polder

Each WMU is named using established local names (such as names of reservoirs, rivers or localities) and given a unique identity number. The Water Management Units are checked

against the specifications of the Water Resources Allocation Plan (as defined in Decree 120/2008/ND-CP, Art. 14).

Figures 7 to 9 are showing the project areas and the respective WMUs as delineated using the above definition. The recommendations on the WMUs were subject to intense discussions with cooperating institutions and stakeholders before fixing the WMUs into their final stage.

The project area Red River part basin has been differentiated into five Water Management Units (see figure 7). Due to the special polder structure of this area, each polder has been defined to form one WMU. Areas out of polders have not been considered but influence the water management situation of each WMU.

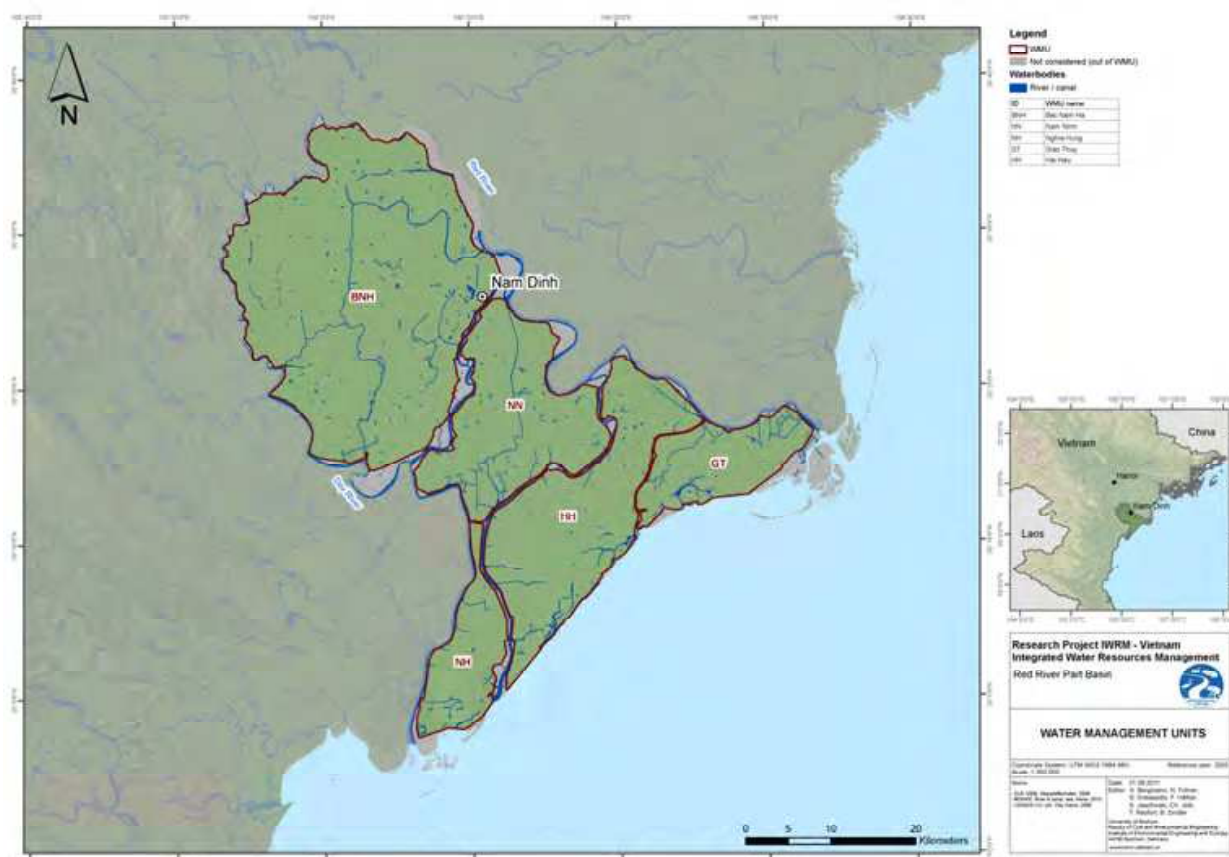


Fig. 7. WMUs in the Red River part basin (province Nam Dinh).

The project area Upper Dong Nai basin holds 22 WMUs (see figure 8). All criteria have carefully been weighed against each other. Finally, IWRM-Vietnam came up with balanced WMUs that only needed minor adjustments after the discussion with local authorities.

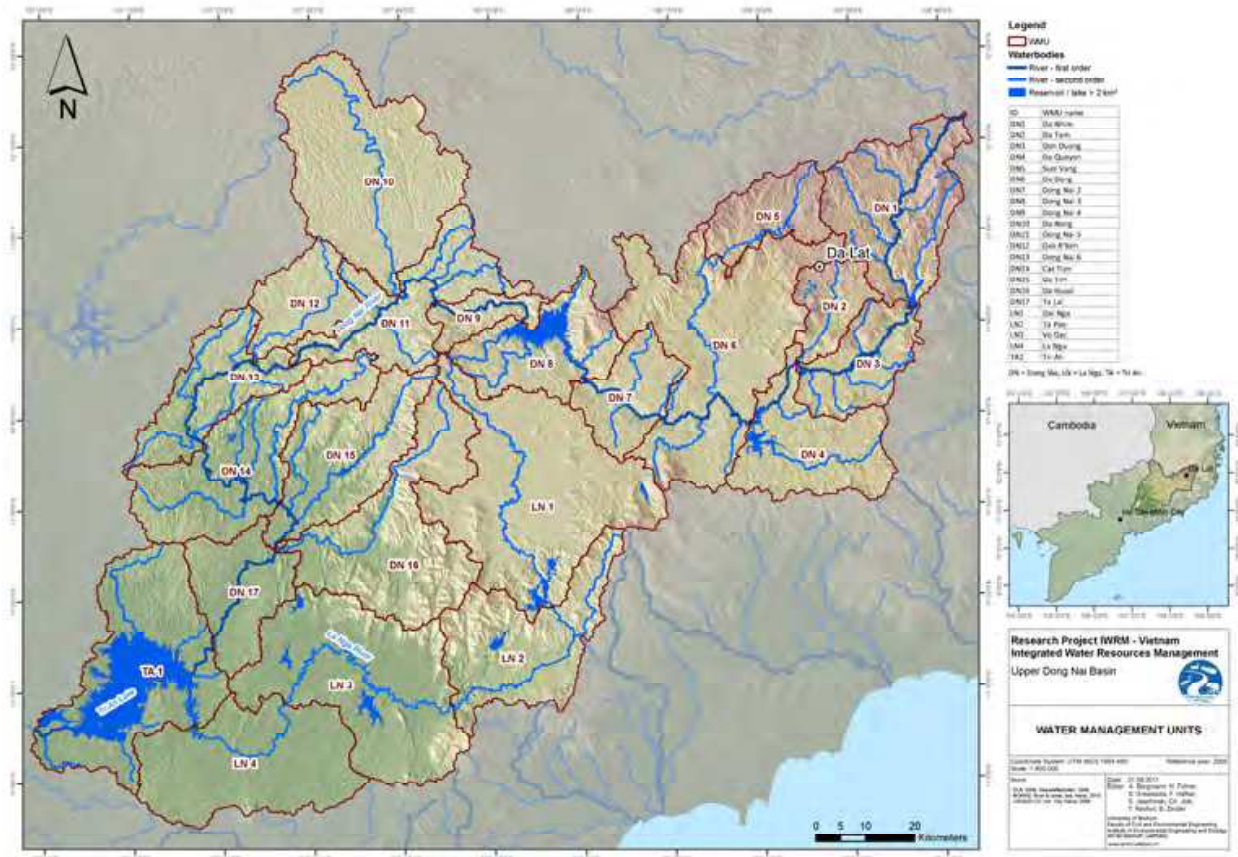


Fig. 8. WMUs in the Upper Dong Nai basin (province Lam Dong).

The project area Cuu Long part basin in the Mekong Delta has been differentiated into nine WMUs (see figure 9). The delineation of WMUs in the Mekong Delta was difficult due to a very homogenous land use and with no obvious flow directions in the rivers and canals. In a first approach, main rivers and canals were used for a delineation of WMUs. However, intense discussions with local experts in the delta were mandatory to delineate acceptable WMUs.

5. Method, planning and decision support tools

The Water Management Units are the spatial basis on which Planning and Decision Support Tools are being applied. The Planning and Decision Support Tools are instruments to spatially identify and prioritize contamination risks (e.g. diffuse agricultural contamination sources or industrial point sources) and water deficits (e.g. overexploitation). Figure 10 is showing three main tools of the developed method.

- The Contamination Risk Tool is used for risk assessment of water quality aspects (ground- and surface water).
- The Water Balance Tool is utilized to record, assess and predict the risk of water deficit (and surpluses).
- The Ranking Tool identifies WMUs with high problem intensities and priority need for IWRM measures.

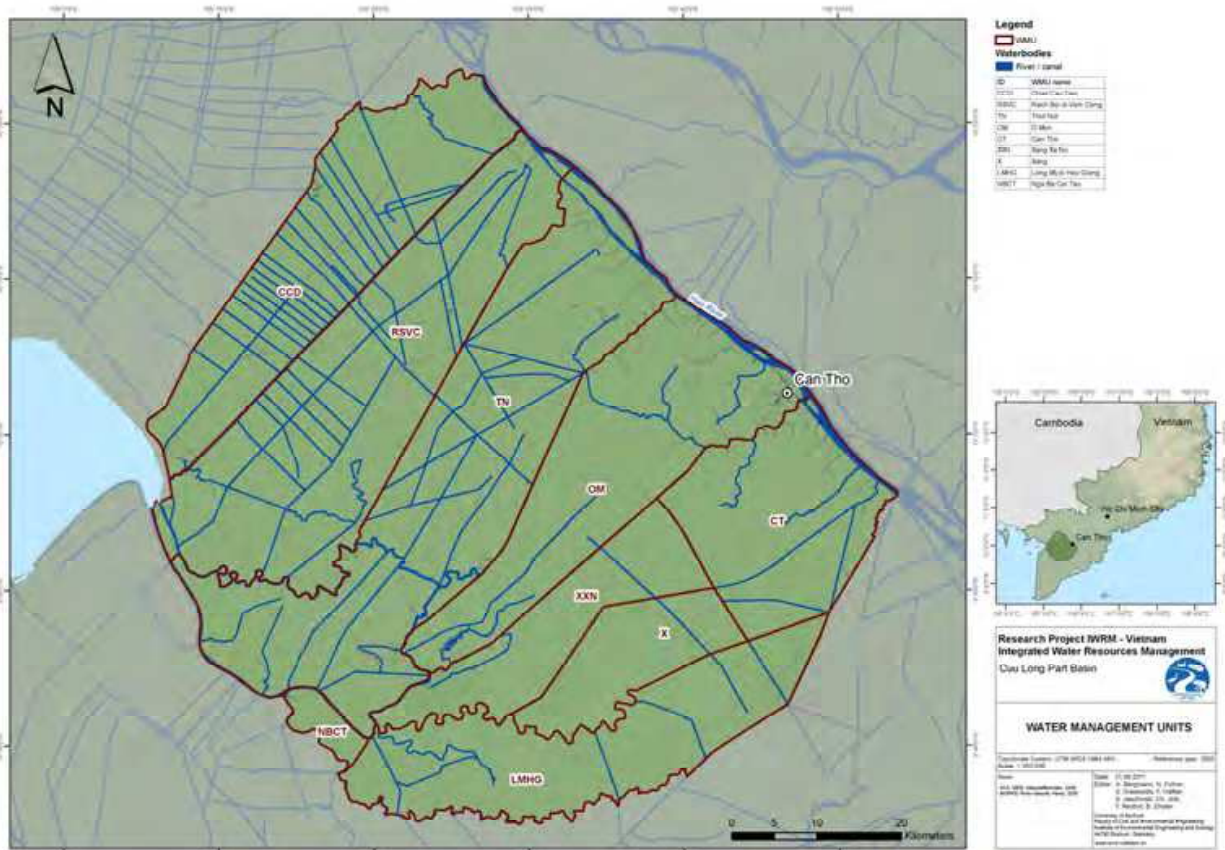


Fig. 9. WMUs in the Cuu Long part basin (city of Can Tho, Mekong Delta).

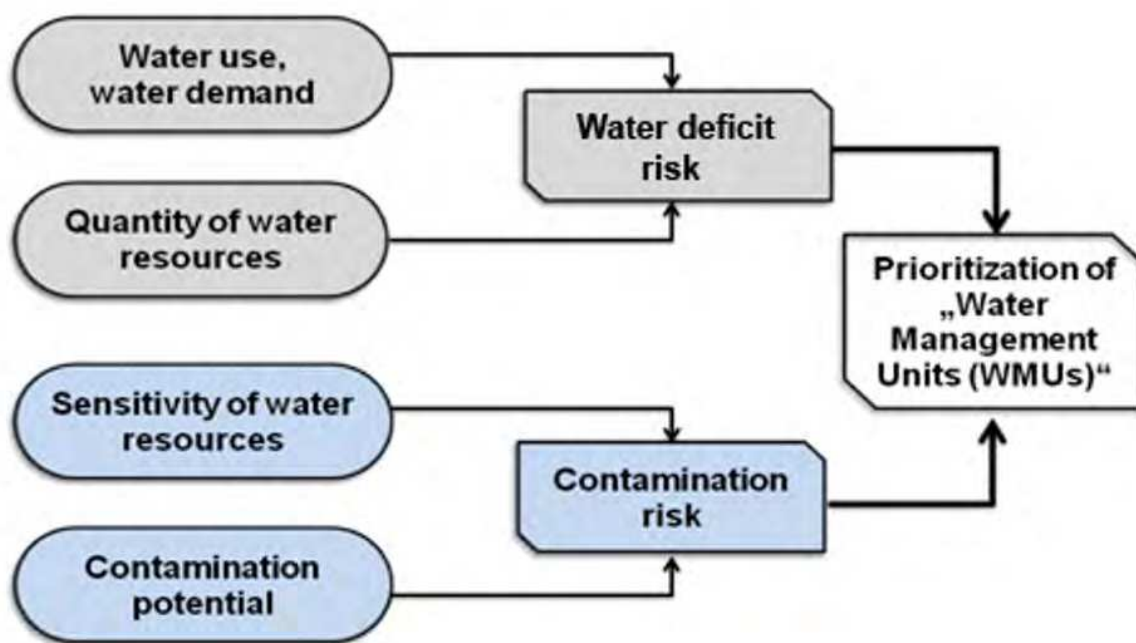


Fig. 10. Planning and Decision Support Tools (boxes) and their input elements (bubbles): Analysis and assessment of water balance (Water Balance Tool) and contamination risk (Contamination Risk Tool), prioritization of WMUs (Ranking Tool).

The Planning and Decision Support Tools are GIS¹- and MS Excel-based. They enable the user to visualize single actual situations as well as results of the water balance, the contamination risk assessment and the prioritization (ranking) of WMUs.

5.1 Contamination risk tool

The Contamination Risk Tool is used to analyze the contamination risk of the water quality of water resources in a WMU. The method is based on the estimation of the sensitivity of water resources (groundwater and surface water) and the classification of contamination potentials from different sources.

Sensitivity of water resources + Contamination potential of polluters = Contamination risk

The contamination risk assessment is being conducted for three possible contamination paths of pollutants that affect the water resources (cf. figure 11 and 12):

1. Infiltration (figure 11 and 12) (into groundwater): Solute pollutants from diffuse and point sources directly infiltrate into the groundwater (e.g. nitrate from agricultural sources, domestic waste water, industrial waste water)
2. Erosive runoff (figure 11) / runoff (figure 12) (into surface water): Pollutants from diffuse sources are being transported by (erosive) runoff into the surface water (e.g. phosphate and pesticides from fields adsorbed to sediments or organic matter)
3. Direct discharge (figures 11 and 12) (into surface water): Pollutants from point sources are being discharged into the surface water (e.g. domestic waste water, industry, seeping landfills)

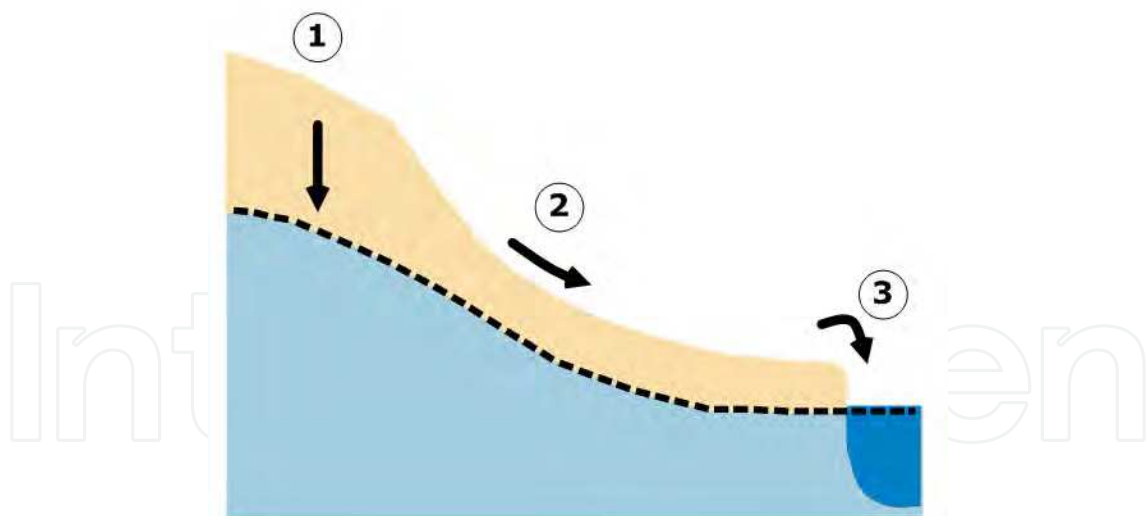


Fig. 11. Possible contamination paths of pollutants affecting ground- and surface water (Upper Dong Nai basin, province Lam Dong).

Figure 11 is showing the possible contamination paths for the Upper Dong Nai basin. The main difference compared to the delta regions (Red River Delta, Mekong Delta) is located in path 2. Path 2 in the Upper Dong Nai basin with its hilly landscape is dominated by an

¹ GIS = Geographic Information System

erosive runoff regime, where contaminants are gravitationally being transported into the surface water. In comparison, path 2 in the delta regions is ruled by inundation controlled runoff of pollutants. Pollutants are being transported extensively and into the surface water (cf. figure 12).

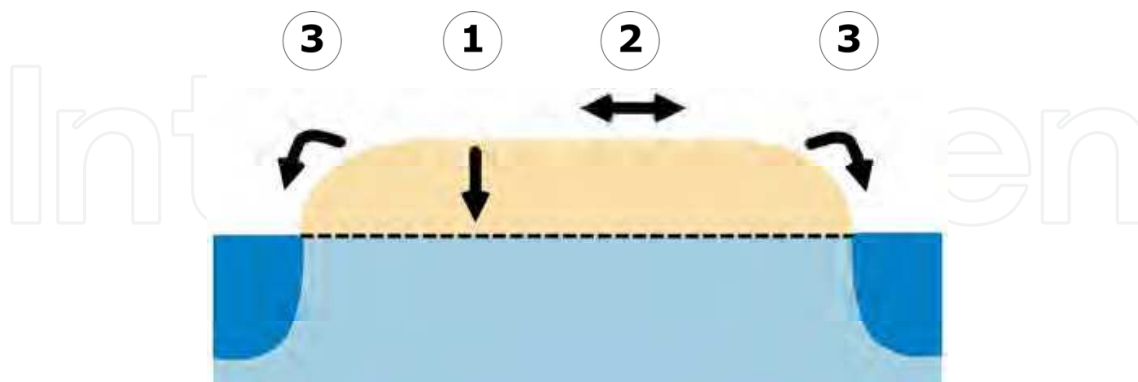


Fig. 12. Contamination paths of pollutants affecting ground- and surface water in the delta regions (Red River part basin, province Nam Dinh / Cuu Long part basin, city of Can Tho).

The contamination risk is evaluated according to these paths. It consists of two elements, the contamination potential and the water resources sensitivity. The contamination potential describes the ability of a certain pollutant to negatively affect the water resources and is graded into four classes (no, low, medium, high). Only the most relevant pollutants for the evaluation of contamination risks in each path have been selected for closer evaluation. Those are for path 1 (infiltration into groundwater) agricultural areas, settlements and point sources (e.g. industries), for path 2 (erosive runoff (mountainous) or runoff (deltas)) agricultural areas and for path 3 (direct discharge) settlements and point sources.

The sensitivity of water resources describes the relative ease of a contaminant applied on or near the land surface to migrate into the water resource. It is a function of different natural characteristics. The sensitivity is graded into five classes (no, low, medium, high, very high). If more than one parameter is being considered to assess a sensitivity class, matrices help to aggregate different class values into a final class. Parameters considered to assess the sensitivity of groundwater are the aquifer type, the soil type and areas with an intense use of groundwater (high density of wells). The sensitivity of surface water is assessed according to the parameters of potential soil erosion and river density. The specific regional characteristics of the different project areas are considered.

The Contamination Risk Tool and the visualization of its results are GIS-based. The tool identifies hot spot WMUs regarding the risk of contamination for water resources and helps decision makers to analyze contamination potentials from different sources. Figure 13 shows an example for a contamination risk map generated using the Contamination Risk Tool.

Table 1 gives an overview of the combinations leading to the qualitative water risk assessment and the resulting available maps. These maps are compiled in a planning atlas (together with additional maps, tables and text). A web-viewer version of the atlas is available on the internet (www.iwrm-atlas-vietnam.de). In this article, examples of maps to be published in the atlas are found in figures 7 to 9 and 13 to 15.

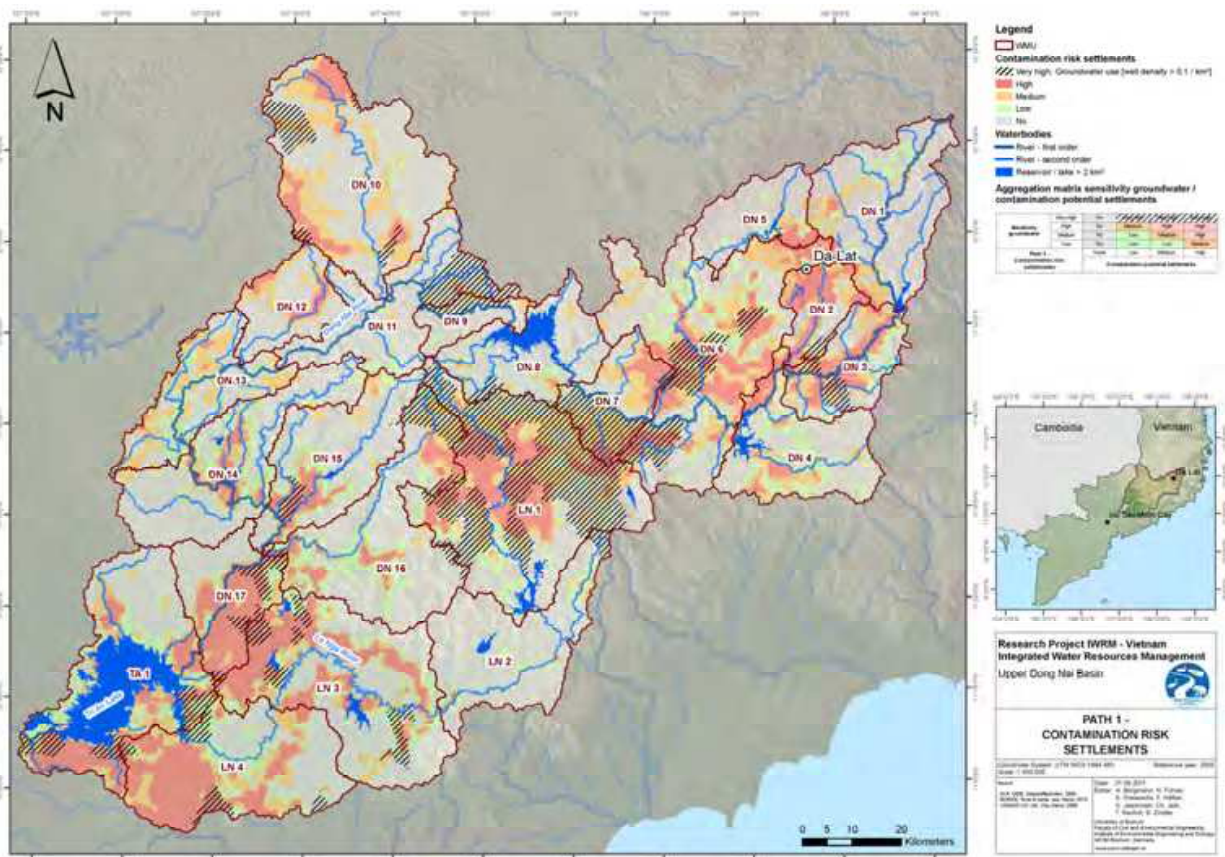


Fig. 13. Example for a resulting contamination risk map in path 1 of the Upper Dong Nai river basin. The contamination potential of settlements is combined with the sensitivity of groundwater to show the contamination risk caused by settlements (red: high risk, yellow: medium risk, green: low risk, grey: no risk).

Contamination paths	Sensitivity	+	Contamination potential	=	Contamination risk	Red River	Upper Dong Nai	Cuu Long
Path 1: Infiltration	Sensitivity of groundwater	+	Contamination potential: agriculture	=	Contamination risk: agriculture	X	X	X
		+	Contamination potential: settlements	=	Contamination risk: settlements	X	X	X
		+	Contamination potential: point sources	=	Contamination risk: point sources	X	X	X
Path 2: Erosive runoff* / runoff**	Sensitivity of surface water	+	Contamination potential: agriculture	=	Contamination risk: agriculture	X**	X*	X**
Path 3: Direct discharge	Sensitivity of surface water use	+	Contamination potential: settlements	=	Contamination risk: settlements	X	X	X
		+	Contamination potential: point sources	=	Contamination risk: point sources	X	X	X

Table 1. Aggregation of sensitivity and contamination potential into contamination risk. The "X" mark available maps for the three project areas.

5.2 Water balance tool

The Water Balance Tool is used to calculate the water quantities of the Water Management Units (WMUs). It identifies the risk of water deficit (and surplus) of a WMU by contrasting water resources and water demands of water users. Values are calculated on a monthly base and for the dry season (December to March), the rainy season (April to November) and the whole year.

$$\text{Water resources} + \text{Water demand} = \text{Deficit risk (or surplus)}$$

The tool is MS Excel-based. GIS is employed in the visualization of results (and supportively). Each WMU is represented by standardized calculation sheets in MS Excel. They include all parameters required to compile the water balance. The sheets are interconnected and conclude into an overview cascade (showing an overview of the water balance situation of all WMUs). Figure 14 characterizes the connection of the WMUs in the Upper Dong Nai basin based on their hydrological conditions and management situation. WMUs in the deltas are interconnected via a wide array of canals (Mekong Delta) or governed by a controlled inflow at the polder entrances (Red River Delta) and do not feature a directional flow as in river systems like the Upper Dong Nai basin.

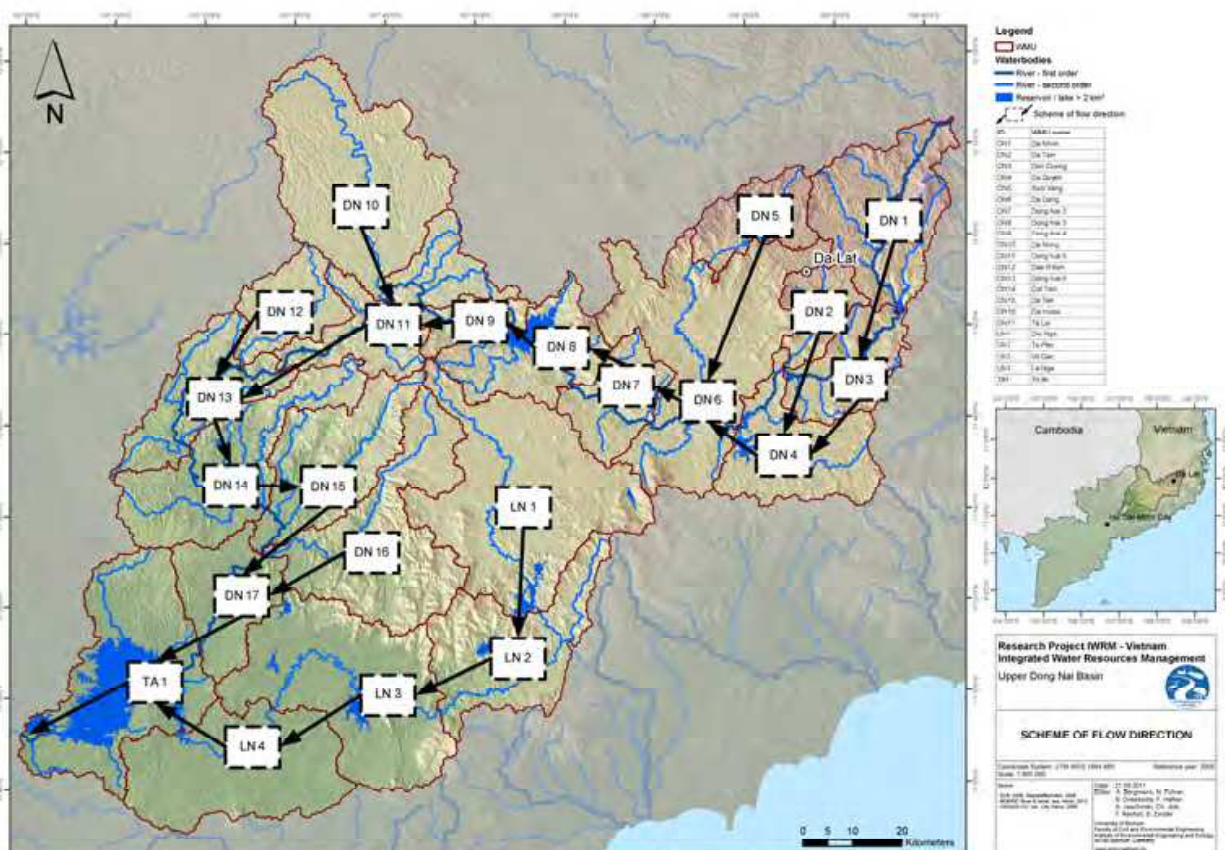


Fig. 14. Scheme of flow direction in the Upper Dong Nai basin (province Lam Dong).

Changes of the input parameters in the calculation sheets are updated automatically (scenarios). One calculation sheet bundles all components of the water balance. The water resources components consist of the discharge generated inside the WMU, the inflow coming from the upstream, the yield of reservoirs or canals, the groundwater resource and the water transfers.

The water demand components consist of the quantitatively relevant water users: rural and urban population, agriculture, industry, service sector (mainly hotels) and the minimum flow requirement (“ecowater”).

The Water Balance Tool identifies hot spot WMUs regarding the available water quantities and possible shortcomings during dry seasons. The tool is a strong instrument for decision makers to analyze water resources quantities and the mixture of water users.

Table 2 gives an overview of the combinations leading to the quantitative water risk assessment and the resulting available maps. These maps are compiled in a planning atlas (together with additional maps, tables and text). A web-viewer version of the atlas is available on the internet (www.iwrm-atlas-vietnam.de).

Water balance			Red River	Upper Dong Nai	Cuu Long
Water resources	+	Water demand	=	Water deficit risk	
			X	X	X

Table 2. Aggregation of water resources and water demands into the risk of water deficits. The "X" mark available maps for the three project areas.

The project area Upper Dong Nai basin features a mere quantitative deficit risk. In contrast, the water resources are abundant in the delta regions (project areas Cuu Long part basin and Red River part basin). Nevertheless, the delta regions hold a certain deficit risk due to temporary high local demands (e.g. agriculture) and water quality limitations (e.g. salt water intrusion).

5.3 Ranking tool

The Ranking Tool processes the results of the Contamination Risk Tool and the Water Balance Tool (aggregated on a WMU basis) in order to prioritize the problem intensities of WMUs within a river basin regarding their water quality and quantity issues. Based on this information, decision makers can effectively prepare decisions, recommend closer inspections and coordinate measures for WMUs with priority need for IWRM measures. Figure 15 is showing an example for the ranking of a contamination risk (here ranking the contamination source: settlements).

Table 3 gives an overview of the ranking. These resulting maps are compiled in a planning atlas (together with additional maps, tables and text). A web-viewer version of the atlas is available on the internet (www.iwrm-atlas-vietnam.de).

Contamination paths	Ranking Contamination Risk	Red River	Upper Dong Nai	Cuu Long
Path 1: Infiltration	Contamination risk agriculture	X	X	X
	Contamination risk settlements	X	X	X
	Contamination risk point sources	X	X	X
Path 2: Erosive runoff * / runoff **	Contamination risk agriculture	X**	X*	X**
Path 3: Direct discharge	Contamination risk settlements	X	X	X
	Contamination risk point sources	X	X	X
Path 1, 2, 3: Aggregation	Contamination risk Path 1, 2, 3	X	X	X
Ranking Water balance		Red River	Upper Dong Nai	Cuu Long
Ranking Water Balance - Water deficit risk		X	X	X

Table 3. Ranking of the Contamination Risk Tool and the Water Balance Tool results. The "X" mark available maps for the three project areas.

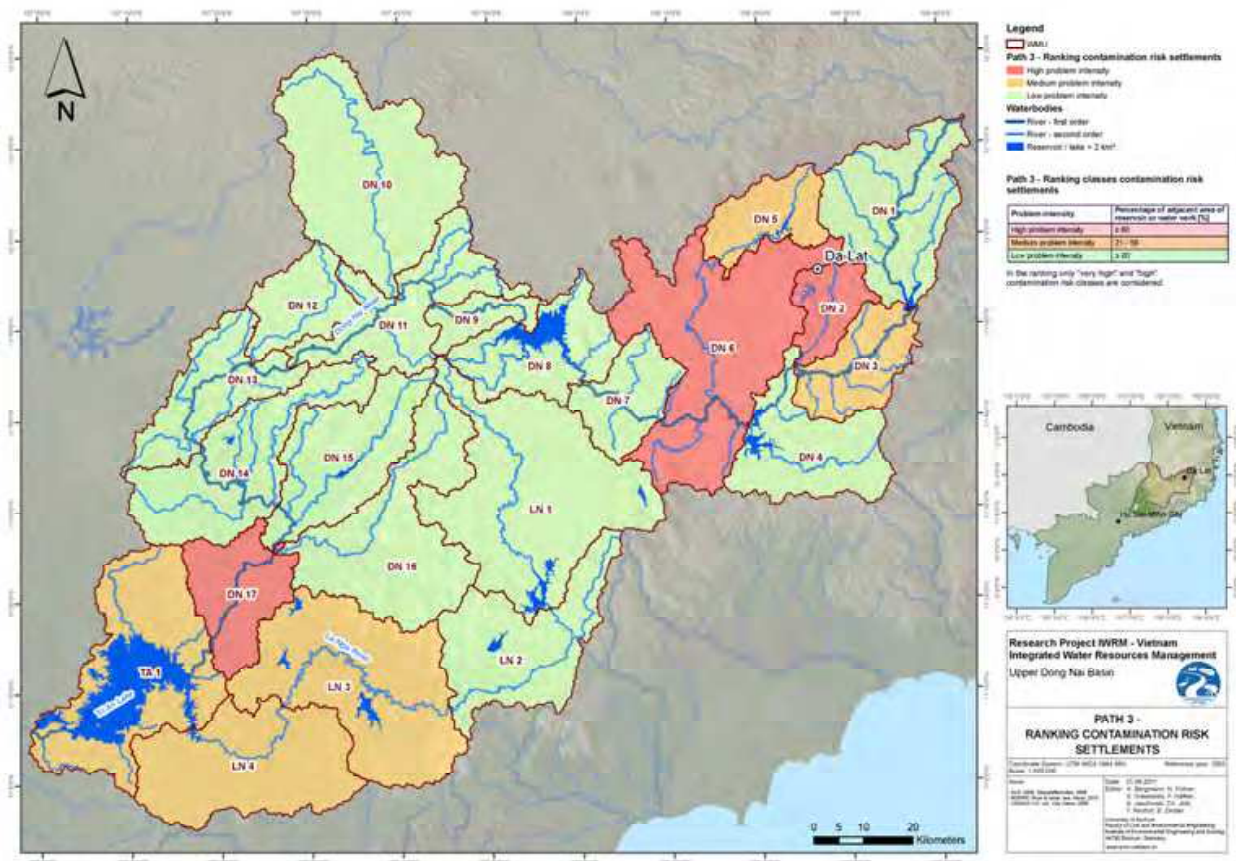


Fig. 15. Result of ranking: contamination risk for the surface water stemming from settlements (red: high risk, yellow: medium risk, green: low risk).

6. Conclusions

The developed Planning and Decision Support Tools are instruments for a sustainable water management along the principles of IWRM as defined by the Global Water Partnership and others. The integrated approach facilitates a consideration of water resources quantity and quality leading to a risk assessment. The result of the risk assessment is the identification and prioritization of areas (Water Management Units) with higher problem intensities regarding the water quantity and / or quality and thus a priority need for IWRM measures. The prioritization of WMUs helps decision makers to efficiently plan water management and funds in order to optimize the impact of IWRM measures.

In order to effectively communicate Planning and Decision Support Tools in Vietnam, it was necessary to develop a transparent, well documented and transferable method. An important aspect of the Planning and Decision Support Tools was to develop a method that fits the needs of Vietnamese water managers and decision makers. Thus, IWRM-Vietnam paid close attention to engage authorities and stakeholders into the process of developing the method in order to make the task of implementation as easy as possible.

The results of the developed methods for the analysis of the water resources on the river basin scale were documented in several reports:

- Handbook of methods: Planning and Decision Support Tools for IWRM in Vietnam
- Definition tables: methods for the estimation of water quantities and contamination risks
- GIS Manuals: step-by-step guides on how to use GIS functionalities to estimate water quantities and contamination risks
- IWRM-Atlas: Planning maps and tables for the IWRM in Vietnam (print version and web-viewer version)

The application of Planning and Decision Support Tools will enable Vietnamese stakeholders to base decisions regarding measures to improve the situation of Water Management Units on a scientific basis. The identification process enables decision makers to effectively attend to the issues with high priority ratings first. The close cooperation between the project and the Vietnamese authorities ensures a holistic implementation of the tools and a close interaction between the method and the legislative framework in Vietnam. The early participation of the responsible water agency on national level guarantees a sustainable adjustment and a nation-wide transferability of the method to Vietnamese conditions. The overall concept developed by the R&D project IWRM-Vietnam is an important step towards the implementation of IWRM principles in Vietnam. Thus, the application of the Planning and Decision Support Tools allows for the improvement of water resources management along the principles of IWRM which will be essential for further development in Vietnam on a sustainable basis

7. Outlook

The developed method (Planning and Decision Support Tools) allows for a layered, problem orientated and efficient examination of entire river basins, initially using a systematic overview examination (scale approx. 1 : 300.000) in order to establish Water Management Units (WMUs) with higher problem intensity and prioritized need for IWRM measures ("hot spots"). The next step should be the development of methods to examine these previously prioritized WMUs in more depth (scale approx. 1 : 50.000), in order to ascertain the types, extensions and locations for necessary IWRM measures.

This results in a systematic approach, rendering possible a labor efficient, targeted and cost efficient process especially for countries, such as Vietnam, which are only just starting to set up an IWRM.

The next step will be to develop methods for the closer examination of WMUs with higher need for IWRM measures on WMU planning level (planning level 4, cf. fig. 2) and to recommend practical local measures on the local planning level (planning level 5, cf. fig. 2). The inclusion of the population and the various participating stakeholders (authorities and institutions) in the planning and decision making process is a vital principle in this context.

Overall this is a holistic approach for planning and decision support for IWRM. This corresponds to the demands on Integrated Water Resources Management as formulated, for example, by the Asian Development Bank (ADB, 2006).

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